Issues in the Automotive Parts Remanufacturing Industry – A Discussion of Results from Surveys Performed among Remanufacturers

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ABSTRACT

A dramatic reduction in the environmental impact of production practices can arguably be made by pursuing product remanufacture in which, in contrast to material recycling, the geometrical form of the product is retained and its associated economical and environmental value preserved. In order to support the design of remanufacturable products, it is necessary to identify and rank the various factors that affect and/or characterize a product's remanufacturability. In this paper, results from three surveys among independent automotive remanufacturers are presented, highlighting what a segment of the remanufacturing industry perceives as critical issues, as well as their relative importance. The first survey contained open-ended questions and its results provide insight in key concerns of a set of remanufacturers. The second survey followed up on these key concerns and more specific questions were posed in order to gain deeper understanding as to the relative importance of the concerns listed. In the third survey, local remanufacturers were asked to perform a direct comparison between key issues identified in the preceding surveys. The results of the surveys clearly indicate that the remanufacturing industry is struggling to keep up with modern production practices from Original Equipment Manufacturers. It was also clear that a number of issues dominate, but that the relative importance can vary among remanufacturers, especially with respect to design and process issues.

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1 Our Frame of Reference – Metrics for Assessing Remanufacturability

1.1 Research Objective

As manufacturers become more and more environmentally conscious, they tend to investigate various means of producing their products in such a manner as to reduce environmental harm, while simultaneously keeping their costs down. Many manufacturers with international markets are particularly concerned with proposed European "Take-Back" Legislation or "closed loop economy laws", which would require manufacturers to reclaim their product at the end of its life-cycle and recycle a certain percentage of it (see, e.g., (Congress, 1992, Fiksel, 1996)).

Product reuse, as opposed to material recycling, would seem to be the more profitable means of product disposition, both ecologically and economically, as the reprocessing and manufacturing expenditures (time, energy, cost, etc...) are avoided (Amezquita, et al., 1995a, Berko-Boateng, et al., 1993, Haynsworth and Lyons, 1987, Navin-Chandra, 1993). Remanufacturing is defined as the practice of disassembling, cleaning, refurbishing, replacing parts (as necessary) and reassembling a product in such a manner that the part is at least as good as, or better than, new. By remanufacturing a product, the product may be returned to service with a reasonably high degree of confidence that it will endure (at least) another full life-cycle.

The largest gain in enhancing reusability and remanufacturability can be made in design (Congress, 1992). In order to assist the product designer to develop parts which can be remanufactured at the end of their first life-cycle, a system of efficient and effective[1] mechanical design metrics is currently being developed in our laboratory. These metrics would objectively, and quantifiably, measure the mechanical remanufacturability of their product, providing the designer with immediate feedback as the design progresses. A good example of efficient and effective metrics in a different domain, which proved successful, are those postulated and validated by Boothroyd and Dewhurst regarding the assembly of products (Boothroyd and Dewhurst, 1991). Their success lies in the simplicity of the usage of the metrics (e.g., everybody can count the number of parts in an assembly) connected to the fact that their metrics are valid and indeed provide a good measure for the assemblability of a product. In order to develop a similar system of metrics for assessing remanufacturability, it is necessary to develop a better understanding of

a) what criteria need to be measured, and
b) how important these criteria were, relative to one another.

In (Amezquita, et al., 1995a), we identified design characteristics which facilitate remanufacturing from literature and general practice. We discussed principal driving factors for remanufacturing, as well as identifying existing remanufacturing guidelines, philosophies, and practices. In (Amezquita, et al., 1995b), we outlined our research approach taken for the establishment of remanufacturability metrics and gave preliminary list of measurables that affect remanufacturability in the form of a worksheet. Overall, we noted that the technology base for remanufacturing is sparse compared to, say, manufacturing or material recycling.

1.2 Focus and Objectives of This Paper

In our opinion, tapping into the knowledge base which has developed in this field over the past several decades will facilitate the identification of valid criteria for assessing a product's

[1] We define <u>efficiency</u> as a measure of swiftness and <u>effectiveness</u> as a measure of completeness and correctness.

remanufacturability. Some of the most notable work in remanufacturing was performed primarily by Robert Lund (Kutta and Lund, 1978, Lund, 1983, Lund, 1984, Lund, et al., 1980, Lund and Denney, 1977, Lund and Skeels, 1983a, Lund and Skeels, 1983b) who performed a survey in the early eighties among remanufacturers. In 1978, Kutta and Lund documented this survey capturing some of the issues important to remanufacturers (Kutta and Lund, 1978). However, we discovered in our interviews with remanufacturers that many changes have occurred in the industry since then (e.g., the restructuring of automotive companies into platforms and the trend towards mass customization of products). This discovery provided us the impetus to verify whether the issues typically listed in the literature are still valid in the current day and age. Therefore, the objectives of the work presented in this paper are twofold:

a) to identify and/or verify general issues of concern in the remanufacturing industry, specifically in the automotive branch, and
b) to identify specific issues critical in a remanufacturability assessment and quantify their importance.

In order to achieve our objectives, three surveys were performed:

- The first survey, a preliminary survey, was distributed at the Automotive Parts Rebuilders Associationís Electrical Clinic in Orlando, Florida in April of 1995. This survey presented several very broad questions about remanufacturing which were intended to solicit the broadest range of responses possible. Section 2 presents the results obtained from this survey, as well as a discussion on the dominating issues that were identified as being particularly significant to the current state of remanufacturing.
- The results to a second follow-up survey to the first survey is presented in Section 3. This follow-up survey was published in the APRA newsletters (*Mechanical Messenger* and *Electrical Connection*, Nov. 95) and circulated on a national (and even international) level to both mechanical and electrical automotive remanufacturers. This survey centered on examining more closely the issues extracted from the first as well as developing a better understanding of the various business practices used in the current remanufacturing industry.
- The third survey, circulated among remanufacturers in the (local) Atlanta area, is presented in Section 4 and the issues identified in the preceding two surveys were prioritized by the remanufacturers using a direct comparison. The focus of this survey was to attempt to quantitatively define the contribution of the various issues to the practice of remanufacturing.

The automotive remanufacturing industry was selected as the primary source of information for an initial survey of remanufacturers, as there is an abundance of companies which remanufacture automotive components (Amezquita, et al., 1995a, Haynsworth and Lyons, 1987, Sorge, 1991, Strandberg, 1990, VDI, 1993). This is a limitation to our work, but the insight gained will also contribute to identifying/verifying and quantifying significant issues in other branches of the remanufacturing industry.

2 The First Survey - An Introductory Look Into Remanufacturing Practice

The survey presented in this section represents an introductory look at the major issues affecting remanufacturing. Therefore, the questions were left very open, in order to solicit the broadest range of responses. Once the responses were gathered, the issues would then be formally identified, and would be further investigated to determine their significance. The questions which asked on the survey form were as follows:

1) *What Makes A Product More Difficult To Remanufacture Than Another?*
2) *Which Operations Are Most Costly?*
3) *What Makes Disassembly Most Difficult?*
4) *What Makes Cleaning Most Difficult?*
5) *What Makes Inspection Most Difficult?*
6) *What Makes Refurbishing Most Difficult?*
7) *What Makes Part Reassembly Most Difficult?*

With the generous assistance of the Automotive Parts Rebuilders Association (APRA), survey forms were distributed at the 1995 APRA Electrical Clinic, in Orlando, Florida, as well as being sent out in the APRA Newsletter, "The Electrical Connection" shortly after the clinic. In addition to the surveys, several company representatives who attended the clinic were informally interviewed.

2.1 Survey Results

Out of approximately 80 surveys that were distributed at the clinic in addition to those published in the "Electrical Connection" following the clinic, 28 surveys were returned. Each category identified in the survey questions were counted to determine how many of the 28 responses identified the same answer to the question (more than one response was permitted). The count was then converted into a percentage of responses, and was plotted as a Pareto chart. In this fashion, a Pareto chart of the responses was generated for each question on the survey in order to provide an ordered list of the issues identified by the companies which responded to the survey. These Pareto charts, as seen in Figures 1 through 7, provide visual insight into what the critical issues in remanufacturing are, as well as and introductory look at how important these criteria are relative to one another. In the Section 2.3, much of the information in the figures is refined and collected to indicate the major points made in the survey.

It is important to note at this point, that these responses were made without suggestions or reminders as to what the issues should be. It is entirely possible that the survey results may be different if the representatives were presented with a common listing of problems. Consequently, if the representatives had gotten the survey in conjunction with such a listing, the responses might have been somewhat different.

It is also important to note that these answers are particular to the Electrical Rebuilders, and as such, it may or may not apply to other remanufacturing sectors, such as other automotive parts which are more mechanically or hydraulically oriented systems. The major difference between these systems is not in what criteria is used, but in how highly these criteria are prioritized.

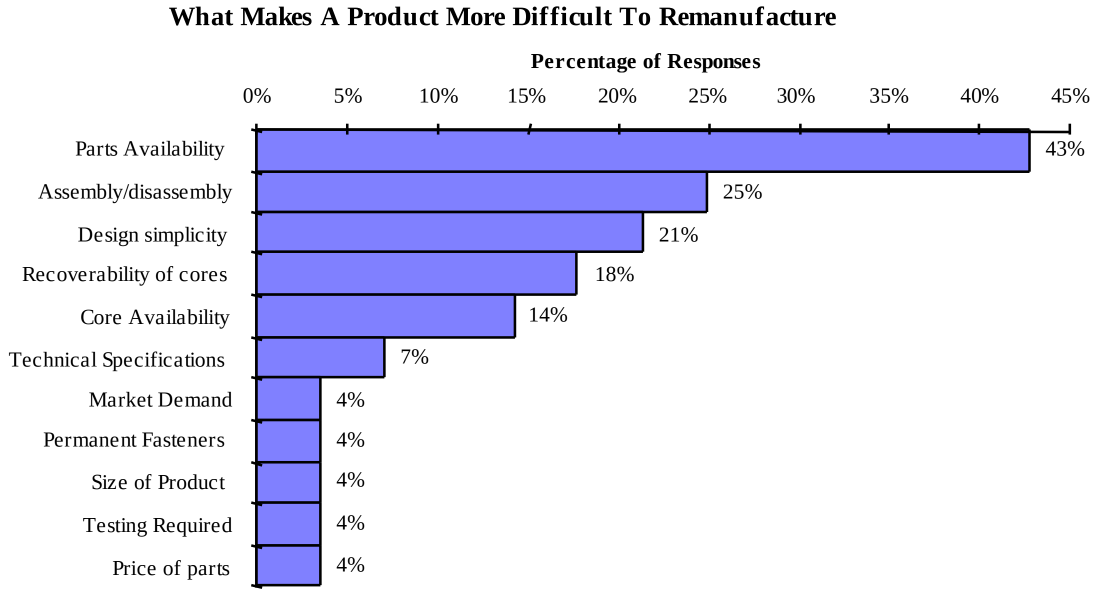

Figure 1 – Responses to Question 1: Difficulties To Remanufacturing

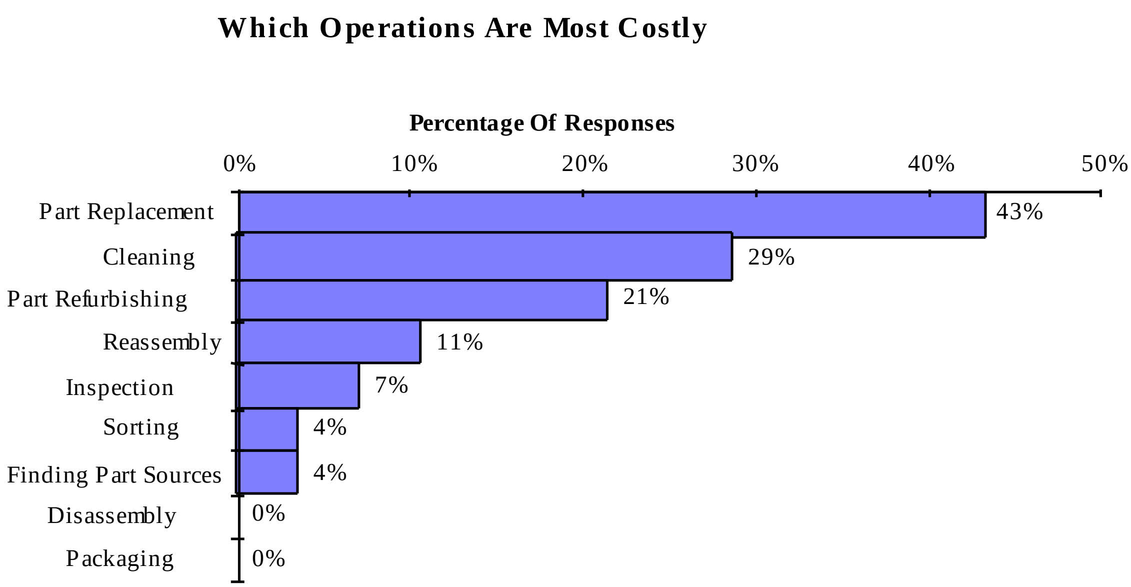

Figure 2 – Responses to Question 2: Most Costly Operations

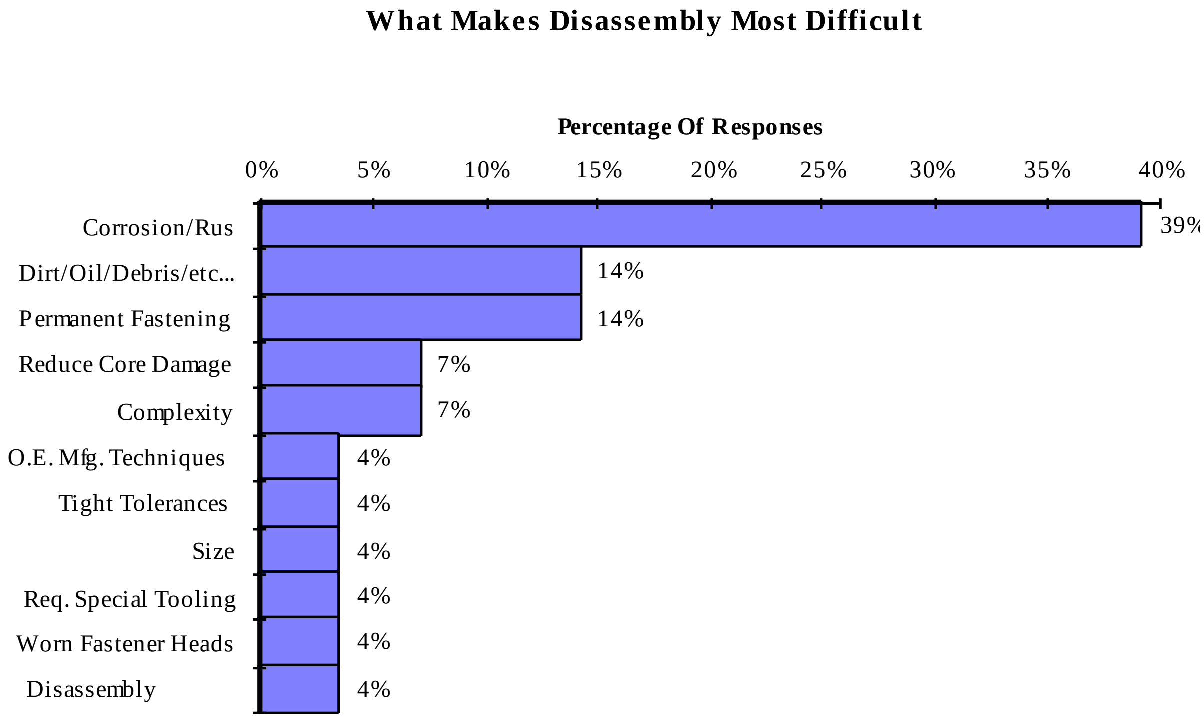

Figure 3 – Responses to Question 3: Difficulties To Disassembly

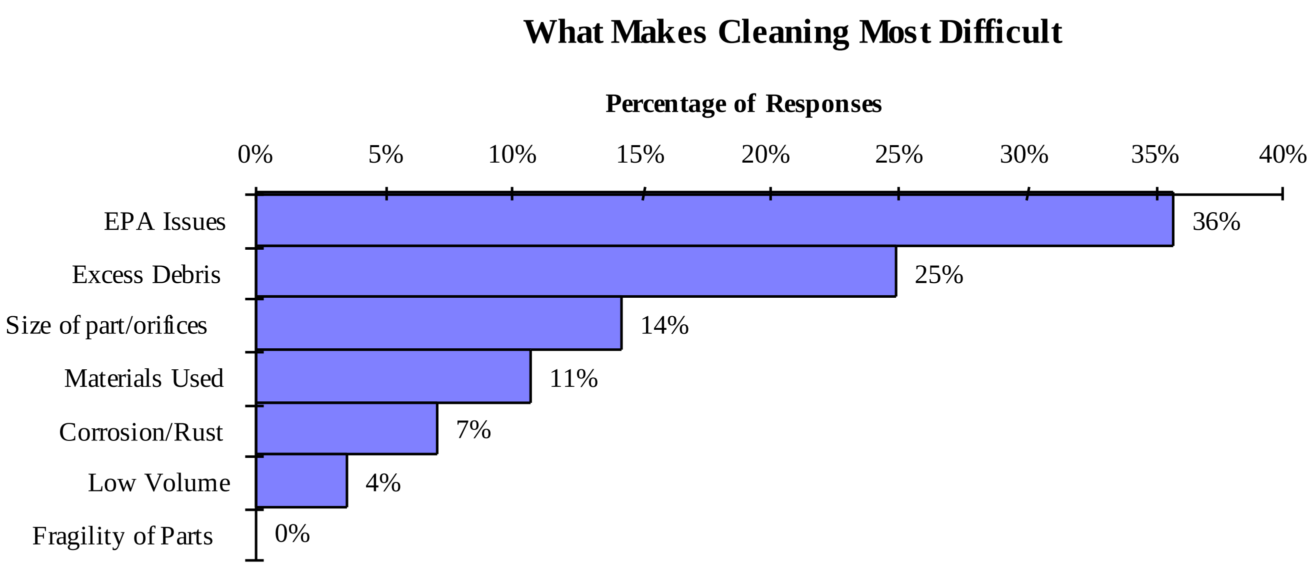

Figure 4 – Responses to Question 4: Difficulties to Cleaning

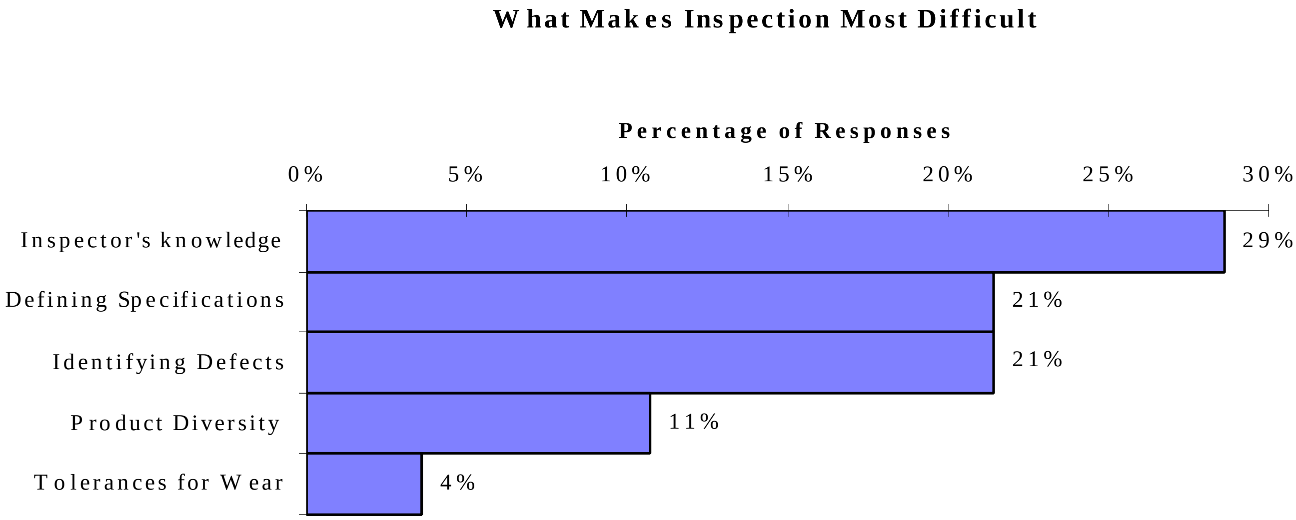

Figure 5 – Responses to Question 5: Difficulties to Inspection

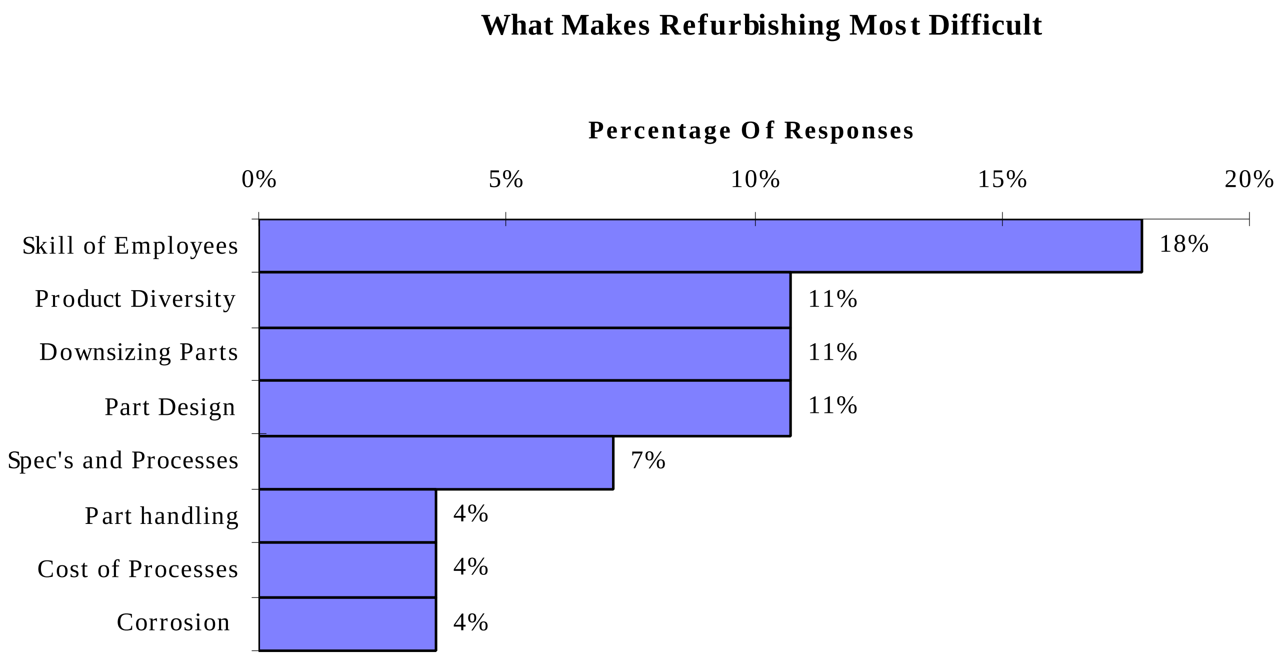

Figure 6 – Responses to Question 6: Difficulties To Refurbishing

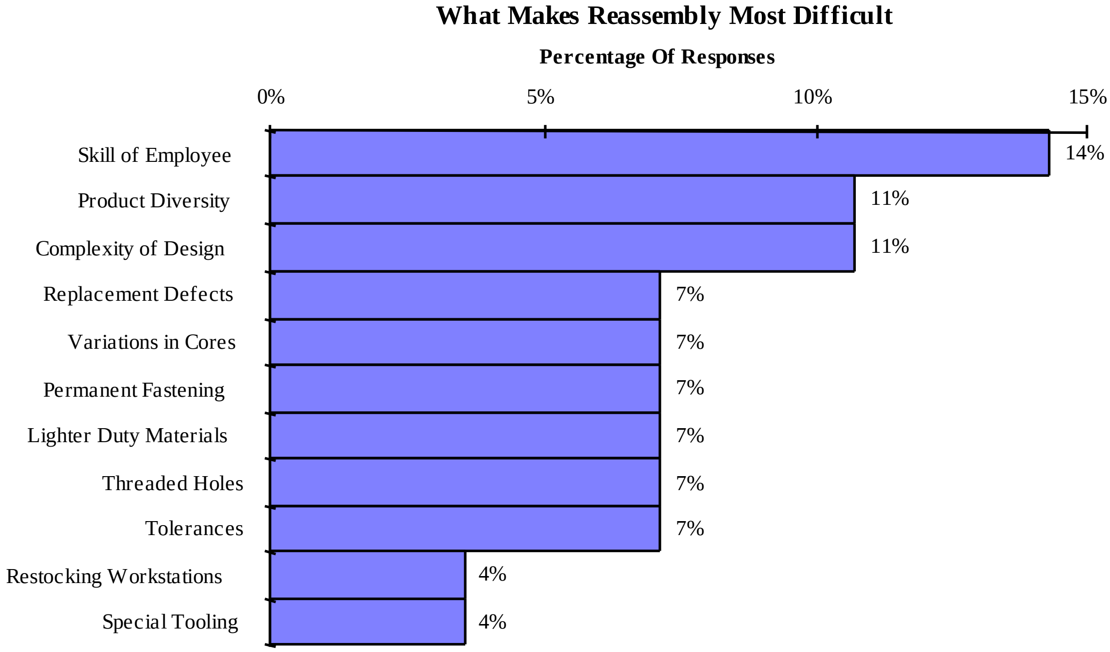

Figure 7 – Responses to Question 7: Difficulties to Reassembly

2.2 Informal Interviews with Remanufacturing Companies

In addition to the written survey, we also conducted informal interviews with remanufacturers. When the remanufacturing representatives at the 1995 APRA Electrical Clinic, in Orlando, were told about the prospect of creating a metric for manufacturers which would let them determine how remanufacturable a product is, several people were very skeptical that this would be a good thing. Many of those skeptical felt that Original Equipment Manufacturers (OEMs) perceive remanufacturers as competition, and might be predisposed to using such metrics to select designs which would make it difficult for remanufacturers to disassemble and/or reassemble their products - consequently ensuring that the remanufacturer would not be able to cost-effectively remanufacture their products.

These skeptics point at an issue which they have termed "Parts Proliferation", which refers to the practice of making many variations of the same product - differing only in one or two minor areas. However, these differences (such as electrical connectors) are distinct enough to prevent interchanging these similar products. For example, for a given model year, a car line may have one or more different alternators for each variation of the vehicle - the alternator for the two-door model would not be able to be used to replace the alternator for the four-door model. Not only can they not be used within the car line, but no other car-line made by the manufacturer can use the part either. To exemplify the amount of parts proliferation in the eighties, consider the following numbers from Rayloc, a large automotive remanufacturer. In 1983, there were approximately 3,400 different part numbers for brake products in Rayloc's Atlanta remanufacturing plant. By 1995, there were approximately 16,500 different part numbers!

Another issue that skeptics point to is that manufacturers tend to use Design for Assembly and Manufacturing processes which make it difficult for parts to be reused or remanufactured. For example, solenoids for starter motors are crimped into their housings. Not only is it difficult to remove the crimps, in order to remanufacture the solenoid, but crimped fasteners cannot be re-crimped without degrading the strength of the crimp.

However, almost all of the representatives were enthusiastic about the prospect of being able to use such metrics to determine how remanufacturable *their* products are. By being able to measure the remanufacturability of the various products, they would be able to make well founded business decisions as to whether or not to remanufacture given products.

2.3 Discussion of Survey And Interview Results

Based on conversations with the various companies represented at the electrical clinic and the data gathered from the survey, several major issues affecting remanufacturing can be identified. Several responses were repeated or seemed to be very similar. These responses, as well as those which scored significantly higher than the others were identified as major categories. These categories are described next.

Availability and Cost of Replacement Parts:

Judging by the number of responses for these categories, availability and cost of replacement parts (including cores) seem to be of key concern overall (see Figures 1 and 2). Parts availability clearly dominates the responses on the question "What makes a product more difficult to remanufacture?" (see Figure 1). Much of the general feedback that was received, both from the survey and from the informal interviews, tend to support this. There are several issues which drive this concern, such as, part proliferation, a lack of cross referencing for aftermarket supplier's parts, domestic vs. imported parts, and so on. Some of our more recent studies with local remanufacturers confirm that, although the total volume of products to be remanufactured remains high, the variety of products has increased significantly due to faster OEM product development times, mass customization, part proliferation, etc., in the past decade. Among other more minor issues, this has led to an increase in the variety and a decrease in the volumes and availability of needed replacement parts. The issue of availability and cost of replacement part is strongly linked to the issue of product diversity (see below).

Design Related Issues:

Design related issues (including such topics as: complexity, fastening methods, means of assembly and disassembly, and so on) are another category of concern which affects most facets of remanufacturing (see Figures 1, 3, 4, 6, and 7). These issues tended to be high on the list of concerns for several questions. Based on interviews, most of these issues cause more time to be spent during the assembly and disassembly phase, or require additional specialized tooling.

Another design related issue that was repeated frequently during interviews with several remanufacturers was, ìIf [Remanufacturers] can take a product apart, it can be remanufactured.î At first, this statement would seem to indicate that the design should focus on disassembly to ensure that the product can be remanufactured. However from examining the interviews further, it becomes apparent that there is more to disassembly than just the process of taking the product apart - there is a hidden assumption in this statement. If this phrase is restated to include this hidden assumption, it would sound like, ìIf [Remanufacturers] can take a product apart without damaging important parts, it can be remanufactured.î The two key ideas that designers should extract from this statement are non-destructive disassembly and preventing key parts from being damaged.

Product Diversity:

Product Diversity (or "part proliferation") is a significant problem which tended to place highly in most of the questions in the survey (see Figures 5, 6, and 7). Once again, the general feedback we received on the survey and at the clinic focused on this general issue. The term "Part Proliferation" is used to describe the practice of Original Equipment Manufacturers' producing multiple unique models of the same part for a given car line, or by changing aspects of the part (making it unique) on a frequent basis - perhaps even more than once per model year.

Problems arising from this practice range from having to keep a large inventory of replacement parts, to having to keep track of several, non-standardized assembly and disassembly processes. An increase in the variety of assembly and disassembly processes also results in an increase of the number of process set-ups that have to be made, causing a reduction in throughput. Employee training also becomes a significant issue as a result, as they must be familiarized with all of the various, unique parts and the processes for each new product.

It is interesting to note that the trend of parts proliferation started in the early eighties. Among others, this coincides with the move of major US automakers to a platform organization and a move towards lean production. Between 1982 and 1990, Japanese automakers nearly doubled the number of models on the road, from forty-seven to eighty-four models. Reacting to this condition, US automakers also increased their models on the road from thirty-six to fifty-three in the same period of time (Womack, et al., 1991). Furthermore, the independence of individual platforms within an automaker's organization seems to have led to a reduction of shared components among automotive models, resulting in decreased standardization and increased parts proliferation.

Cleaning:

Cleaning was identified as one of the highest cost contributors to remanufacturing, second only to replacement parts (See Figure 2). Not surprisingly, the largest cause for cleaning costs was identified as complying with Environmental Protection Agency and other environmentally oriented legislation (see Figure 4). It is significant to note, however, that it is not clear from the survey results what environmentally regulated cleaning processes are being referred to - solvent based cleaning, detergent based cleaning and/or baking.

Corrosion:

Corrosion was identified, several times, as relating to different problems (see Figures 3, 4 and 6). It was ranked highest in terms of complicating the disassembly process. During the disassembly process, corrosion can cause adjacent parts to stick together, such as two halves of an alternator casing. Corrosion also posed problems for cleaning and refurbishing. Given that this is a survey performed among remanufacturers of electrical products, it is not surprising that corrosion is treated somewhat higher in priority than for a purely mechanical system. Corrosion prevents or degrades the performance of electrical contacts, which can create reliability problems. As such, electrical rebuilders are very careful to ensure that corrosion is removed and then prevented via protective coatings.

Part Size and Lighter Duty Materials:

Part Size and Lighter Duty Materials Used were factors which were also indicated as problems facing multiple facets of remanufacturing (see Figures 1, 4, 6 and 7). Both of these issues are directly related to design, as current designs are being optimized primarily to reduce weight, space and cost. This benefits the manufacturer, but it would seem that some of these practices can cause remanufacturers difficulty. Several comments were made in interviews which pointed out that as the parts get smaller and use lighter duty materials, the number of remanufacturing cycles that the parts may see tends to reduce.

Employee Skills:

Employee Skill was an issue that was predominant in three separate categories - inspection, refurbishing, and reassembly (see Figures 5, 6 and 7, respectively). As previously mentioned, much of this is due to the diversity of unique products which the employee must be familiar with, and the different assembly and disassembly techniques required for each. It is interesting to note that in two of the three categories (refurbishing and reassembly), skill was immediately followed by product diversity, which seems to emphasize this point. The third category - inspection - seems to be more related to the availability of the operator to identify which quality standards the specific part must measure up to. In this category, skill is followed by specification availability, which exemplifies the fact that aftermarket remanufacturers must often define their own part specifications, as these specification are mostly not available from the manufacturer.

2.4 Insight Gained from the First Survey

Although many issues were identified due to the open nature of this (first) survey, they can be grouped in a few major categories, namely, the availability and cost of replacement parts, the increased product diversity, cleaning, corrosion, employee skills, and design related issues such as complexity, fastening methods, means of assembly and disassembly, as well as increased part fragility due to reduced part size and lighter duty materials. Many of these issues (e.g., the design related issues) have been noted before in the literature and the survey results verify that these issues are still of concern. However, some issues (e.g., the increased product diversity) have emerged more strongly in the eighties. Next to providing a verification of general concerns, the survey results also provide, more importantly, a first insight on what a group of practicing remanufacturers perceives as the relative importance among issues listed.

3 The Second Survey – A Follow-Up on Key Issues

Based on the results from the first survey two goals were set for a follow-up survey:

- First, the relative importance of each of the categories identified in the preliminary survey needed to be established relative to one another.
- Second, since these metrics are not intended for use exclusively by electrical remanufacturers, additional feedback from the balance of the remanufacturing community needed to be gathered. It stands to reason that a significant issue to one branch of remanufacturing may not be as significant in another branch.

In addition to these goals, several additional questions were posed to gain further insight into the management practices in the current remanufacturing industry.

Therefore, a second survey was generated and distributed to many remanufacturing companies through the APRA newsletters, namely, *The Mechanical Messenger* and *The Electrical Connection*. This survey was also circulated to companies within the Metro Atlanta Area. This survey was intended to further investigate the information gathered in the preliminary survey, as well as to take the criteria identified there and to attempt to rank them - noting any differences between types of remanufacturers (i.e., electrical, mechanical, hydraulic, etc...).

In the next section, the questions which were posed in the survey are presented, followed by a brief summary of the data obtained from analyzing the results. In Section 3. 2 the results are presented, analyzed, and tentative conclusions drawn.

3.1 Survey Questions

As mentioned previously, several questions were posed which dealt specifically with developing a better understanding of issues brought to light in the first survey presented in Section 2. Several other questions were posed to seek out other general information about the business practices of the remanufacturing industry as a whole, as well as to locate any differences between the various branches of remanufacturing (mechanical, electrical, hydraulic, etc...).

The following list presents a summary of the questions that were posed in this survey:

1. *How would you rate the following issues, based on their impact on the process of remanufacturing? {Disassembly, Sorting, Cleaning, Part Replacement, Reassembly, Testing, Appearance, Regulations, Parts Supply, Market issues}*
2. *How would you order the issues from Question 1?*
3. *How do you decide whether or not to remanufacture a given product?*
4. *How severe are the following conditions which are the results of parts availability? {Parts need to be fabricated, parts are not cross-referenced, quality is inconsistent, price of parts}*
5. *What is the minimum average (Net) profit to remanufacture a given product?*
6. *How often do you track your costs? {daily, weekly, monthly, etc...}*

7. *What is the best way to track remanufacturing costs? {process, product, end-item, batch}*
8. *How often do you communicate with {Customer, suppliers, manufacturers}? {daily, weekly, monthly, etc...}*
9. *What design issues affect remanufacturing the most?*
10. *What major changes have occurred in the remanufacturing industry over the past several years?*
11. *What would be the benefits and consequences of a [theoretical] partnership between OEMís and Remanufacturers.*

Out of these, questions 1, 2, 4 and 9 dealt specifically with addressing issues from the first survey. Questions 3, 5, 6 ,7, 8 and 10 were posed to gain further insights into the behavior and decision making processes of a presumably representative cross section of the current remanufacturing industry. The final question was intended to explore the perceptions (and the skepticism) of remanufacturers about the (hypothetical) opportunity of working in conjunction with OEMís to remanufacture. As can be seen from the above list of questions, the survey comprised of mostly very specific questions supplemented with a few open ended questions.

3.2 Survey Responses and Analyses

Seventeen surveys were returned and the responses could be organized in three general categories of remanufacturers:

8 electrical remanufacturers (alternators & starters),

4 mechanical remanufacturers (engines, transmissions & driveshafts), and

5 fluids related remanufacturers (water pumps, fuel delivery, and brake systems).

In the following, the responses are given and followed by analyses.

3.2.1 Ranking of Remanufacturing Issues

In Figure 8, the responses to the first question (to rate the significance of the listed issues with respect to their impact on the process of remanufacturing) are given. The rating scale ranged from 0 to 9, with 9 having the most impact. The responses were grouped according to type of remanufacturer and tabulated. As shown in Figure 8, the average values and standard deviations for each issue was calculated for each category of remanufacturer. Finally, the average and standard deviation was calculated for the whole set (regardless of type of remanufacturer).

	Electrical		Mechanical		Hydraulic		Total	
	# Resp = 8		# Resp = 4		# Resp = 5		# Resp = 17	
	Avg	Std Dev.	Avg	Std Dev.	Avg	Std Dev.	Avg	Std Dev.
Disassembly	5.4	2.7	6.5	3.8	4.6	1.1	5.4	2.6
Sorting	3.0	3.2	5.3	3.9	3.0	1.9	3.5	3.0
Cleaning	6.8	2.0	7.5	1.9	5.4	2.5	6.5	2.2
Part Replacement	5.8	2.4	4.8	3.8	6.8	2.3	5.8	2.7
Reassembly	6.9	2.4	8.8	0.5	8.2	1.3	7.7	1.9
Testing	7.3	3.1	5.5	4.4	7.6	1.1	6.9	3.0
Appearance	8.3	1.3	7.0	2.8	7.8	1.8	7.8	1.8
Regulations	3.4	2.3	8.3	1.0	5.6	2.3	5.2	2.8
Parts Supply	6.6	2.6	7.0	2.2	8.6	0.5	7.3	2.2
Market Conditions	6.9	2.4	6.3	3.6	6.2	1.6	6.5	2.4

Figure 8 – Results for Question 1: Ranking of Remanufacturing Issues

Question 2 addressed the same basic problem as question 1 - that of identifying how significant each of the listed issues are relative to each other. However, this question took a different approach. Instead of assigning a numerical value to the various issues, the issues are ranked relative to one another, as shown in Figure 9. This serves two purposes. If in the process of analyzing the results from question 1, two or more categories receive approximately the same average score, this ranking may help to clarify which actually should be considered more important. Also, by addressing the same problem from two directions, it can be used to confirm the consistency of the responses.

		Mean	Rank	Std. Dev.
E	Reassembly	3.6	1	2.5
F	Testing	3.8	2	2.9
G	Appearance	3.9	3	2.5
I	Parts Supply	4.6	4	2.6
C	Cleaning	4.7	5	2.6
J	Market Conditions	5.3	6	3.7
D	Part Replacement	5.5	7	2.8
A	Disassembly	5.9	8	2.6
H	Regulations	7.1	9	3.0
B	Sorting	7.9	10	3.0
K	Other: Managing People	1.0	(high)	
M	Other: Parts Quality	1.0	(high)	
L	Other: Overall Liability	9.0	(low)	

Figure 9 – Results for Question 2: Order Of Remanufacturing Issues

Reviewing the results of questions 1 and 2, presented in Figures 8 and 9, one of the first things which becomes apparent is that the data is particularly varied. The standard deviations in question 1 for almost every issue range between 2.0 and 3.0 (even within the same categories of remanufacturers). Considering that the scores only range between 1 and 9, this variation seems very significant. Due to this variation it was deemed prudent to contact some of the respondents to try to determine what the root cause of the variation was.

Several issues came to light as a result of these conversations. One of the more obvious differences between several respondents was that the size of the remanufacturing operation affects how they prioritized the issues. For example, smaller companies do not have the machinery or automation that a larger company has to speed up the processes. On the other hand, the smaller remanufacturer tends to produce much less in the way of cleaning residue, and as such, are not as affected by environmental legislation as their larger counterparts.

Another difference between certain respondents was that some of the remanufacturers did more work for industrial grade applications, such as railroads (locomotive starters) or trucking fleets (hydraulics/brakes). Since these remanufacturers have a (captive) industrial customer base their answers reflect more of an emphasis on product issues than on market or customer issues.

Since there is such a variability in the responses, it was decided to perform another brief survey which would more specifically address a quantification of the importance of issues for remanufacturability. This survey, presented in Section 4, was, however, more focused on developing metrics for remanufacturability, as opposed to general data gathering.

3.2.2 General Business Practice

The third question in the survey (see Section 3.1) begins to delve more into the business practices and the decision making processes used by practicing remanufacturers. Like the questions posed in the survey in Section 2.1, this question was left very open in order to draw the largest possible range of responses. Figure 10 presents a Pareto chart (again similar to those from Section 2) of the responses to question 3.

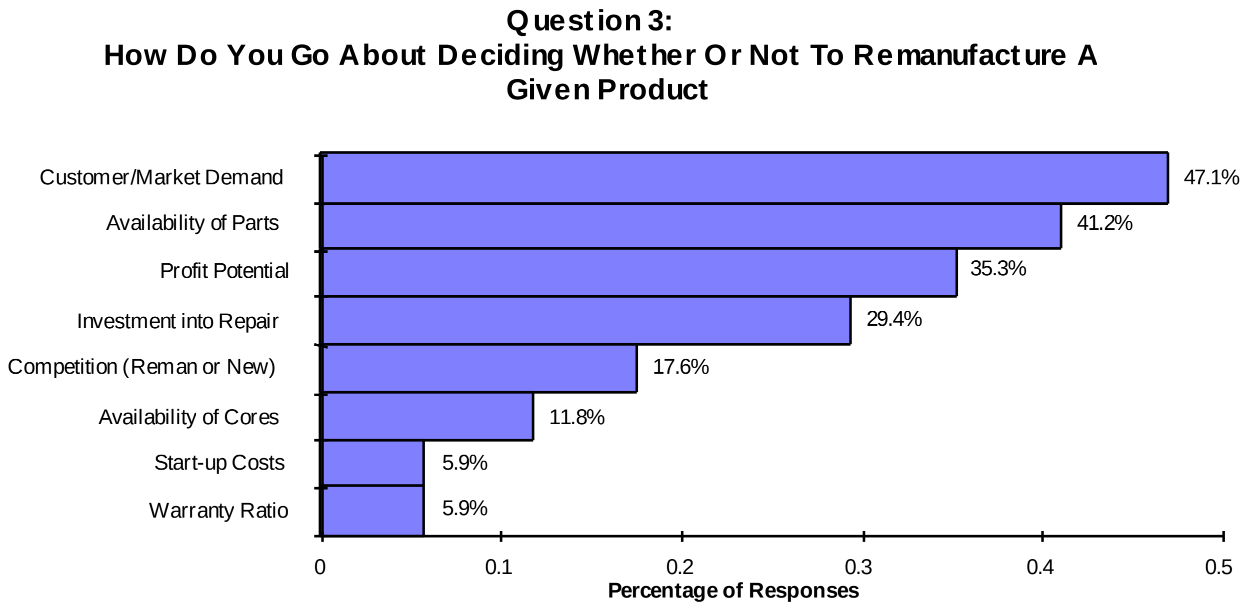

Figure 10 – Responses to Question 3: How The Decision To Remanufacture Is Made

Question 3 was an important background question, since it identifies the criteria that remanufacturers look for when deciding whether or not to remanufacture a product. It is interesting to note that the top two criteria with the most responses (see Figure 10) have nothing whatsoever to do with the design of the part itself. The first criterion seems almost obvious - customer/market demand - as without this remanufacturing a product would be a fruitless endeavor. The second criterion - parts availability - was also identified in the previous survey as a crucial issue.

Profit Potential and Investment into Repairs were also listed frequently (see Figure 10) and these issues are both related to the design of the product. Both of these issues are related, in that profit is a measure of overall investment required to remanufacture the product relative to its market value. However, since investment into refurbishing was mentioned frequently, it seems to indicate that it should rank relatively high compared to other issues.

3.2.3 Parts Availability

In question 4, an issue that appeared to be significant from the first survey was examined - parts availability - with the intention of determining what remanufacturers most often had to do to compensate for parts not being available and how severe those conditions were. Using the same rating scale as in question 1, a brief list of criteria were presented and the remanufacturer was requested to assign a rating as to the severity of these conditions due to the availability of parts. As with question 1, this data was partitioned between the three areas of remanufacturing represented by the returned surveys and the mean rating and standard deviation of the ratings were calculated (see Figure 11). The mean and standard deviation were also calculated for the whole set of responses for the sake of comparison.

As found in questions 1 and 2, the results were varied (see Figure 11), so it was difficult to draw any conclusions from the data. However, price and quality seemed to be comparatively more severe of a problem than the others. In addition to the responses shown in Figure 11, two additional issues were identified by certain remanufacturers under the ìotherî heading:

1. Parts not cataloged, and
2. Parts have to be imported (not made domestically).

Each of these were only listed once, but tend to suggest that there are additional issues are present relative to parts availability.

	Electrical		Mechanical		Hydraulic		Total	
	# Resp =	8	# Resp =	4	# Resp =	5	# Resp =	17
	Avg	Std Dev.	Avg	Std Dev.	Avg	Std Dev.	Avg	Std Dev.
Parts Must Be Fabricated	2.6	1.7	5.0	4.2	4.6	1.5	3.6	2.1
Parts Not Cross-Referenced	3.8	3.2	3.0	1.4	5.8	2.9	4.3	3.0
Price Of Parts	4.9	2.9	7.0	1.4	4.6	3.0	5.1	2.7
Inconsistent Quality of Parts	4.0	2.5	8.5	0.7	8.0	0.7	5.9	2.8

Figure 11 – Results for Question 4: Rating Of Parts Availability Issues

3.2.4 Specific Business Practices

Questions 5 through 8 do not directly have any direct bearing on design metrics being developed in our work, but were posed to establish a better understanding of specific business practices, in particular how the remanufacturing industry behaves with respect to tracing costs.

Question 5 was related to the business practices common across the remanufacturing industry. By determining the minimum average profit that is acceptable for a given product, a fair amount of insight into the industry can be obtained. Most obviously, given the minimum profit, an estimate of the investments required for remanufacturing can be, at least partially, assessed from a financial perspective. Also, it can be used as an index as to how much emphasis is placed on how cost effectively a product can be remanufactured. *Based on the survey results, the minimum average (Net) profit acceptable for remanufacturing lies within the range of 30% ±10%.*

The sixth question pursues the business practice line of questions, by asking how often costs are tracked in the remanufacturing. The results were tabulated and entered into a Pareto chart - see Figure 12 - which shows the percentage of responses for each time frame.

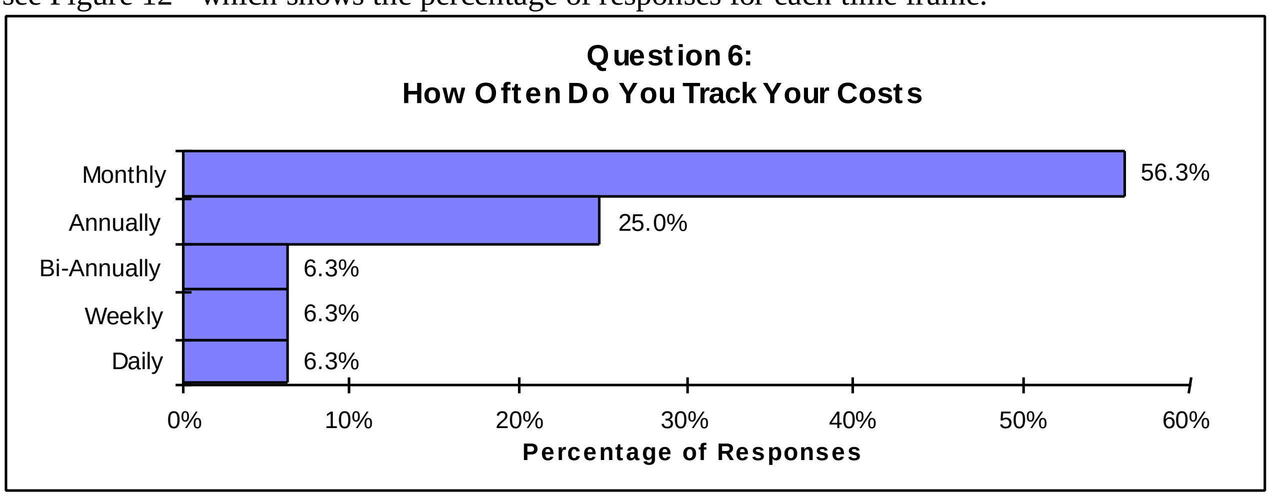

Figure 12 – Responses to Question 6: Frequency Of Tracking Costs

While on the subjects of frequencies and business practices, question 7 asks the remanufacturer what the best means of tracking their costs were. All of the responses have been tabulated, converted into percentages of responses and presented in a Pareto chart shown in Figure 13.

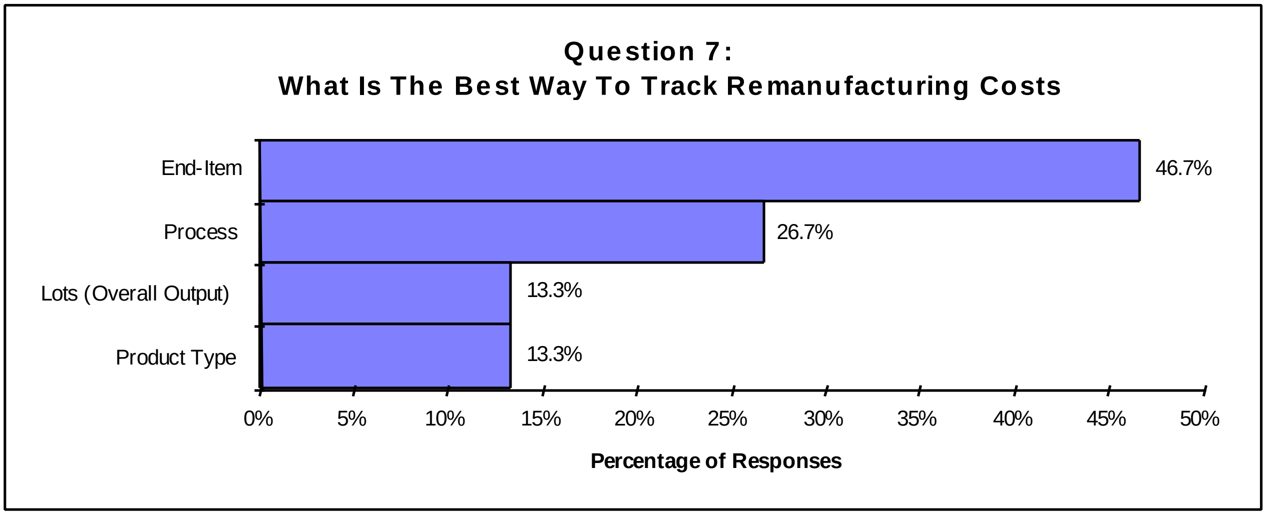

Figure 13 – Responses to Question 7: Best Way to Trace Cost

Question 8 asks the remanufacturers to indicate how often they interact with their customers, suppliers and manufacturers. The responses for each were tabulated and the Pareto charts for each were combined into the chart presented in Figure 14.

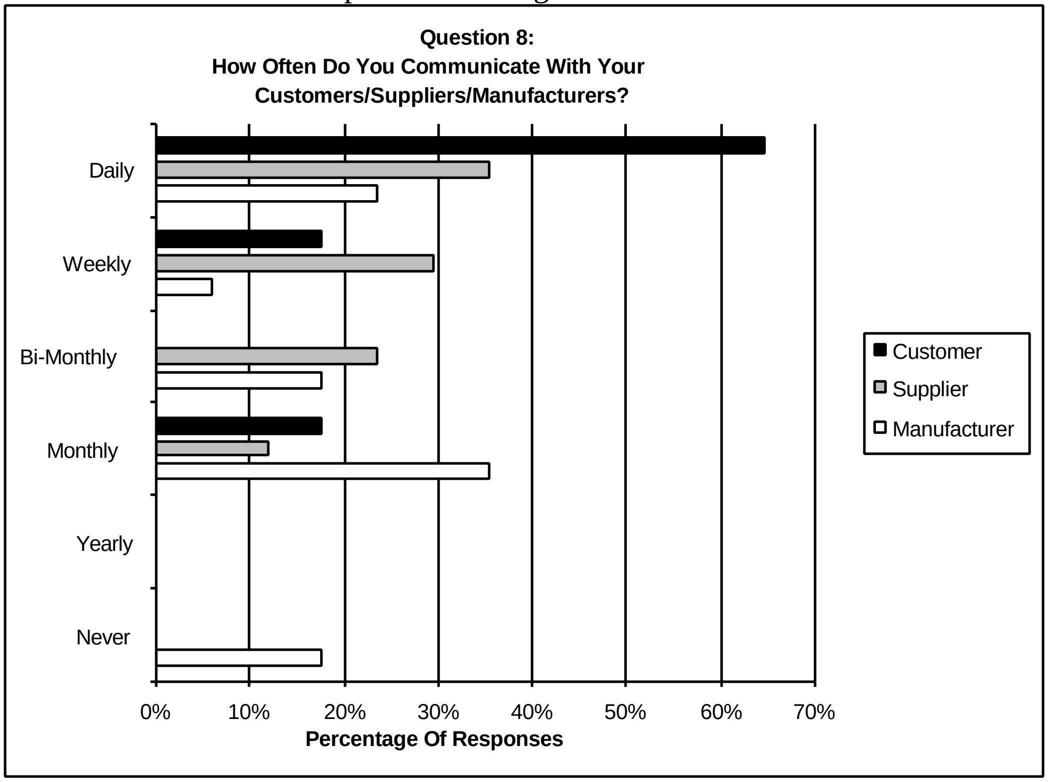

Figure 14 – Responses to Question 8: Frequency of Interactions

Summarizing the responses to the business practice questions, monthly cost tracking seems to be the most used practice (see Figure 12). The end-item (product) was noted as the best means for tracing cost, followed by the process (see Figure 13). As stated, the results for question 5 indicate that the minimum average (Net) profit acceptable for remanufacturing lies within the range of 30% ± 10%. The frequency of interaction with customers, suppliers and manufacturers is varied, ranging from daily to monthly (see Figure 14). Some of the remanufacturers are industrial grade remanufacturers with a captive customer base. These would interact more frequently with their customers, in general.

3.2.5 Ranking of Design Issues

Question 9 brings the focus back from business related issues to the development of metrics for remanufacturability. Question 9 goes directly to the point of asking what design issues affect remanufacturing most (see Figure 15). The results of this question are intended to highlight and reinforce issues identified in the first survey and the issues here should be somehow accounted for in the metrics to be developed. The responses to question 9 can be seen in the Pareto chart in Figures 15.

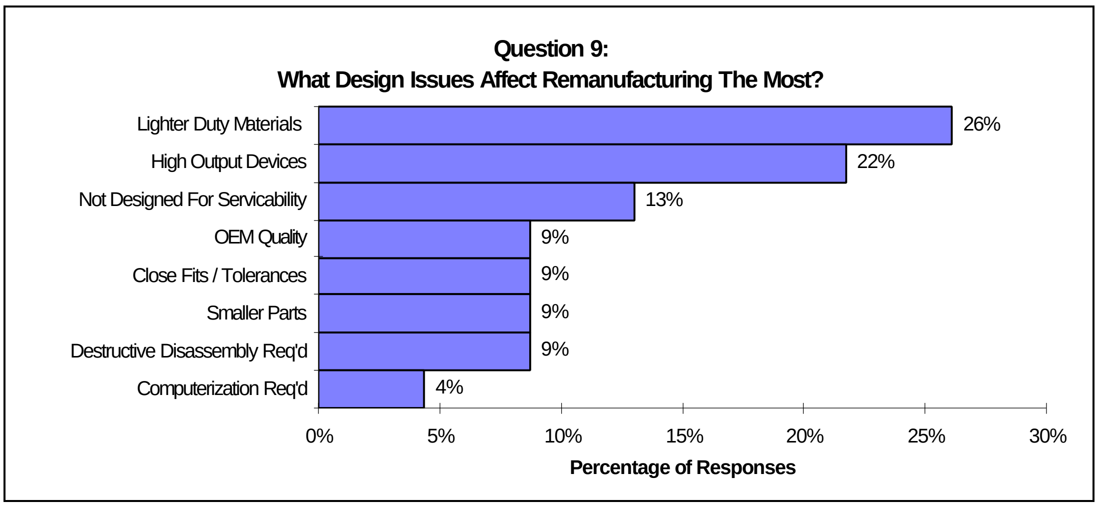

Figure 15 – Responses to Question 9: Design Issues Which Affect Remanufacturing

The top two issues identified in Figure 15 have to do with the OEMs optimizing their products - (1) the use of lighter duty materials and (2) high output devices (smaller, more efficient designs which have higher output than previous designs).

The use of lighter duty materials, like plastic or aluminum in place of steel or cast iron, tends to make parts more fragile or more likely to break during disassembly or refurbishing. Original equipment manufacturers tend to use lighter duty materials since they often result in reduced cost and weight, and frequently also result in subsequent improvements in the productís performance (due to the reduction of weight).

The products that most remanufacturers work with were often significantly over-designed in past decades. Much of todayís products are being redesigned to eliminate the inefficiencies that have been present in the design of products for a long time. By doing so, an OEM can frequently reduce the size, weight and/or cost of their products, while maintaining or improving the performance of the products. The problems that arises stems from the fact that as the excess capacities are taken out of the design of the product, the product becomes much more fragile, and less likely to be remanufacturable. Often these products cannot be remanufactured simply because they failed during use, as opposed to gradually wearing out to the point that performance is below minimum acceptable levels. Failure during use often results in a catastrophic destruction of several (if not all) of the key parts in the assembly. Also, these products tend to have more extreme operating conditions than their older counterparts, and are consequently subject to additional wear, thermal problems and/or fatigue.

The next design issue that affects the remanufacturability of products is another OEM practice - or lack thereof. Many products, particularly highly complex products like engines, are not typically designed to be serviced beyond routine, scheduled maintenance. In interviews, remanufacturers frequently link this problem with parts proliferation to indicate that OEMs are using their design capacity to eliminate independent competition in the replacement parts market.

3.2.6 Industry Changes

Question 10 directs the remanufacturers attention away from business practices or design issues, and looks for significant historical changes to the remanufacturing industry. It is expected that several of these changes have driven many of the business practices used to change as well. The major changes that were identified by the remanufacturers are presented in Figure 16.

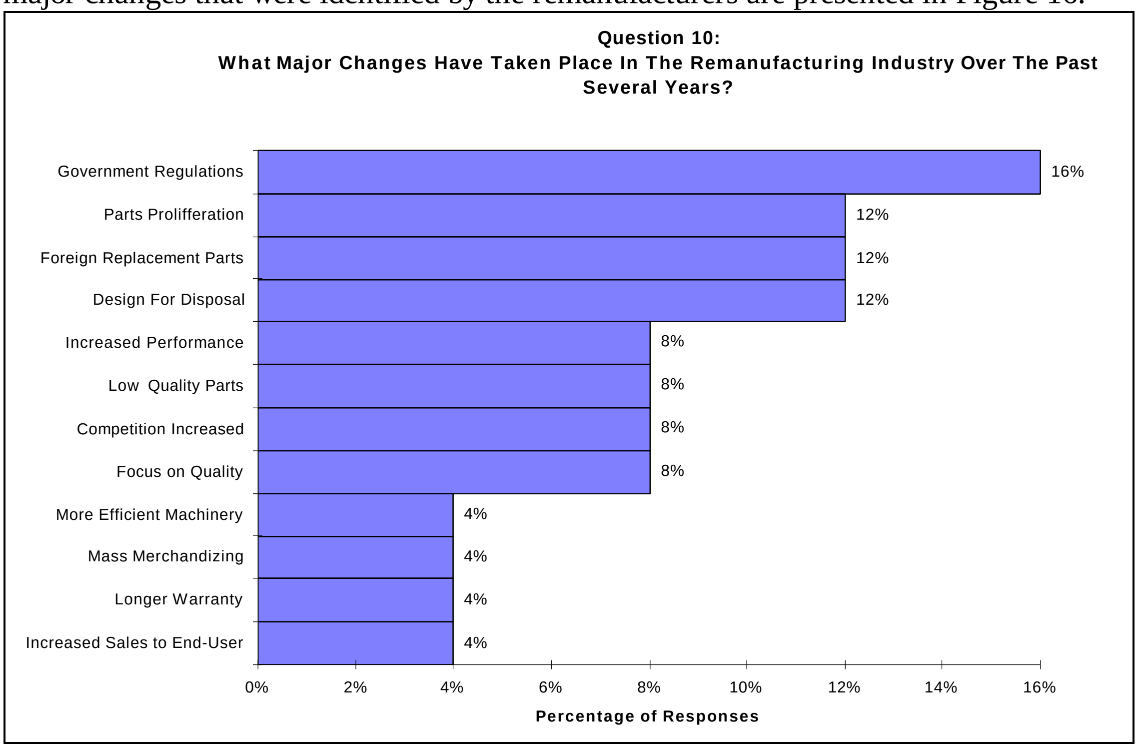

Figure 16 Responses to Question 10: Changes To The Remanufacturing Industry

The tenth question also picks up on the theme of OEM practices that hinder remanufacturing in two of its relatively highly placed responses as to changes which have taken place in recent years (see Figure 16). Many respondents pointed out that parts proliferation and competitiveness (both domestically and abroad) in the remanufacturing market have increased in recent years. Another related point that the respondents identified is that many products are designed to be disposed at the end of their service life. Such products are often designed such that they cannot be disassembled without destroying key parts.

The most recognized change in recent years noted (see Figure 16) was an increase in governmental regulations that affect remanufacturing. These include such areas as health and safety (like OSHA requirements) as well as environmental legislation. In the first survey, the environmental legislation aspect with respect to cleaning affluents was also noted.

On a more positive note, it was also pointed out that much more attention is being paid to quality issues than in previous years. Also, the machinery has improved significantly in the recent past, resulting in better equipped remanufacturers than previously. Furthermore, warranties have been lengthened, and sales to end-users have grown.

3.2.7 Partnerships with OEMs

The final question presented a hypothetical, mutually beneficial partnership between remanufacturers and OEMís to see what the remanufacturers believe the benefits and drawbacks would be to such a relationship. This question stems from the interviews following the previous survey, in which the opinion was repeatedly stated (frequently with a good deal of emotion) that the OEMs were trying to hinder the remanufacturing industry for competitive gains. This last question drew the broadest range of responses. The responses which were obtained to this question do not lend themselves to being tabulated as done for the previous questions since several of them are somewhat conflicting. Some remanufacturers maintained that such a relationship was not possible, or at the very least would benefit only the OEM. Even those who accepted the premise for the sake of discussion did not see much hope for establishing a truly mutually beneficial relationship with OEMs.

Those who did respond to this question felt that there would be varied benefits and costs for each side. From the remanufacturerís side, some benefits that might be expected would include improved customer satisfaction (from confidence), higher overall quality of products, use of OEM tolerance specifications, parts that are designed to be remanufactured, replacement parts would be more available, and the reduction in the proliferation of parts. On the other side of the coin, it is also expected that this kind of partnership may put many replacement parts manufacturers out of business. Also, the remanufacturers expect that such a relationship would eliminate a great deal of freedom and reduce the independence of the remanufacturer.

On the OEMs side, the responding remanufacturers expected that the quality of the design of the parts would improve due to the feedback provided by the remanufacturers. Also, there would be additional opportunity for the OEM to expand its sales in the realm of replacement part to the remanufacturing community. There were mixed feelings as to whether OEMs would gain or lose market share in the realm of replacement parts, but it was clear that the resulting share would not be anywhere near the apparent goals of the OEMs for this business.

The net response was that this hypothetical situation would never truly come to pass. Some noted that in isolated cases, this situation does exist, but that these remanufacturers work more or less exclusively for the OEM. In these cases, the remanufacturers tend to be treated more as contractors or consultants to the OEM than partners. In general, the prospect of working cooperatively with OEMs was not well received. Many opinions were expressed to the effect that the OEMs would be satisfied with nothing less than a monopoly on the parts replacement industry. Several of these opinions were very clearly lined with strong emotions and in some cases outright defiance.

3.3 Insight Gained from the Second Survey

The goal of this survey was to obtain a better understanding of the issues identified in the first survey as well as their importance. The responses to the second survey collaborated with the first survey, however, a (sometimes significant) amount of variability in some answers was noted. During post-survey interviews, we discovered that the size and type of company is an influencing factor, more than the type of product (see also Section 4). For example, remanufacturers who do industrial grade work are less concerned with market issues due to their captive customer base. Nevertheless, parts availability clearly is a key concern to all. The minimum net profit of 30% (± 10%) reported is comparable with the fact reported in (Lund and Skeels, 1983a) that remanufactured products are typically sold between 40% to 80% of the product's new price. Also, the majority of responding remanufacturers do not believe that cooperation with OEMs will be possible in the near future.

4 The Third Survey – A Direct Comparison of Remanufacturing Issues

Although the second survey provided good insight in general, the results with respect to establishing a quantified prioritization of remanufacturing issues were not as conclusive as was hoped. Based on the post-survey interviews, it was concluded that the respondents had very different perspectives about remanufacturing as a result of

- differences in the scale of their businesses and
- the type of customer that they primarily serviced.

Therefore, it was decided to focus a third survey on a single type of company - regardless of the product being remanufactured - in an attempt to obtain more consistent information.

4.1 Approach and Questions

It was decided that smaller remanufacturing companies were the most appropriate choice for subjects, primarily because they rely heavily on the most frequently used remanufacturing process: manual operations with hand tools. One thing that was noticed in the responses from the previous survey is that the type of product being remanufactured did not seem to have a major influence on the responses - responses from different product groups all averaged out very close to each other, with similar standard deviations. Therefore, little emphasis was placed on limiting this survey to a particular type of product remanufacturing.

In order to ensure that the surveys were only distributed to small remanufacturing companies, many companies in the Metro Atlanta Area were contacted by phone to establish their qualification and willingness to participate in the survey. Out of the companies polled, 19 companies were willing to review the survey and provide feedback. Out of these, only six actually filled out the form and returned them. Of the remainder, several withdrew their participation either for policy reasons that the contact person did not know about originally or because their business requirements would preclude the time needed to review the survey within a reasonable period of time.

In order to avoid confusion, a direct approach was taken in this survey. The remanufacturer was asked to perform three different sets of comparisons for a number of issues identified in the previous surveys. The three comparison sets presented were as follows:

1) The first set contained five issues extracted from the previous surveys (i.e., disassembly, cleaning, inspection/testing, refurbishing, and reassembly) which characterize and the remanufacturers were asked to perform a comparison between each issue. They were given a comparison scheme and asked to compare the issues with each other relative to the typical amount of time, energy and/or resources invested in each.
2) The second set presented the remanufacturer with the task of comparing very broad, top level issues that affect the overall remanufacturability of a product (including transient factors), i.e., design, market, social, and regulatory issues. This was done to gain a perspective as to how much of the overall remanufacturability was specifically accounted for by the design metrics under development in our laboratory.
3) The third set delved into comparing lower-level issues, namely, coating, replacement, and repair, covered under the heading of ìrefurbishingî in the first set of comparisons.

4.2 Results and Analysis

The results from all responses to the third survey are given in Figure 17.

Remanufacturing. Issues						
Disassembly	10%	5%	0%	10%	0%	50%
Cleaning	30%	15%	20%	10%	35%	30%
Inspection/Testing	0%	25%	10%	0%	15%	15%
Refurbishing	25%	25%	25%	45%	30%	0%
Reassembly	35%	25%	40%	30%	15%	0%
Design Issues	5%	5%	20%	35%	40%	50%
Market Issues	30%	55%	45%	35%	40%	40%
Social Issues	25%	35%	5%	20%	15%	5%
Regulatory Issues	40%	5%	30%	10%	10%	5%
Coating	5%	45%	10%		5%	5%
Replacement	20%	10%	35%		40%	25%
Repair	75%	45%	60%		55%	70%

Figure 17 – Results from Survey #3: Relative Importances From Comparisons

In comparing the results listed in Figure 17 with the results listed in Section 2, the responses from this survey were more consistent in a very general sense, and were thus more useful when generating a weighting scheme for remanufacturability metrics. As done in the previous surveys, all of the remanufacturers were contacted following the survey and informally interviewed regarding how and why they answered the way that they did. From these interviews, it was noted that the sixth respondent did not use investment as a basis for the comparisons as requested - instead the basis for the comparisons reflected the order of process sequence. The other respondents did, however, use investment as a basis for their comparisons, so only the first five are used for the remainder of the analysis of the responses.

In the first set of comparisons it appears that, in general, cleaning, refurbishing and reassemble placed more highly than the other issues. Disassembly and testing both placed relatively low compared to the top three issues. Of the top three issues there does not seem to be a consistent trend as to which requires more of an investment than the others. It makes sense that inspection is viewed more important by a starter/alternator remanufacturer given the larger number of components and higher potential to failure in these systems as compared to a cylinder head.

The second set of comparisons was somewhat less consistent than the first set, but market issues seem to rate consistently high. The other categories seem to fluctuate between very low values and nominally high values. From this, as well as the post-survey interviews, it is clear that each business is affected differently by each of the listed issues, and as such, each business perceives its environment somewhat differently.

The third set of comparisons were more consistent than the first two sets. In general, part repair was ranked highest, followed closely by replacement. Coating of parts (such as painting or rustproofing) scored consistently low.

4.3 Insight Gained from the Third Survey

Although one can argue that the data-set is small, the results from third survey showed us (again) that it is difficult to identify a clear and uniform ranking of issues characterizing remanufacturability. Therefore, when pursuing metrics for remanufacturability, one should embody an amount of flexibility that allows for customization of such metrics to a specific remanufacturing situation.

5 Closure

In this paper, we presented results from three surveys among automotive remanufacturers with the objectives to a) identify and verify issues that affect remanufacturability according to practicing remanufacturers, as well as b) quantitatively rank their (relative) importances in order to support the development of design metrics for assessing and enhancing remanufacturability. The survey results presented in this paper have provided background information about the current remanufacturing industry, the issues that affect it, as well as the relative priorities of the issues identified. The information presented in this paper is based on feedback from a sampling of the automotive remanufacturing industry, and does not necessarily represent the perceptions of the entire industry. Based on the survey results, we can make the following observations:

- In general, many issues affecting remanufacturability listed in the literature are valid. Even older literature is still valid with respect to many points. For example, Lund and Skeels already noted the critical nature of replacement parts in the early eighties. However, results from our surveys indicate that the automotive remanufacturing industry has become under more severe pressure due to a sharp increase in parts proliferation, governmental legislation, and product performance optimizations by OEMs.

- Although many issues can and are identified that affect remanufacturability, some issues are clearly dominating, especially parts availability.
- It is difficult to obtain a clear ranking of design and remanufacturing process issues. This could potentially hinder the development of design metrics for assessing and enhancing a product's remanufacturability.
- Moreso than from differences in type of products, a large source for the variations seems to stem from the different perspectives about remanufacturing as a result of a) differences in the scale of businesses and b) the type of customer primarily serviced.
- Pressure from environmental and other legislation issues seem to have increased as well, but this seems to be of greater concern to larger remanufacturers than to small remanufacturers.
- Cooperation between OEMs and (independent) remanufacturers seems unlikely in the near future according to (independent) remanufacturers.

Although the results to this survey were in certain cases imprecise and limited, they do, however, indicate trends across the industry which can be used as a basis to make directional assumptions that are incorporated into metrics for assessing product remanufacturability. As a result of our surveys, we focused our initial efforts to develop a metric for assessing remanufacturability based on technical issues only. Furthermore, we have used an assessment scheme analogous to the well-known Design for Assembly assessments from Boothroyd and Dewhurst. Preliminary investigations and case studies performed in conjunction with practicing remanufacturers seem to indicate that the resulting metrics listed in (Hammond, 1996) for assessing the remanufacturability of a product do match "real world" trends.

As a result of the surveys, we are also working on improving remanufacturing processes in parallel to our work on developing design metrics. The noted trends in mass customization and parts proliferation will not decrease, in our opinion, and the small to medium sized independent remanufacturers seem to suffer most from these trends. The surveys also pointed out the differences and sometimes hard "us versus them" attitude between independent remanufacturers and Original Equipment Manufacturers, leading us to believe that the sharing of design information between OEM and remanufacturer is not a feasible solution and/or option in many cases. Hence the only way we can help increase the remanufacturability of those products is by improving the remanufacturing processes. Current remanufacturing processes are heavily batch oriented. Interestingly enough, our findings indicate that the introduction of lean production techniques (which are one of the main causes of part proliferation and product diversity) in the remanufacturing industry, and hence creating lean remanufacturing processes, can lead to significant process improvements and savings (Amezquita, 1996).

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