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Remanufacturer Waste-Stream Data Collection for Development of Design-for-Remanufacture Guidelines

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Abstract: The Life-cycle Design Lab at the University of Toronto is analysing waste streams of various types of remanufacturers. The purpose of this work is to develop comprehensive design-for-remanufacture guidelines that will provide help for product designers in the initial and detailed design stages. It is believed that remanufacture is a valuable economic and environmental strategy, but one which has not yet received the attention needed to ensure that designers can create products that can be remanufactured in the most cost-effective way. This paper describes the data collection for this project at an automotive engine parts remanufacturer.

Introduction: In recent years, 'design-for-x' strategies have proliferated. Design for manufacture and assembly (DFMA) was one of the first such developed, and has been adopted for use by industry and as a subject of research in university. Some of these new 'design-for-x' approaches have been very general, in the sense that they attempt to deal with a wide variety of design issues under the umbrella of one strategy. Such is the aspect of the 'design-for-quality' approach. [1]-[3] Others, like 'design for inspection,' have developed very specific guidelines or checklists. [4] With so many choices, what strategies does management of a company choose that its designers should follow? Obviously, not all can be implemented, since designers do not generally have the time to review all the repercussions of a specific design, especially at the concept stage when important choices are being made. Even a design team, though it may have broader experience, would have difficulty if asked to consider ease of manufacture, assembly, reliability, inspection, remanufacture and recycling on a equal footing. As well, since DFMA may be firmly established in an industry or company, additional design strategies must be made compatible with this. Simple and expeditious methods to resolve any conflicts that are posed by new design considerations must be well integrated.

Recently, as well, the environmental impact of manufacturing processes has been receiving more attention. Environmentally conscious design and manufacturing conferences and textbooks now exist that relate product design and ecological impact. [5]-[8] Life-cycle design and engineering is a rapidly growing field. Of course, many of the 'design-for-x' strategies mentioned above respond to design concerns for a specific stage in the product life cycle. One of the most important effects of life-cycle design has been to bring end-of-life issues to the fore; recycling and 'design for recycling,' especially in the electronics industry, is the most notable. There are, however, other end-of-life strategies, remanufacture, for instance. Remanufacture has a long history, and throughout the last few decades, the topic and practice have been reviewed by a few researchers interested in economic, inventory, and design aspects. Until recently, it has not, however, been as popular a strategy as recycling, although the two are not, of course, incompatible. There have been several commentators who support the importance of remanufacture from an environmental-resource conservation point of view. [9] If such an argument is true, then it behooves manufacturers and designers to take a closer look at a practice that is both economically and ecologically beneficial.

This is the context for the proposed research work. The integration of manufacture with remanufacture would clearly seem a logical step, but as yet designers are unfamiliar with how to create a product that will promote this end-of-life option. Indeed, with the pressure of other concerns (manufacture and assembly, quality, and cost), how is it possible to add remanufacture to the mix? And some designers may be just getting used to the idea that they must design for recycling, let alone remanufacture and recycling. So, essentially there are two main problems. Comprehensive design-for-remanufacture guidelines do not exist, for many types of products; and how is such a strategy, when developed, to be integrated with other management and designer priorities? The first purpose of this work is to develop design-for-remanufacture guidelines. The second is to integrate these with other life-cycle design strategies.

Remanufacture: There have been several efforts to propose remanufacture guidelines. German VDI Standard 2243, 'Designing Technical Products for Ease of Recycling' contains fundamental rules for both material recycling and 'product recycling,' otherwise known as remanufacture. The rules are very sound, since they are general, however, it is not clear that they are sufficient to provide adequate guidance for all products. The Systems Realization Lab at Georgia Tech has also shown a strong interest in the remanufacture problem. This Lab based their work on some of the first research into remanufacture ([10]-[13]), synthesized ideas for each 'design-for-x' stage in remanufacture (disassembly, cleaning, inspection, refurbish and reassembly), and then produced remanufacture metrics that allow comparisons between products to be made on the basis of their overall ease of remanufacturability. Researchers at MIT have long had an interest in remanufacture, and more recently the emphasis has been on a structured design approach and reliability issues. [14]-[16] The plan at the Life-Cycle Design (LCD) Lab at the University of Toronto is two-fold: to test the guidelines and rules (but not the metrics) already in existence against empirical data, and to note any omissions that might become new rules or design guidelines. The research aims to develop new, more comprehensive design for remanufacture guidelines. The approach taken is to analyse the waste stream of remanufacturers. It is believed that by noting which parts of a system cannot be remanufactured, suggestions to eliminate waste, for use in the original design process, can be created. Graduate researchers at the LCD lab are analysing the waste streams of different remanufacturers: toner cartridge and electronic products, furniture, tires, and automotive parts. The longer term goal is to explore the possibility of creating comprehensive but general guidelines that might work for a wide variety of products and industries, by compiling the remanufacture information from various existing remanufacturers. This paper deals with the research at automotive engine remanufacturers.

Engine Parts Remanufacturing: There are about four or five engine remanufacturers in Toronto. Remanufacturers are distinguished from rebuilders (of which there are many in the area) by the production batch nature of the job, and by the return of the product to a like-new, rather than a merely functional, condition. Data has been obtained from three of the four remanufacturers, and the fourth will be visited in the near future. One remanufacturer is an OER (Original Equipment Remanufacturer) that has a contractual relationship with a specific automotive manufacturer, and the remaining three are independent. The data-gathering process lasted four months. During this time, the large OER was visited approximately three days a week; on these days, all parts from the major centres (disassembly, refurbishing, reassembly) that were discarded for recycling were examined. The smaller, independent remanufacturers were visited once a week, this being sufficient time to examine all the scrap that had accumulated in the period between visits. Essentially, two questions were asked about the scrap material: how had the part failed? and why was the part scrapped? This paper describes the responses to these questions.

The necessity for physically counting the scrap might be questioned. After all, do not remanufacturers have production schedules, and do they not themselves track what is scrap, so that they can maintain a proper inventory? This is partly true. The large remanufacturer maintains a scrap profile for each engine 'from history.' Initially, when an engine is first remanufactured the number of non-remanufacturable parts from that particular product is counted, until an accurate profile of part loss exists. This profile is the basis for core delivery and parts inventory. For example, the remanufacturer needs 30 cylinder heads of a specific type. But it is known that, on average, eight percent of cores received at disassembly contain damaged heads that cannot be repaired. The remanufacturer will order 32 or 33 cores for disassembly, hoping to obtain 30 good heads. Disassemblers will record the actual number of scrap heads, however, the remanufacturer is not concerned with why the part cannot be refurbished, unless there is a design problem that should be acknowledged to the manufacturer. Additionally, the scrap counts of some parts, like connecting rods and camshafts, may not be recorded, if their inventory is already large. Therefore, data collecting required checking all recycling bins for damaged parts, and questioning disassemblers and machinists as to why they were scrapping these. The information relies upon the accuracy of representation of these workers.

This research also concentrates on only larger engine parts. Initially, at the OER, an attempt was made to count smaller parts, like valves and rocker shafts, but these are discarded by the hundreds, and an employee could not be spared to detail the failures of every small part. A record of the common failure types for such pieces was made, but the daily scrap was not counted. Also, at the independent remanufacturers, some systems, like water pumps, were remanufactured that were not handled at the OER. There were too few of these assemblies, given the low production volumes at the independents, to provide significant information. Thus, overall, data were collected on: engine blocks, cylinder heads, crank shafts, camshafts, connecting rods, oil pans, valve covers, timing covers, cylinder sleeves, rocker shafts, valves, intermediate shafts, balance shafts, air deflectors, exhaust manifolds, hydraulic lifters, oil pumps, and

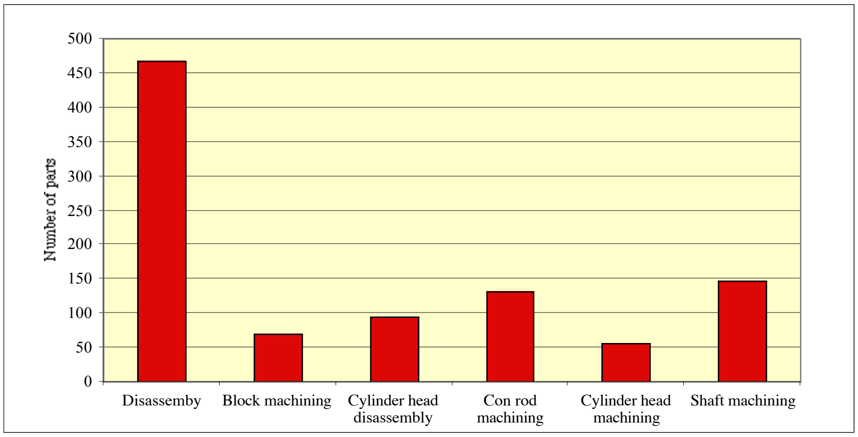

Figure 1: Breakdown of scrap parts by line and station.

water pumps. Information from only the first nine of this list (the majority of the parts counted) is being used to develop remanufacture guidelines. Figure 1 is a summary of the number of parts counted at the different remanufacture stations.

Disassembly: It is clear from figure 1 that the majority of scrap comes from the disassembly station.

Disassemblers at the OER have a triple job: they must disassemble cores, inspect parts, and do some sorting of small parts like fasteners. These people play a critical role in the remanufacture process: batch runs are tightly scheduled, and four workers must disassemble between 60 - 100 cores a day, depending on the type of engine. Working conditions, too, are somewhat hazardous, due to the noise of pneumatic tools, fumes from nearby cleaning processes, and contact with engine oil. Much of design for remanufacture (like design for recycling) concentrates on disassembly, and making this work easier deserves attention.

Though clearly disassembly is important, so too is ease of inspection, but this is less well recognised. When disassemblers send inappropriate material through cleaning to the machining lines, time, energy, and material at these other stations are wasted. The OEM supplies the OER with bulletins for disassemblers, to help them identify specific failures of which they have become aware. The disassemblers themselves complain, though, that their chief problem is product recognition. Many of the engines are very similar; the differences are important, but difficult to detect. Since different products occasionally receive different treatment (certain parts of some systems become scrap automatically, and should not be sent through the machining lines) identification difficulties create slowdowns and conflict.

Figure 2 shows the overall scrap breakdown from disassembly. Disassembly is the only station where different kinds of parts are scrapped. After cleaning, parts go to their separate lines by part type for refurbishing, as shown in figure 1. Oil pans, valve covers, cylinder sleeves, and timing covers only appear at disassembly, because disassemblers can more easily distinguish parts of these types that cannot be refurbished, and because most of these components that cannot be repaired come back to disassembly (for the

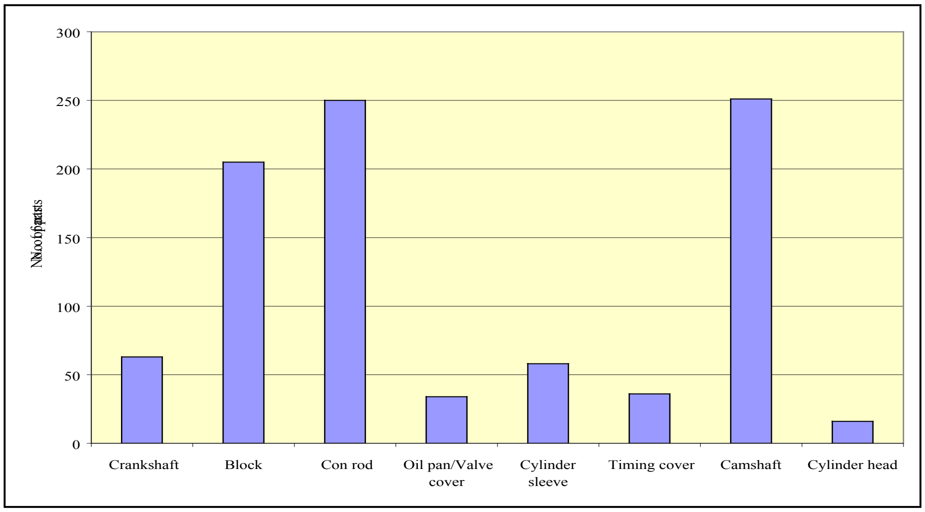

Figure 2: Scrap parts from disassembly

sole reason that it is the most convenient place) for scrapping.

All disassembly data come from the OER, since independent remanufacturers do not scrap from this station. At the independents studied, all parts are turned over to their several machining lines for inspection and refurbishment or scrapping. There were, however, few reasons to scrap parts at the machining stations that did not also occur at disassembly. Disassembly scrap is, therefore, representative. Most failures differed only in degree, but not in kind. That is, blocks were scrapped at disassembly and at block machining because they were cracked, the difference being that machining could detect smaller fatal cracks. The failure profile of parts at disassembly is shown in figure 3. The meanings of the failure modes are self-evident. Although the failures could have a more detailed description (as they indeed originally did), for the purposes of developing remanufacture guidelines, the similarities among all types of wear (on bearings, bores, other mating surfaces) meant that these could be grouped together. An important note here is necessary: the following failure and scrap mode analyses are performed on a part basis. Later, a mass analysis will show somewhat different results.

Failure mode part analysis for disassembly: It is more than a little ironic that the largest category had to be labelled 'no failure.' Most of the parts scrapped at disassembly were functional: economic reasons caused these to be recycled rather than remanufactured. This economic problem is, for the time being, outside the scope of the design guidelines being developed. As well, perhaps, the meaning of the category 'design flaw' might not be clear. This is a group of parts that did not function in service as intended, and were recognised as flawed by the OEM. Since this design could not be corrected at the remanufacture stage, all these parts were automatically scrapped. Categorising the parts by failure mode provided one basis for the development of remanufacture guidelines.

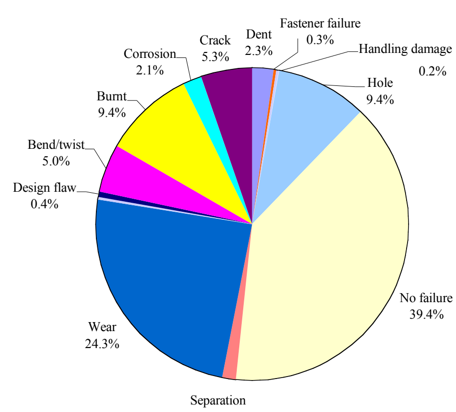

Figure 3: Failure modes at disassembly

Scrap mode part analysis: Complementing this analysis, however, was another that looked at reasons why parts were scrapped. Although a part may have failed in a certain way, it is still possible to refurbish it. A few scrap modes were determined, as shown in figure 4. The scrap modes may need some explanation.

Overstock: First, overstock is roughly equivalent to the 'no failure' category above. Parts were scrapped because, essentially, there were too many to carry in inventory.

Under/oversize: The second largest category (under/oversize) consists of parts that were recycled because refurbishing the part would mean material removal that put the part outside the specification. Additionally, there were some parts (fewer in number) that had already been returned to the remanufacturer a second or third time. These parts had no remaining material allowance for repair, and again, would not meet specifications. The remaining categories consist of far fewer parts.

No process: Some parts were scrapped because a repair process did not exist at the remanufacturers. Truly, there are repair processes for almost all of the failure types encountered, however, many remanufacturers choose to scrap a part rather than repair it, due to the time and cost involved in the effort.

Material loss: This category refers to parts that were damaged in other ways than by direct wear (which would usually result in the part being oversize or undersize). These system components were damaged incidentally by others that had failed. The category is largely made up of engine blocks that were hit by loose connecting rods.

Mating part lost: Occasionally, cores are returned to the remanufacturer missing certain pieces from a set that must remain matching due to their specific wear patterns. Rarely, a mating part is lost at the remanufacturers. In these cases, the mismatched or widowed pieces must be scrapped.

Cosmetic: A few engine parts, like covers and sleeves, are damaged, but not in any way that impairs their function. These parts, are however, visible to the consumer, or engine mechanic, who may not trust that they can perform well with even superficial flaws. Consumers usually prefer to see recently purchased systems looking like new, as well as operating like new. Parts that do not meet certain visual standards are discarded.

Unreliable: Lastly, some components may be repaired, but their reliability is suspect. Disassemblers and machinists have a certain amount of discretion: they may choose not to repair a part if they are concerned about warranty problems with the reassembled engine. Bent connecting rods may be straightened, and may function well; cylinder heads with some welding also operate normally. Often, though, even at disassembly, a

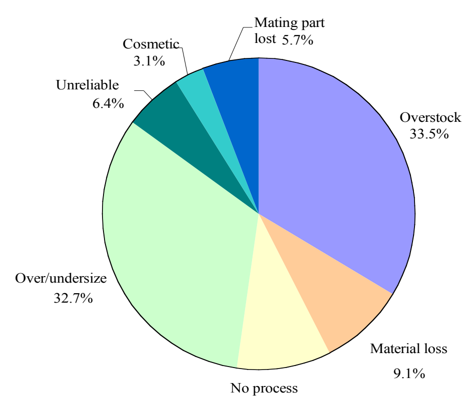

Figure 4: Scrap modes at disassembly

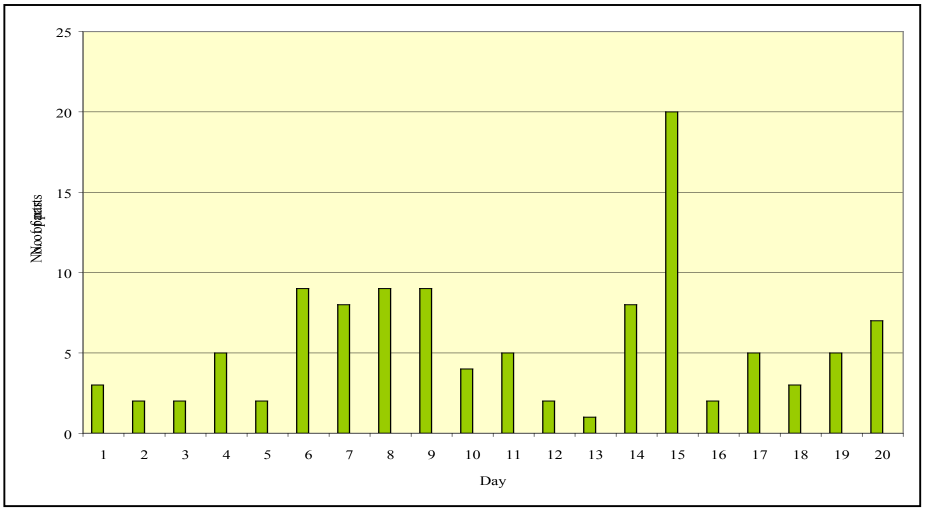

Figure 5: Scrap profile from block machining line

worker will judge a part not worth repair because it would, in their eyes, be too weak.

Machining stations: As noted above, the same types of failures were encountered at the machining stations as were found at disassembly with few exceptions. Cracks that were harder to detect were found at block machining. Loose or missing mating parts were also more commonly found at the individual stations. Parts with too much welding, whether brought to the remanufacturer in this condition, or welded at the remanufacturers, were usually scrapped at machining stations. Certain types of handling damage, like machinists errors, were also, of course, singular to these lines.

There was slightly more difficulty in obtaining data from these stations than from disassembly. Workers on the machining lines rotated through the weeks, and some machinists described failures differently than others, putting stress on different aspects of remanufacture problems. Machinists were also reluctant to divulge scrap due to handling problems or machine errors. Some also felt that they were being blamed for not being able to repair a piece, even after repeated assurances that this was not the purpose of the data collection.

The record of scrap counts at the machining lines gives a good idea of how scrap accumulates through the weeks. At block machining, a couple days may go by in which there is no scrap; so as with cylinder head machining. There is always scrap at crankshaft machining, but depending on the type of engine in production, the number may go up or down. Figure 5 shows the variation in daily scrap production from the block machining line. The profile is typical of all lines.

Generating guidelines: The data collection from automotive engine remanufacturers is essentially complete. Some final work will be done at a remanufacturer who works primarily with an OEM whose scrap engine parts have not yet been assessed. The data collected so far will become the basis for the development of remanufacture guidelines. In general, the failure and scrap categories provide the foundation for design suggestions to prevent parts being lost to recycling when greater economic and environmental benefits can arise from remanufacture. The overall picture from which the guidelines are developed, on the basis of scrap mode, is shown in figure 6. This figure illustrates that there is a second way to consider material savings: on the basis of mass.

Scrap mode analysis mass basis: The previous figures illustrating scrap production have been generated on a part basis. Assuming one goal is to prevent part loss, the part-based analysis is valid. But certain parts represent much more material savings than others. If another goal is to conserve embodied energy (assuming that, in general, a larger, more complex part took more energy to manufacture originally), then it may be appropriate to also analyse scrap according to mass.

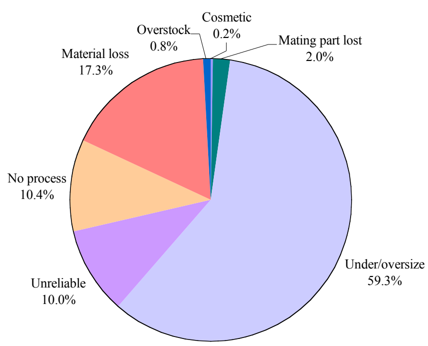

Figure 6: Scrap modes on mass basis

From figure 6, it seems that the problem of overstock is much less significant. Although there are many parts that are scrapped because they are inexpensive to manufacture from virgin materials, these parts are not very massive. However, under- and oversize parts become even more prominent in this scenario. The importance of each guideline for designer consideration may depend on the significance of the problem, as reflected by the mass of scrap found in each category.

The same contrast could be made between failure-mode part analysis, and failure-mode mass analysis. This as well shows a shift in emphasis to the failures of the larger mass parts. Of course, there are other possible breakdowns for the data, by metal type, for example. The analysis selected depends on what the remanufacturer is trying to achieve: reduction in part scrap or mass scrap or in a type of metal to recycling. Guideline priorities can be selected according to the aim of the remanufacturer.

Future work: As discussed in the introduction, however, these guidelines must as well be reconciled with other design approaches employed at manufacturers. The starting point for looking at trade-offs among 'design-for-x' considerations will be a 'customer' (manufacturer, remanufacturer, vehicle owner, environment) needs analysis in a House of Quality. Technical design requirements among customers that are related to remanufacture (conflicting or supporting) will be assessed. The results of this assessment will form a supplement to the more general guidelines developed by the waste steam analysis. The method of integrating all concerns will rely on analytic decision-making processes.

Conclusion: An analysis of the waste stream of remanufacturers is being undertaken to ensure that comprehensive design-for-remanufacture guidelines can be developed for the designs of new products. Remanufacture is considered to be an environmentally and economically preferential strategy. Recycling is still, of course, necessary, but should be preceded by remanufacture, for many products that are energy- and material-intensive to manufacture. Thus although it is of critical importance to get designers to consider ease of remanufacture during the original design process, design for remanufacture must be integrated with other strategies being pursued.

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