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Analysis of Toner-Cartridge Remanufacturer Waste Stream

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Abstract

Environmental concerns with the disposal of laser-printer toner cartridges are being addressed, in part, by the remanufacture of toner cartridges. Remanufacturing, or recycling at a part level, involves the disassembly, restoration to like-new condition and reassembly of a used product. Remanufacturing offers significant environmental benefits by reusing the energy and resources expended during original manufacture, and by diverting solid waste from landfill and incineration.

Since the primary purpose of remanufacturing is to reuse parts, the parts that are not reused enter the remanufacturers' waste stream and may be studied to identify difficulties in remanufacture. The research undertaken aims to quantify the amount of product discarded (as opposed to reused) and to categorise reasons for discard in the toner-cartridge industry. From the discard reasons, it may be possible to identify product design factors that directly affect the remanufacturability of the product. This knowledge may be used to formulate design strategies to facilitate remanufacturing. The waste streams of three toner-cartridge remanufacturers were studied. Data gathered over a period of four months showed the main reasons for discard and highlighted areas in toner-cartridge design that are problematic for remanufacture.

I. Introduction

As laser printers became more affordable and prevalent, an environmental concern arose over the volume of spent toner cartridges that was discarded. The toner-cartridge remanufacture industry grew as more recognised the opportunity for profit while reducing environmental burden by refilling and refurbishing toner cartridges.

The remanufacturing process targets the reuse of products and thus diverts material from the waste stream. In 1992, approximately 24,000,000 cartridges were remanufactured in North America, diverting 38,000 tons of waste from landfilling and incineration (Judge 1997). However, difficulties in the remanufacturing process prevent the reuse of some parts of toner cartridges that consequently enter the remanufacturer's waste stream.

Identification and quantification of the discard reasons that cause the parts to enter the waste stream will highlight major obstacles to the remanufacture of these products. These obstructions may be social, economic or technical. However, strategies for product redesign may reduce some of these difficulties and thus decrease the amount of the product entering the remanufacturer's waste stream.

Relevant research on remanufacturing included the following. Lund (1996) conducted surveys on the extent of remanufacturing and estimated annual industry sales of $53 billion in the U.S. Boks et al. (1998) presented an overview of legislation and end-of-life scenarios and concluded that legislation affected product design and end-of-life decisions. Beretta et al. (1997) suggested remanufacturing as a preferred end-of-life strategy in life-cycle planning. Farkash and Mueller (1995) described Xerox's program to reduce, recycle and ultimately reuse/ remanufacture toner containers, and noted that design changes were required to facilitate reuse or recycling.

Other related work examined engineering influences such as design methodologies and product characteristics on remanufacturing. Rose et al. (1998) linked end-of-life options, including remanufacturing, to general product characteristics, such as wear-out life, functional complexity, and disassembly steps. However, they realised that not all of these characteristics were available early in the design process. Amezquita et al. (1995) examined engineering systems to identify design characteristics that facilitate remanufacturing. They emphasised that quantitative metrics were required to aid designers, especially in the early stages of design. Shu and Flowers (1995) studied the effects of fastening and joining methods on remanufacturing, and found that design for remanufacturing is sometimes in conflict with design for manufacture and design for assembly. Bartel (1995) focused on specific products: toner containers and optical photoconductors. One of his recommendations was to include recycle and reuse concepts as part of the design for environment program. Also relevant is Pope et al.'s (1998) study on designing "successional" products to reduce environmental impact at end of life. Modular design was proposed to facilitate reuse, remanufacturing and recycling.

The approach of this work is novel in that the remanufacturer's waste stream is systematically studied to develop design-for-remanufacture strategies. Since the primary goal of remanufacture is to reuse parts, parts that are not reused enter the waste stream and embody impediments to remanufacturing. The identification of dominant factors that contribute to the waste stream will be used to formulate corresponding design strategies to increase the efficiency of product remanufacture. This paper focuses on the toner-cartridge industry while preliminary results of the automotive industry were presented by Sherwood and Shu (1999).

II. Data Collection

Three remanufacturers of toner cartridges were visited over a period of four months. Two were small- to medium-sized (fewer than 25 employees, producing fewer than 5000 cartridges per month) and the third was large (over 200 employees, production of approximately 65 000 cartridges per month). The object of the data collection was to record, by part count and mass, the parts discarded during the remanufacturing process, and the corresponding discard reasons. The waste that was sampled was comprised mainly of the plastic husks of toner cartridges with some metal components. None of the waste counted and presented in this paper was subsequently recycled for material content due to difficulties in finding plastic recyclers.

A. Process Differences

The large company was able to process the different models of cartridges in separate assembly lines due to volume. The smaller companies generally had a set of technicians who could work on any model as required by purchase orders. Therefore, data at the large company was available by specific model whereas the smaller companies had all waste grouped together. Also due to volume, waste from the large company was discarded every day. At smaller companies, waste from two or three days was aggregated and counted together. The large company had an Original Equipment Manufacturer as a client, but operated its own quality department that researched and developed remanufacturing process guidelines.

The large company was able to control the process input to a greater degree than the smaller companies. The larger company used mostly cartridges that were used only once and never remanufactured. Smaller companies had to contend with more uncertainty in supply origin and quality of cores, which are the cartridges to be remanufactured.

B. Process Similarities

In all cases, the remanufacturing process of a cartridge was very similar. The cartridge would be completely disassembled, cleaned and inspected, repaired if required and possible, and then reassembled and tested. At all companies, direct consultation with the technicians was used to determine the discard reason. Mass was used as a measurement standard with part count also being recorded. Although data by product model was not recorded at the smaller companies, similar models were remanufactured at all companies.

C. Methodology

Companies generally had specific areas where waste was discarded, usually at or near the technician's work area. The technician who disassembled or assembled the product made the decision to discard. The basis of this decision was explained verbally. Once the discard reason or thought process was recorded, the discarded parts were counted and weighed. If there were more than one discard reason for a part, all reasons were recorded for that part. Where production data was available, it was obtained for the days on which data was gathered.

The larger company generated enough waste on any given day for data collection. Visits were made once a week over several months. On days when data collection was carried out for only part of the day, production data for that day was amortised for the number of hours of the data collection. The smaller companies would store their waste for two or three days as space allowed before a visit. Each of the smaller companies was visited once a week for a minimum of three weeks.

D. Discard Reason

Discard reason refers to the physical problem for which the part or product was being inspected prior to reuse, e.g., *Broken Protrusion* was such a category. There may have been secondary reasons, such as no existing remedy for defect, however, this was assumed rather than counted as a separate category since the data collection was constrained to the waste stream. That is, the waste stream contained only those parts that failed and were irreparable. Parts that failed but were repaired were not counted. The exception to this was *Overstock*, where parts without physical defects were discarded.

III. Data Findings and Analysis

A. Discard Reasons

Following are brief descriptions of thirteen discard reasons that were identified.

Broken Protrusion: Protrusions included those that were structural, e.g., connecting arms, and those that were functional, e.g., guide fins. A variety of protrusions were found to be susceptible to breakage.

Coating Damage: One part in particular, the magnetic roller, had a coating that was easily scratched. Some rollers could be repaired, the others were discarded.

Contamination: Certain parts of the product must be free of dirt or grease to work properly. Toner dust interfered with seals, and grease was difficult to remove from plastic surfaces.

Core Quality: As mentioned before, the smaller companies could not always control their supply of cores. If they had a core that they suspected had been poorly remanufactured previously, they would discard the cartridge rather than take the risk of unseen damage.

Cosmetic: Although a toner cartridge is hidden from view during use, the customer still expects it to look new when it is unpacked. Visual defects such as scratches or stickers that could not be removed without damage were not acceptable.

Deformation: This included breakage, distortions, bends, etc., anywhere on a part besides a protrusion.

Glue (Degradation of): Glue was widely used as a joining mechanism, especially for Mylar seals. In the majority of cases in this category, the glue degraded and the seal was loose or missing. The part with the degraded glue was discarded.

Joint Damage: Damage of the area where two parts met was classified as joint damage.

Missing Part: Cartridges may be received with parts missing, but no other defects. In the usual case where no replacement parts were available, the husk may be stripped for usable parts or discarded depending on production needs.

Overstock: Some usable parts were discarded when there was a surplus of such parts and inventory space was limited.

Sacrificial: This discard reason referred to those parts or pieces of parts that were discarded as a direct result of the remanufacturing process. The category was mainly due to one cartridge model where the back of the outer shell was cut away to access the blade inside. The opening was covered with an alternative material and the original piece was discarded.

Technology Change: For one particular cartridge, the model was changed such that a particular step of the remanufacturing process, which was tailored to the newer model, had limited success for older models. Because of this, and because the market was comprised mostly of the newer model, a proportion of older models that require the above step were discarded.

Wear: This category referred to those parts or pieces that were consumed (or worn) in the normal use of the product. This category was comprised of various parts with coatings.

B. Findings and Analysis

The sample size of counted waste in each product-model part population was statistically analysed at a 95% confidence level using a binomial test (waste/not waste). Production data from the larger company were available for each product line. From the statistical analysis, the sample of waste stream analysed was representative of the general-population waste stream. Table 1 shows the confidence intervals at 95% confidence levels of the proportion of waste within each product-model part population.

TABLE 1. Waste-Stream Part-Count Probabilities and their 95% Confidence Intervals for Large Company by Product Model.

Product Model	Part Count Percentage of Population	Confidence Interval Width
EPS Developer	26.30	5.13
EPS Waste Hopper	10.30	3.19
EPS Cover	18.60	4.14
HPIV	3.23	2.26
IIP Developer	28.10	5.21
IIP Waste Hopper	23.30	5.12
Corona	4.54	1.78

Some product samples showed evidence of more than one discard reason, however, any one discard reason was sufficient to scrap the part, therefore, each category was analysed separately. Where there were multiple discard reasons per sample, each discard reason included the total mass of the product sample.

In the process of quantification of the waste, some samples having the same discard reason were weighed together without recording the number of individual samples. The corresponding part count data was reconstructed from qualitative data logs and an approximation based on recorded mass. The minimum part count was used as a lower bound to avoid falsely affirming a discard category.

Differences between large and small companies are identified below and addressed in the Discussion section. Figs. 1 and 2 show the mass and part-count data collected for the large company and the small companies.

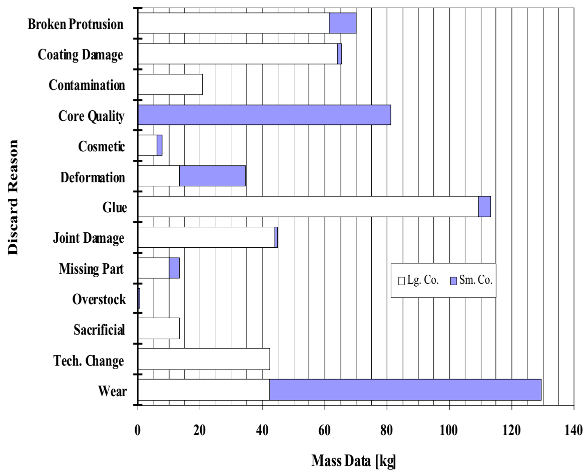

Fig. 1. Discard Reason by Mass (Large and Small Companies).

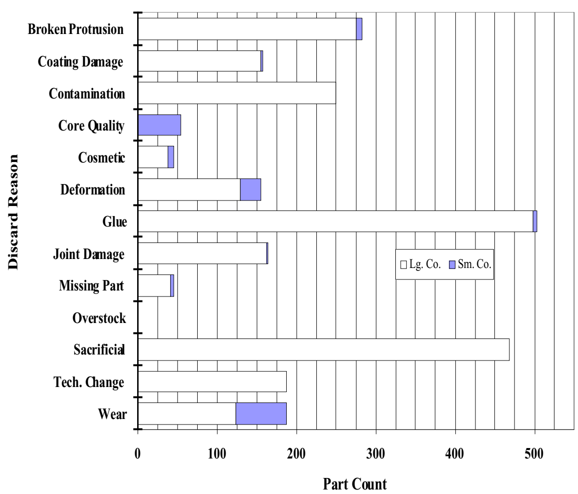

Fig. 2. Discard Reason by Part Count (Large and Small Companies).

Some discard reasons were found in only one type of company, large or small. For example, the discard reasons *Sacrificial*, *Technology Change* and *Contamination* were found in the large company only, while *Core Quality* and *Overstock* were found in the small companies.

Figs. 3 and 4 show another difference between large and small companies: the ranking of discard reasons by mass. The large company's top three discard reasons by mass were *Glue, Coating Damage* and *Broken Protrusion*. The top three for small companies were *Wear, Core Quality,* and *Deformation*. However, smaller sample sizes were available at the small companies, resulting in wider confidence intervals that indicate more uncertainty about the discard-reason probabilities for small companies.

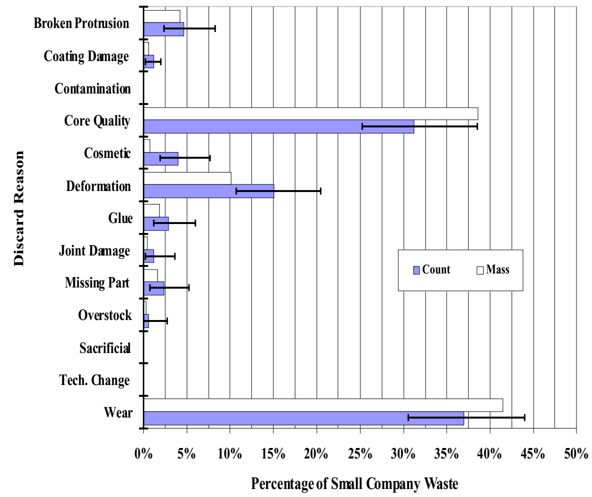

Fig. 3. Discard Reason by Part-Count Percentage with Associated 95% Confidence Interval and Mass Percentage for Small Companies.

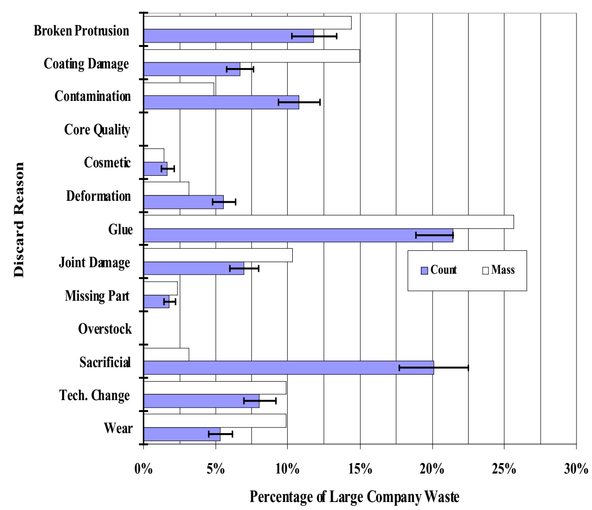

Fig. 4. Discard Reason by Part-Count Percentage with Associated 95% Confidence Interval and Mass Percentage for Large Company.

Fig. 5 shows part-count probabilities, their 95% confidence intervals and mass probabilities for large and small companies combined. The confidence intervals were found using binomial F test for each category.

The largest interval was 4.54% for *Sacrificial;* however, this category comprised only 2.08% of the total waste-stream mass. The remainder of discard reasons had confidence-interval widths less than 3.5% at a 95% confidence level. The top three discard reasons by mass (*Wear, Glue, Core Quality*) had confidence intervals of 2.09%, 2.45% and 1.01%, respectively.

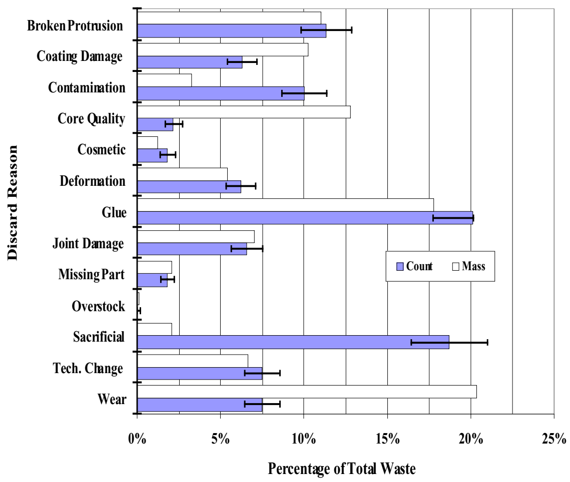

Fig. 5. Discard Reason by Part-Count Percentage with Associated 95% Confidence Interval and Mass Percentage for All Companies Combined.

Most discard reasons could occur in any part, e.g., the waste half or the developer half of the cartridge. However, the categories *Sacrificial* and *Contamination* each involved primarily one part: waste hopper and corona wire, respectively. The back panel of the waste hopper was sacrificed in disassembly. Because it was a small portion of the waste hopper, the proportion by mass was relatively small compared to the proportion by count. The same trend was seen for the corona wire, a lightweight component of the cartridge.

C. Discussion

The presence of categories *Core Quality* and *Overstock* in the small companies only, and the prevalence of *Wear* in small companies may be due, in part, to the economic advantages of the large company. While collecting part-count and mass data, it was found that the large company was able to refurbish certain parts, such as the magnetic rollers, that were designed to be consumed in normal cartridge operation. As a result, these parts did not enter the waste stream and the *Wear* category was not prominent. Also, the large company controlled the input supply of used cartridges to the extent that the majority were never before remanufactured, thereby resulting in fewer problems of incoming *Core Quality*. The large company also had greater warehouse space and could store more surplus parts, resulting in fewer parts discarded due to *Overstock*.

The smaller companies did almost all of the remanufacturing by hand, whereas the large company was able to invest in specialised machinery to aid disassembly. This machinery allowed the large

Fig. 6. Broken Protrusion: Male Snap-Fit Lock.

company to replace worn parts in large production volumes. This added capability reduced waste in the *Wear* category, but resulted in two new categories with less mass than if the worn parts were discarded. These differences in process were responsible for *Technology Change* and *Sacrificial* categories being present in the large company and not in the small ones.

As mentioned previously, the ranking of top discard reasons, when sorted by mass, was different in small and large companies. However, within the top five categories of each company type, not including those specific to company size, the categories *Broken Protrusion* and *Glue* were common to both company sizes. These two categories could point to areas in product design that add difficulty to the remanufacturing process regardless of the size of operation.

For the discard reason of *Broken Protrusion*, some design guidelines could be: avoid protrusions if possible, make the protrusion stronger, use modular

Fig. 7. Unglued Seal.

designs, or design the feature to be compliant. In the specific case of damage to the male half of a snap-fit lock (Fig. 6), designing in compliance to facilitate disassembly may be a solution. Another example is the *Glue* discard reason. Glue is often used as a joining mechanism and can degrade or become contaminated (Fig. 7). Once this occurs, the usual result is a toner leak that renders the cartridge unusable. Either a better joining process or a better design to contain toner could be found.

IV. Conclusion

Part-count and mass waste-stream data were collected at three toner-cartridge remanufacturers of varying sizes. Statistical analysis indicated that the waste-stream data was representative of the population at a 95% confidence level. Segregation of the data by company size and further analysis showed differences between the large and small companies. These differences included a different ranking of discard reasons between small and large companies, and the presence of discard reasons in one size of company and not the other. These differences may be due to advantages of the large company's size and production volume.

The identification and quantification of discard reasons revealed several difficulties in the remanufacturing process of toner cartridges regardless of company size. It was illustrated how this information may be used to generate possible design strategies to improve the efficiency of the toner-cartridge remanufacturing process.

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