Analysis of the waste stream of an original equipment remanufacturer: Towards the development of integrated life-cycle design guidelines

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Abstract:
This paper describes the research pursued at an automotive parts Original Equipment Remanufacturer (OER) with the goal of developing integrated remanufacture and life-cycle design guidelines. This work involves the analysis of the waste stream of an OER in order to identify difficulties in the remanufacturing process that lead to unnecessary scrap. By analysing the failures and the reasons behind scrapping parts, we will arrive at design guidelines for remanufacture that can be integrated with other design for X strategies (design for manufacture, design for assembly, and even other design for environment criteria). In the end, the goal is to achieve design metrics that, while requiring a trade-off with other design guidelines, will at the minimum require remanufacturing be taken into account at the design stage, and at a maximum ensure the primacy of an integrated life-cycle strategy. The investigation into failure modes and scrap allocations is essentially just beginning. In general, however, it is already clear that manufacturer policy, economics, and consumer behaviour will, in the short term, preclude any improvements that can be suggested by the waste stream survey.

Keywords: automotive, remanufacture, life-cycle design, scrap, waste stream

1 Introduction

This research into the development of integrated design guidelines is being pursued at an automotive engine remanufacturer. In a recent survey, the automotive sector comprised 46% of all remanufacturers [1], and is therefore the major target for this assessment. Additionally this sector has invested heavily in design for manufacture and assembly, and more recently both life-cycle and environmentally conscious design conferences on automotive products have been supported [2, 3]. Since other design strategies are well developed in the industry, and interest in new ones is burgeoning, it is an ideal candidate for this analysis.

While remanufacture is a (relatively) new term, the practice is much older, but has often been pursued under the name 'rebuilding.' Some general disagreement still exists about the definitions of the different terms: remanufacture, repair, reuse, and rebuild. For some, the distinction between remanufacture and rebuilding pertains only to the production-batch nature of the former and the individual job scale of the latter [1]. 'Repair' sometimes denotes the return of a product to a merely functional condition, as opposed to 'like new' [4]. At the automotive OER where this work is being done, a specific view of remanufacturing is held, that defines the OER in opposition to independent engine rebuilders. Here, remanufacturing means that original equipment parts only are used when new replacement parts are needed, that engine cores are completely stripped and cleaned before being built back up, and that a warranty is provided for each remanufactured assembly. Many independent remanufacturers, however, also strip and thoroughly clean the cores, and provide a warranty for their product.

The distinction that this OER makes with respect to independent remanufacturers is pertinent in the light of recently published industry survey results. Here, independent automotive parts remanufacturers state that OEMs hinder remanufacturing, and say that, except for isolated cases, working co-operatively with OEMs is not a desirable or achievable situation [5]. If such a view is wide-spread, it may have a deleterious impact on the adoption of guidelines such as those we wish to develop. Any environmentally oriented strategy, such as life-cycle design will, in order to succeed, need the support of all players. Therefore, it is important to return to the industrial and commercial context of remanufacturing, even when undertaking the development of theoretical design guidelines, since omitting consideration of industry characteristics may mean that new design procedures are unusable, inapplicable or impractical.

The benefits of remanufacturing are usually cited as three-fold: environmental, legislative, and economic [4]. Although much of what is normally written about the advantages of remanufacturing is true, it is true in a limited way with respect to the OER at which this work is being done. For example, in support of remanufacturing, the overwhelming amount of industrial solid waste arising from materials extraction, processing, and manufacturing is often noted. While remanufacturing can reduce industrial solid waste, it has also been recognized that it promotes product diversity or part proliferation [5, 6]. The existence of a remanufacturing infrastructure supports the availability of replacement parts for automotive models no longer in production at the OEM, so that the OEM can turn to satisfying the sharpening consumer demand for the latest model. Not only has the number of models manufactured by U.S. automakers nearly doubled since 1982, but some are now considering premiering new models two times a year, instead of just once. In part because the remanufacturers can return older model parts to service, materials, energy and labour are invested in new products more than ever. One must be careful of the environmental or ecological claims made about diverting or reducing material and energy consumption in this case.

As well, remanufacturing in the United States started during the Second World War, as a response to reduced material supply [1]. The OER under study has been remanufacturing engines since 1957. In 1978, the company expanded and began serving the U.S. market. Thus any attribution of the impulse for this activity to incipient take-back laws is clearly misplaced. Most of the remanufacturing work in Canada, in the automotive sector, predates any environmental concern on behalf of the government. In addition, although European laws may affect the European subsidiaries of North American manufacturers, and although the U.S. government has made a few statements encouraging recycling and waste reduction efforts, Canada, at least, is not considering any product take-back legislation [7, 8].

This leaves economic factors as the driving force behind remanufacturing. These are not inconsiderable. A recent estimate of the industry size quotes $53 billion in annual sales [9]. Eastman Kodak and Xerox have both saved millions of dollars through remanufacturing office equipment such as photocopiers [7]. The results of the above quoted survey of independent remanufacturers show that the minimum average (net) profit for remanufacturing lies with the 30% (± 10%) range [5]. We will corroborate: the data on this remanufacturer's waste stream reflects the primacy of economic factors. These notes of caution as to the environmental superiority of remanufacturing over other end-of-life strategies, and about the claim to its development as a response to dawning environmental awareness on the part of manufacturers are not made to derate the overall value of remanufacturing as an ecologically beneficial activity. It is clearly important, however, in the context of the evolution of an integrated life-cycle approach to recognise the limitations of different strategies, and the barriers inherent in their present operation.

1.1 Design for remanufacture and other design methodologies

The essential goal in remanufacture is part reuse. Other product design methods that facilitate any of the steps involved in remanufacture (disassembly, sorting, cleaning, refurbishment, reassembly and testing), may facilitate remanufacture. If a part cannot be reused as is or after refurbishment, however, the ease of disassembly, cleaning or reassembly (or the various design strategies that promote them) will not matter. In opposition to general design methods that promote light weight, easily manufacturable materials, literature on automotive remanufacture frequently suggests parts be designed for greater durability, since more material provides a larger margin to work with, and sturdier parts mean less damage [10–12]. While attempts to design entire products for a greatly extended life cycle are likely to result in a waste of resources [13], it may be possible to incorporate some properties of more durable products that facilitate remanufacture without undue expense. Concentrating anticipated wear and failure in detachable, consumable parts such as inserts and sleeves is one way of facilitating refurbishment. Mitigating the cost factor involved in increased durability somewhat neutralizes the advantage of other design guidelines for manufacturers. However, there are reasons other than wear or failure which result in product disposal. Products may become technologically or aesthetically obsolete, or they may never have successfully satisfied their intended function.

For example, at the remanufacturing facility, engine blocks with 10-mm bolt holes (for mounting the block) are automatically scrapped. The '10-mm bolt hole' block was found to be a functional failure, and was replaced with one having 11-mm bolt holes. The old blocks cannot be remanufactured to the larger bolt size. If the designers had originally considered that their new 10-mm design could cause considerable scrap if it resulted in mounting problems, they might have stayed with a tested design, or designed a 'back-up' method (providing for inserts, or an additional fastening method) to prevent waste. The issue of technological obsolescence is likely to be a more difficult one to handle in the context of integrated guidelines. The worst vehicle exhaust emissions are produced at start up, because the engine is cold, and combustion less complete. To mitigate this problem, manufacturers are looking at producing thinner blocks, that heat up more quickly. Thinner blocks, however, mean fewer, or perhaps no material allowances for the remanufacture of an oversize. (Removing worn or damaged material to create a 'like new' surface finish within specified tolerances, usually on bores or bearing surfaces, makes an oversize part.) The new blocks may not be made of cast iron, but of a sintered powder that cannot be machined. Both redesigns will pose formidable challenges to the automotive remanufacturing industry, but it will be difficult as well to develop general life-cycle design guidelines in such cases.

In some ways, that an integrated life cycle design will require compromise and perhaps a reordering of priorities has not been fully appreciated. Witness the recent statement that an optimum automotive life cycle plan must not sacrifice the environment for economics, economics for the environment, or compromise the original design in safety, durability, and affordability [14]. This comment implicitly recognises that designers consider assembly, disassembly, ease of manufacture (methods that reduce product cost) and product quality and recyclability. It ignores such obvious conflicts as those between specifying new or used material, when there is a heavy environmental burden associated with metal procurement, and it ignores that light weight, fuel-efficient designs require durability sacrifices, and arguably safety ones as well. Other recent life-cycle studies of automobiles or their parts do not even consider remanufacturing as a viable end-of-life strategy; recycling, landfill, and incineration are the only options suggested [15, 16]. To a certain extent, therefore, both remanufacture supporters and design for environment promoters have not fully considered the interaction between, or the possibilities provided by, overall life-cycle design and different end-of-life options.

To approach this problem, we began by collecting information on the waste stream of remanufacturers, believing that this will lead to an identification of remanufacture difficulties or process inefficiencies. While at present cataloguing economic, technical, or logistical impediments, and studying the usable parts constitutes the majority of the work, the design context of the products will also be reviewed. Thus the eventual result will be guidelines for end-of-life product design to achieve environmentally responsible design and manufacturing, based on present remanufacture difficulties.

Additionally, although this research concentrates on the automotive remanufacturing industry, and specifically on engine components, the design guidelines that we intend to develop are not to be limited to one product or industry. The conclusions drawn here are placed in the context of the automotive sector, because our research into the waste streams of plastic products (specifically toner cartridges) and of tire remanufacturers is in its nascency. In the end, all the information will be compiled and generalised. Thus this work will have to perform a bit of a balancing act, walking the fine line between what is pertinent only to individual industries, or even to individual assemblies, and what can be extended to more comprehensive life-cycle guidelines.

2 OER Waste Stream Analysis

The data collection task sounds deceptively simple: count the automotive parts scrap and determine the reason for its relegation to the recycling bin. In practice, it is not always easy to determine if a part has actually ‘failed,’ and why remanufacture is not an option. Such is the case since the oft-repeated phrase ‘not to specification’ is ubiquitous but unenlightening. In reply to the question, ‘why is this part being scrapped?’ the expression means that the manufacturer has specified minimum or maximum sizes (of shafts, bores, the angle of valve seats, the thickness of cylinder heads, etc.) that the part no longer meets.

This OER remanufactures gasoline and diesel engines. These 'cores' usually contain the cast iron or aluminum engine block, in which the crankshaft, connecting rods and pistons are found. On top of the block, the aluminum cylinder head with its camshaft, valves, guides and springs sits. Long blocks (engines with many additional components, including timing belts and covers) or short blocks (containing few additional components, perhaps only the cylinder heads) arrive from the warehouse each day, 'just-in-time' for the specific order that assembly will need to fill in a week.

At the OER, parts are scrapped from every station; see figure 1 for a disassembly and repair station flow diagram. A brief summary of the process follows. Long or short blocks are delivered to disassembly. Upon detection of major failures: holes, burns, cracks, etc., engine blocks or components are scrapped. Manufacturer instructions to disassemblers require them to discard all pistons (with pins and rings), main and connecting rod bearings, gaskets and seals, timing belt, obsolete parts, parts of questionable quality, visually non-genuine parts, and non-repairable parts. To operationalize these instructions requires some training in the available downstream processes. 'Questionable quality' is occasionally further defined by manufacturer bulletins, and 'non-repairable part' is, between reason and general process limitations, left to the discretion of the disassembler. It is not appropriate, however, to be too conservative, and burden the machining lines with significant amounts of scrap. Aluminum and steel parts are washed, sandblasted, and painted. Some scrap is found at these other stations, for the cleaning process may reveal fractures or gouges disguised by oil and dirt. Engine blocks go to thread repair and cylinder boring. Shafts and cylinder heads flow to their respective machining lines. Valves are sent to a grinding room, and connecting rods to their own station for inspection and machining. All parts meet again in assembly. There are few parts scrapped from the assembly line, but some internal cracks do not show until pressure testing in the later stages, so it is not rare.

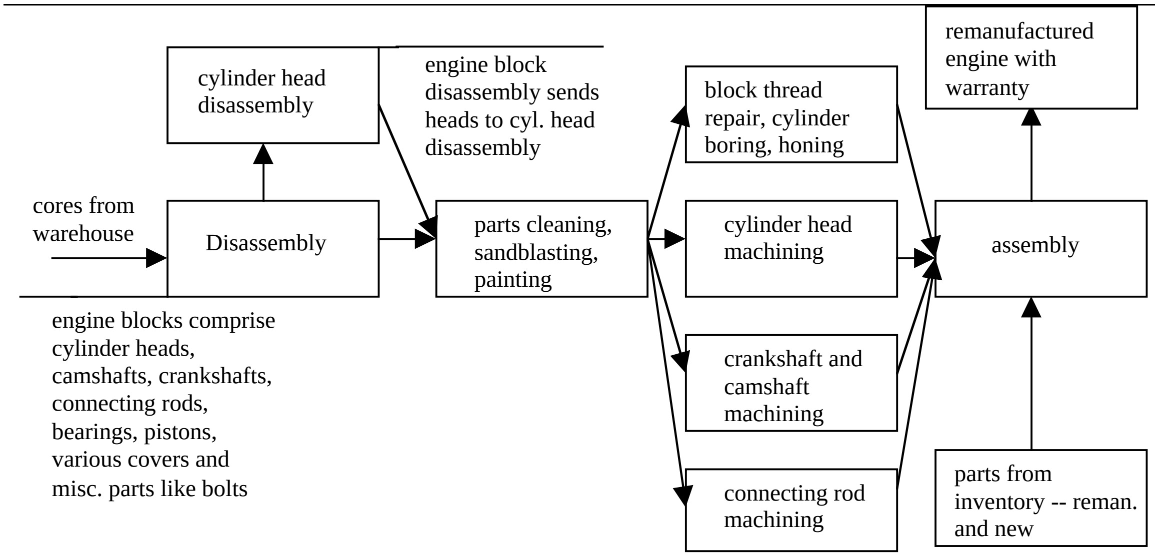

Figure 1 Parts flow through disassembly and repair stations.

It may seem improbable that an OER does not quantify and categorize its own scrap, both to identify additional economies, and for inventory and process control. In fact, each line or station counts its own scrap, and daily or weekly this information is entered into the OER's material tracking computer system. However, this information is not as complete as it might be. If there is sufficient stock of a certain part, or if it is not required to account for a part for other reasons (100% scrap parts: pistons, bearings, wrist pins, some bolt types), these scrap counts are not filed. As well, the OER does not routinely track reasons why parts are scrapped. When a new product is received — an engine core that has not previously been remanufactured — the OER will monitor the part scrap rate to build up a profile to be fed back to the manufacturer. After an initial period, a percentage loss profile is established for the core, and no further tracking is usually pursued. In general, for the OER, there are, at this point, few reasons to scrap a part: parts are nonconformist (not to specification), or no process to remanufacture to a like-new condition exists. If the expected number of salvaged parts are being recovered, other information is not considered useful.

The first step in the development of remanufacture guidelines that are to be integrated with other design priorities is to determine and categorize the barriers to product reuse by remanufacturers. To this end, we began counting and classifying scrap from all the processes. As expected, disassembly sends the bulk of scrap parts to recycling. Figure 2 shows the breakdown by line, based on the total number of parts counted as scrap during our inventory period.

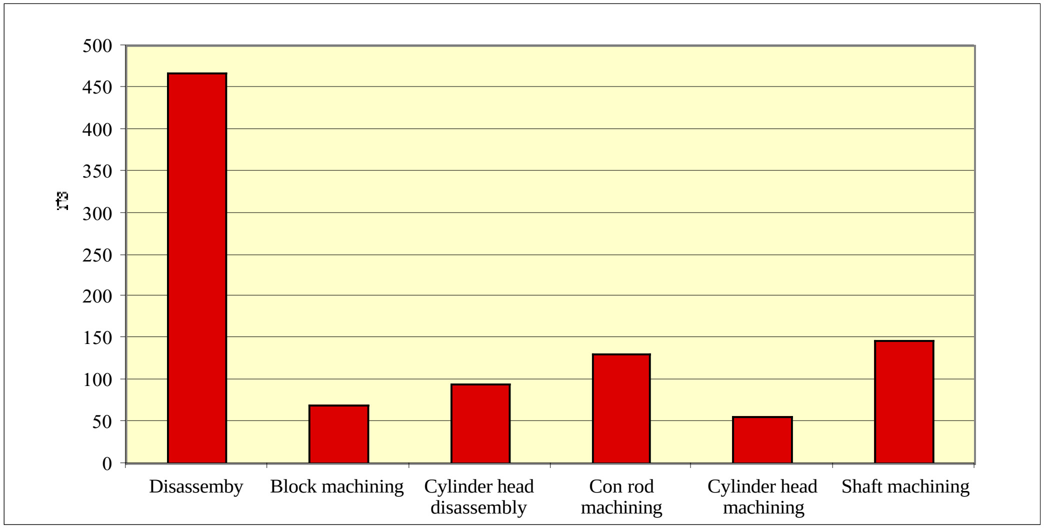

Figure 2 Number of scrap from lines and stations

Although disassembly scraps the most parts (at this OER), the major barriers to part reuse may not, in general, occur at disassembly. At present, we have the most detailed scrap rate information from this station, and this paper concentrates on the scrap generated there. Overall, however, the influence of all stations and lines will be considered.

Figure 3 shows the results of scrap classification from the disassembly line. In all cases, parts were categorized by their failure mode (crack, hole, dent, corrosion, undersize, etc.), and by their scrap 'mode.' The failure modes were numerous. Fewer scrap categories emerged, but these are more complex, as will be explained. Eventually, after enough parts have been surveyed, we hope to draw some conclusions about the failure and scrap mode correlations, but at this point, there is insufficient information to make generalizations, since independent remanufacturers have not yet been studied. It should be noted that from the survey at the OER, failure mode and scrap mode are not necessarily the same thing. A dent, crack, or a burn may be the reason that the part arrives at remanufacture, but it is scrap because no oversizes are allowed (although available), or the repair process is considered too labour intensive.

In many cases, the manufacturer can procure new parts more cheaply than it can make provision for remanufacture. For example, in one hour, 40 2-litre blocks were scrapped; over 1500 kg of cast iron were discarded because the block and four pistons are cheaper new. In the same period, 82 hardened steel camshafts were scrapped, not because they were undersize or burnt (as is generally the case), but because they were uneconomical to remanufacture. Overstock is another reason why non-flawed parts are scrap. If palettes of cylinder heads are piling up in the storage area, heads arriving at disassembly may be scrapped. (In a recent case, 5000 heads were disassembled for their small parts, but the aluminum blocks were dumped because 20 000 more were arriving from Mexico.) When inventory becomes low, disassembly will be directed to collect the parts again. In figure 3, all such economic decisions are characterized by the term 'overstock,' and clearly 'overstock' is the major reason for scrapping parts.

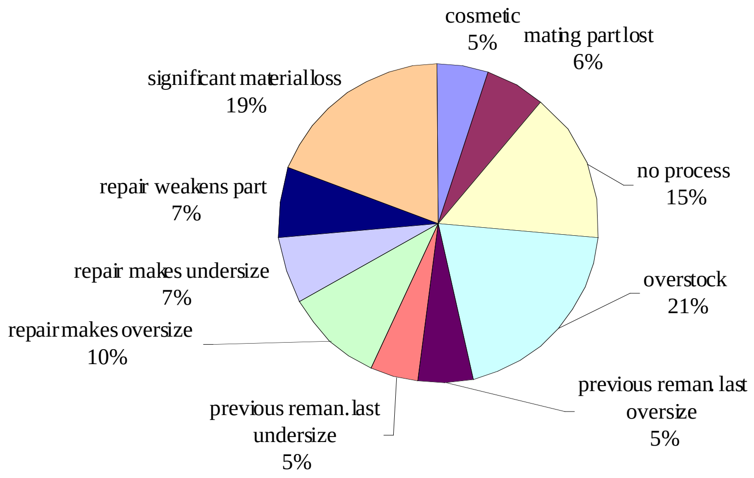

Figure 3 Categorization by Scrap Type

The second largest contributor to disassembly scrap are those parts in the 'significant material loss' category; engine blocks and connecting rods are the culprits. The 'material loss' keyword describes parts with holes, or parts that have broken pieces. Those with either of these types of failures are usually retrievable: patching processes for blocks with holes do exist, and, as well, it is possible to weld connecting rods or crankshafts. In the first case, however, the process is too time-consuming to be considered feasible, at the OER level, and in the latter case a warranty could not be provided for the part.

Scrap parts labelled 'no process' have more diverse failure modes (cracks, corrosion, fastener failures and inherent design flaws), but part diversity is low: cylinder sleeves, timing covers, and engine blocks fill this category. There is presently no process for successfully repairing a crack in a cylinder sleeve, or in a timing cover (welding a major crack causes material damage). Some blocks in the ‘no process’ category had not actually failed. These are new engine blocks for which no tooling exists for disassembly, nor indeed a manufacturer ‘infrastructure’ that would provide for remanufactured engines to go back into service.

It is clear that the classification scheme is not straightforward. Parts that have failed due to breakage are grouped in a category that indicates that the damage was in some ways too severe to repair, although repair processes exist. In these cases, repair does not produce a part that can withstand normal stresses, according to OER criteria, and cannot be returned to service. These parts are then different from those that are never considered, even by independent remanufacturers, to be repairable, due to inherent weakness in the rebuilt part. Such cases are labelled ‘repair weakens part’ in figure 3. Some non-failed parts are overstock, and some are ‘no process,’ where the difference is determined by the remanufacturer, in the way it inventories parts. In both cases, the ultimate reason for not reusing the part is economic. For our purposes an ‘uneconomical’ category is not very illuminating, since the majority of parts would comprise this one division.

The remaining parts from disassembly are scrap because they are undersize (shafts) or oversize (bore damage). Camshafts and crankshafts are usually burnt on their main journals. Such burns, caused by insufficient lubrication, can be removed by machining, if the material incurs no other material damage in the process. Machining the bearing surface takes the part to the next undersize, and often no undersizes are allowed, since oversize bearings are then required. Standard size new parts are inexpensive enough that for many engines, parts requiring a mating part that is oversize are not allowed. For blocks with bore damage, it is possible to machine the cylinders to an oversize (generally three oversizes are allowed) but after this point, the blocks are scrap.

There is a small category of scrap parts called ‘cosmetic.’ The failure mode for the majority of these parts, which are largely plastic, is ‘dent.’ Actually, the dent does not cause the part to ‘fail’ in the sense that it can no longer properly perform its function. Parts are scrap because the manufacturer’s perception is that the customer will not accept a component that may still show traces of the original flaw. For example, oil pans are often dented when drivers hit low curbs or concrete parking blocks. The pans can be sanded and repainted, but traces of the scuffing might remain. Because customer expectations are high, all oil pans, even those with scratches, are scrap.

In summary, then, from the disassembly line, we have parts scrapped because: new parts are cheaper, or a sufficient number of remanufactured parts are already carried in inventory; parts have too much material loss; there are no processes in place to remanufacture the parts; and because specifications preclude the use of the next undersize or oversize. From a design for remanufacture point of view, a few conclusions can be drawn. If manufacturers would consider the remanufacturing issue from the moment that the first model comes off the line, a significant amount of scrap could be avoided. At the present time, there is little provision for the remanufacture of new model engines since the OER is not supplied with tools or specifications for disassembly, and there is no market for the remanufactured product. In our case, new, undriven engines were being scrapped because neither the manufacturer nor the remanufacturer had the warehouse space or budget to store the engines until such time as a remanufacturing infrastructure could be put in place.

Secondly, if manufacturers would consider increasing (or in some cases allowing) the number of under- or oversizes, the remanufacturing cycles for shafts and blocks could be increased. A more detailed examination of the limitations for such specifications needs to be conducted. As well, block holes, causing ‘material loss’ scrap, often occur in a non-critical areas. If designers consider that 60 kg of cast iron is scrapped because of a 2 or 3 cm diameter hole, perhaps a more economical patching method, one that could fit the production line set-up of the remanufacturing floor, could be implemented.

Additionally, small gains might be made if there were a clearer understanding among manufacturers, consumers, and mechanics about remanufactured automotive parts. If consumers were able to accept (perhaps with the prompting of the mechanic) a slightly dented or scratched oil pan or valve cover, many scrap parts could be salvaged. As well, if designers were required to use remanufactured parts in their original designs, new material use would be discouraged. Part models standardized for a minimum period of time, until a technology change warrants a design revision, would reduce scrap. For example, engine block redesign to satisfy a new bonnet style should be discouraged. Requiring designers to work with what is available, to be constrained by environmental considerations, would change overall design priorities. The type of products offered to consumers would also change: a ‘new’ car containing some remanufactured parts would have, initially, a lower price tag, and replacement parts after the (perhaps shorter) warranty period would also be less expensive. And, as noted above, design for remanufacture may require that design for quality guidelines that reference aesthetic characteristics become less rigorous. The usability of the product is in no relevant way affected, but appearances may suffer.

Finally, if the externalities of metal mining and processing are never captured and internalized by the primary and secondary material users, the problem of new parts being cheaper than remanufactured will never disappear. The ‘material loss’ problem is also related: labour is time-consuming and increases overhead. Human labour per se, however, is not environmentally damaging. As new material prices increase, investing in labour would become more profitable.

Conclusion

This study characterizes the waste steam of the disassembly line at an original equipment automotive engine remanufacturer. From this initial work, we learn to appreciate the importance of the roles of OEM (and government regulatory) policy, economics, and consumer behaviour in shaping the present inefficiencies. We may conclude that a major barrier to significant improvement is the emphasis OEMs place on cost reductions in the initial design and manufacture stages, without fully internalizing the costs incurred at the material recovery and processing or disposal stages. At the same time, the OERs are very conscious of labour costs, as well as of advantages provided by cheaper new material prices. The changes that can be suggested by an initial survey of the remanufacturer’s waste stream must be made in the context of a revision of present manufacturer design strategies. Such a revision, in its most complete form, entails the internalization of the costs of non-renewable resources, and the acknowledgement of the primacy of environmental considerations.

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