INTEGRATION OF REMANUFACTURING ISSUES INTO THE DESIGN PROCESS

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ABSTRACT
Remanufacturing is the process of returning a used product to like-new condition with a warranty to match. The efficiency and effectiveness of this process greatly depends upon product design; there are certain product properties that may have a positive or negative effect on steps of the remanufacturing process. The concept of 'design for remanufacture' or 'DfRem' is a design task dedicated to improving the remanufacturability of a product. However, it would appear that very few products are currently designed for remanufacture and the reasons behind this have yet to be fully explored. This paper provides an overview of the problem and a discussion of some of the preliminary findings of a study aimed at improving designers' ability to carry out DfRem. The findings provide an early indication of some of the factors affecting the integration of DfRem into the design process.

Keywords: remanufacture, design for remanufacture, sustainable development

1 INTRODUCTION
Manufacturers and designers are becoming increasingly under pressure to consider a product's end-of-life, when the product no longer meets the requirements of the user and is discarded as a result. 'Extended producer responsibility' legislation such as the WEEE (waste electronic and electrical equipment) and ELV (end-of-life vehicle) directives aim to ensure that the original producer is financially responsible for their products' environmentally sound end-of-life management and therefore it is in many companies' interest to design products that can be dealt with in a sustainable, low cost manner once the product has reached the end of its life.
One end-of-life strategy is remanufacturing, the process of returning a used product to like-new condition, with a warranty to match [1]. The process includes sorting, inspection, disassembly, cleaning, reprocessing and reassembly. The sequence of these activities will vary with different products and remanufacturers [2]. Parts which cannot be brought back to their original condition are replaced, meaning the final remanufactured product may be a combination of new and reused parts.
Remanufacture is often considered to be a sustainable end-of-life strategy, as it can be both profitable and environmentally beneficial. As the products are reused at component level, much of their value (energy and labour) from original manufacture is retained. As a result, remanufacturing costs are lower than that of new manufacture and remanufactured products can be sold at a lower price, typically 30-40% less [3]. Clearly, if manufacturers are able to extend the life of their products in this way, they will also increase the profitability of their products through multiple lifecycles.
Remanufacturing often benefits the environment as it diverts products from landfill and is typically less energy intensive than new manufacture. Many of the processes of new manufacture, such as raw material extraction, are greatly reduced or not required in remanufacturing [4]. Choosing to remanufacture can often be considered a more sustainable option when compared to recycling because of the reduced processing requirements, resulting in less waste and greater profitability. This enables remanufactured products to be sold at a lower price than newly manufactured equivalents. By remanufacturing their used products, OEMs can meet environmental legislation and avoid much of the costs of waste disposal and reprocessing.
Today a wide variety of products are remanufactured, from automotive products to photocopiers and medical equipment. A remanufacturable product is typically characterized as being of high value, high durability and with technological stability. Of course there must also be customer demand for the remanufactured products. However, whether a used product can be effectively remanufactured or not at an acceptable cost and time period greatly depends upon decisions made in the design process [5,

6]. There are certain product properties that may have a positive or negative effect on the remanufacturing process. For example, it is preferable that durable materials are selected that will withstand remanufacturing steps such as cleaning and reprocessing. On the other hand, a design that cannot be disassembled without damage to vital components will hinder remanufacturing. It is from this understanding that the concept of design for remanufacture or 'DfRem' has emerged. As the name would suggest, DfRem is most often viewed as a distinct design task concerned with enhancing the remanufacturability of a product, in line with the concurrent engineering 'design for X' approach. 'Designing for remanufacture' could involve making design choices such as additional material for resurfacing, avoiding sharp corners that trap dirt and arranging a component assembly sequence that also enables effective disassembly.

2. PREVIOUS RESEARCH

DfRem is a fairly popular subject in remanufacturing research, due to its high impact on the remanufacturing process. However, the overall body of remanufacturing literature is still relatively small, and there is still much to learn about the subject. Much of previous DfRem research has involved the investigation of remanufacturing problems that can be related back to product design, and the subsequent development of design aids- tools, methods or approaches intended to alleviate those problems.

For example, Bras and Hammond [7] developed a set of DfRem metrics intended to quantitatively assess the remanufacturability of a design. Shu and Flowers [8] created software calculations that would allow a designer to select the best fastening and joining methods for a remanufactured product. Gehin et al. [9] have developed REPRO2, a tool that assesses the remanufacturability of a design concept by finding analogies with products already successfully remanufactured. As well as tool development, other researchers have focused upon improving the robustness of the qualitative DfRem guidelines found in the literature [6].

Another common trend in DfRem research is the proposal of existing design approach concepts considered relevant to the enhancement of remanufacturability. Familiar concepts such as FMEA, modularisation, platform design and QFD, have been suggested as possible ways to include remanufacturing considerations in the design process [10-13]. These concepts hold the advantage of being well-known and providing benefits outwith DfRem, yet are not specifically developed for the task and therefore may not provide holistic guidance.

3. INVESTIGATION

It would appear that in reality, very few if any of the proposed DfRem aids are utilised in industry today, and the reasons behind this have yet to be fully explored. Tools and methods have been developed without questioning why DfRem remains an unknown or unpopular activity, despite its potential benefits. An informal evaluation of the current DfRem methods and tools on offer would suggest that many are complex and time-consuming, lack product lifecycle awareness (i.e. consideration of other issues such as manufacture, assembly or the environment) or are only suitable for late in the design process, when the most major decisions have already been made. Furthermore, the methodologies adopted by previous researchers have primarily involved the study of remanufacturers only. This means that those who are directly involved in DfRem- the OEMs (original equipment manufacturers) and the designers- have yet to be consulted. This would suggest that current DfRem design aids may not be meeting user requirements as effectively as possible. Indeed, it has not been considered whether the provision of methods and tools in itself is sufficient in integrating DfRem into the already-complex design process. Similar studies in the field of 'design for environment' (of which DfRem is often associated with) would suggest that other factors such as management and motivation may also affect DfRem integration [14, 15]. However, because the motives, goals and concerns of DfRem significantly differ from design for environment, it cannot be assumed that these findings are entirely compatible.

The aim of this investigation is to gain an understanding of the organisational conditions that enable DfRem to be integrated into the design process. From a series of case studies in the mechanical/ electromechanical sector (most established in the remanufacturing industry), the research findings will be used to map these organisational conditions and contribute towards achieving in situations where designing more remanufacturable products would be of benefit to the OEM. As mentioned above, the current lack of DfRem practice would suggest the methods proposed in previous research are not fully meeting requirements, and a study of the organisational factors concerned will improve overall understanding of this problem. A key feature of the study is the inclusion of the OEM and designer's perspective in an organisational context. However, it is also important that the view of the remanufacturer is not overlooked. Firstly because it is essential that any remanufacturing research is carried out with a sufficient understanding of the remanufacturing process, also because OEM-remanufacturer relationships are of significant interest in this particular investigation.

A pilot study was carried out with an automotive contract remanufacturer. Lund [4] states that there are three possible remanufacturing scenarios:

1. OEM (original equipment manufacturer) remanufacturing, when the original producer is also responsible for the remanufacture of their used products.
2. Contract remanufacturing, when a company remanufacture under contract from either the customer or the OEM, who continue to own the product.
3. Independent, 3rd party remanufacturers who buy used products to remanufacture and resell. These companies have no connection with an OEM.

In much of the literature, it is only the first scenario- OEM remanufacturing- that is discussed as a feasible environment for DfRem [5, 16-18]. However, whilst it is clear an OEM would have no desire to enhance remanufacturability for the benefit of a 3rd party company, the possibility of DfRem within an OEM-contractor relationship remains unclear. The pilot study is being used to make initial observations regarding current design problems, OEM communication and design feedback in a contract remanufacturing organisation.

4. CONTRACT REMANUFACTURER PROCESS

The remanufacturing process at the pilot study company varied depending on product type and the source of the used product (called 'cores'). The business activities at a contract remanufacturer appear to be diverse and opportunistic: as well as having contracts with various automotive OEMs, the remanufacturer will also accept cores from distributors, scrap yards and car dealerships, all which may take slightly different paths through the remanufacturing facilities. However, cores arriving from contract OEMs generally go through the same process, which is outlined in Figure 1. This process closely resembles the generic remanufacturing process diagrams that have been developed by previous researchers [1, 2]. The cores, which are collected by the OEM through their own reverse logistics processes, arrive at the facilities and are initially stored. For each core, the entire remanufacturing process from disassembly to final testing will be carried out by the same member of staff, ensuring efficiency and accuracy. However, parts requiring specialist skills are remanufactured concurrently by other operators. The final remanufactured product will be put into storage until requested by the OEM, and will have a warranty at least equal to a newly manufactured equivalent. The OEM will pay for this service.

5. PRELIMINARY FINDINGS

From the pilot study, there were three key issues that were identified for further investigation.

5.1 Design problems: durability

One key design-related problem the remanufacturer faced was durability. Durability is a key feature in DfRem guidelines, yet the company has been experiencing a significant drop in durability over the past few years. Lighter, less durable materials are increasingly being selected in automotive design because they reduce the weight of the vehicle and therefore reduce fuel consumption, a clear environmental benefit. However, these products wear out at a much faster rate than previous designs, and when sent for remanufacture, have to be discarded more frequently, or at least are more difficult and costly to return to like-new condition. Clearly this is costly for customers and should be undesirable to OEMs too, as they are paying for the remanufacturing services. This is a good example of the many conflicts in DfRem: the conflict between improved environmental performance and retained remanufacturability. Furthermore, the increasing use of plastics in automotive products presents a similar problem: these materials are cheaper to produce yet are impossible to remanufacture and must be replaced, making the remanufacturing process more costly.

5.2 OEM Feedback

Whilst the remanufacturer would regularly provide 'diagnostic' feedback relating to specific product failures and faults, they were unaccustomed to providing DfRem (i.e. design optimisation) feedback to the OEM. Overall communication with the OEMs was considered a complex, slow and generally unrewarding procedure. One reason given was the globalisation of the company's clients: the management responsible for making design changes may be located in another country. It is also possible that being acclimatised to design norms and the same working conditions over time means that personnel at a remanufacturing plant are unable to recognise product design-related issues.

5.3 Design Documents

A key barrier to effective remanufacture was lack of design information. The remanufacturer did not have access to the original design documents, despite having direct links with the original manufacturer. The reason behind this is clear: protection of intellectual property (IP). If an OEM were to provide their contractor with key design information, there could potentially be an information security risk from the OEMs competitors (who may use the same contract remanufacturer). However, this IP sticking point means that cores are remanufactured based upon reverse engineering, a complex and time-consuming task that is unlikely to be 100% accurate.

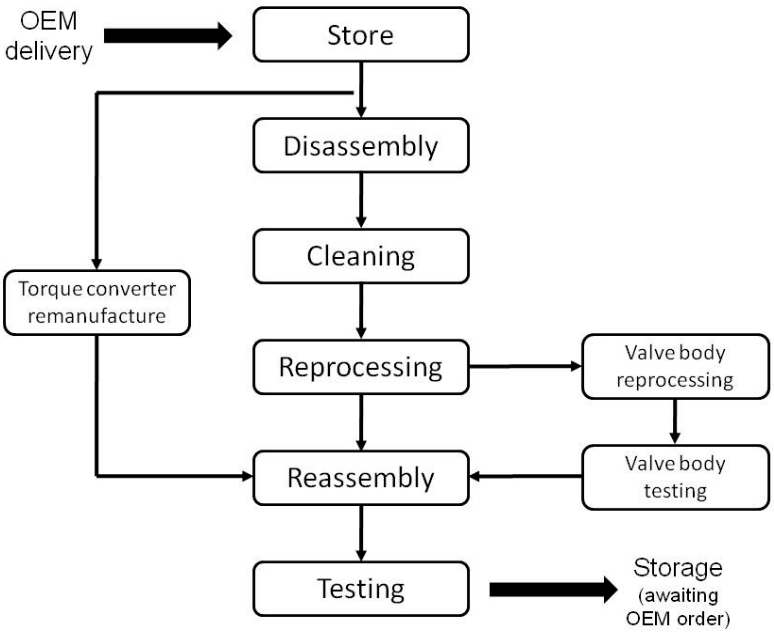

Figure 1: Remanufacturing process at pilot study company

6. DISCUSSION

This research involves mapping the organisational conditions that enable DfRem to be integrated into the design process, beginning with a review of the literature followed by a pilot study of a remanufacturer's problems and OEM-remanufacturer relationship issues that could affect the integration of DfRem into the design process. The preliminary findings from one automotive contract remanufacturer have raised some issues that should be taken into further consideration. A common criticism of current DfRem guidance is that it lacks lifecycle awareness [6, 8]. The fact that the used products in the study had been designed for optimal environmental performance- thus hindering effective remanufacture- would suggest there is truth in this concern, as well as suggesting that remanufacturing concerns are not perceived to be of primary concern in new product development. Any approach to integrating DfRem would have to acknowledge this.

Lack of design feedback could be a major issue affecting DfRem's stance in the design process: it is possible that designer's are not considering remanufacturing issues simply because they are not aware of them. Previous researchers have suggested that designers may be lacking in the necessary knowledge to carry out effective DfRem [6, 17] and therefore feedback from the remanufacturer may be key to raising awareness. Whether lack of communication is due to OEMs not listening, remanufacturers being acclimatised to problems, or a combination of both, remains unclear.

The remanufacturer observed in the pilot study was working under contract with automotive OEMs. As most previous discussions around DfRem have mainly been concerned with OEM remanufacturers, the specific issues of this relationship remain little explored. Preliminary findings would suggest there is a lack of trust between OEMs and contract remanufacturers that is hindering the flow of design information and discussion. If this restriction on communication was found to be unavoidable, it may be deduced that DfRem is indeed only feasible when the OEM is directly involved in remanufacture.

7. CONCLUSIONS

In general, it can be said that research in the area of design for remanufacture is becoming increasingly relevant because end-of-life considerations are becoming increasingly critical to industry. Although few companies may see DfRem as an essential requirement today, in the near future this is anticipated to change. When product take-back laws and other environmental legislation leave OEMs with vast quantities of used products to deal with, design for end-of-life will become a necessity to retain competitiveness. However, in reality, it would appear that an increase in DfRem activity in industry and an appreciation for the importance of DfRem has yet to be realised.

This is a problem that requires deeper investigation. Gaining new knowledge and understanding of what conditions enable effective DfRem to take place will facilitate progress in making the task more accessible to designers. To achieve this goal, it is essential that the requirements of the OEM and the designer are taken into consideration, a feature that is missing in many of the previous developments of DfRem research. However, this does not mean that the needs of the remanufacturer may be overlooked, and therefore this investigation has begun with a pilot study of an automotive remanufacturer. In order to obtain the 'wide picture' of DfRem in industry, issues such as design guideline conflicts, prioritisation of remanufacturing issues and OEM-remanufacturer communication, trust and feedback have been highlighted as in need of further investigation. These are just some of the issues that must be taken into consideration when mapping the conditions that may enable designers to carry out effective DfRem as part of the design process.

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REFERENCES

[1] Ijomah W. *A Model-Based Definition of the Generic Remanufacturing Business Process*: The University of Plymouth; 2002.

[2] Sundin E. *Product and Process Design for Successful Remanufacturing*. Linkoping: Linkopings Universitet; 2004.

[3] Giuntini R, Gaudette K. *Remanufacturing: The next great opportunity for boosting US productivity*. Business Horizons. 2003(Nov-Dec):41-8.

[4] Lund R. *Remanufacturing: the experience of the United States and implications for developing countries.* Washington DC: World Bank; 1984.
[5] Amezquita T, Hammond R, Salazar M, Bras B. *Characterizing the Remanufacturability of Engineering Systems.* Proceedings of ASME Advances in Design Automation. Boston1995. p. 271-8.
[6] Ijomah W, McMahon C, Hammond G, Newman S. *Development of robust design-for-remanufacturing guidelines to further the aims of sustainable development.* International Journal of Production Research. 2007;45(18):4513-36.
[7] Bras B, Hammond R. *Towards Remanufacturing- Metrics for Assessing Remanufacturability.* 1st International Workshop on Reuse. Eindhoven, The Netherlands1996. p. 35-52.
[8] Shu L, Flowers W. *Application of a Design-for Remanufacture Framework to the Selection of Product Life-cycle and Joining Methods.* Robotics and Computer Integrated Manufacturing. 1999;vol15:pp. 179-90.
[9] Gehin A, Zwolinski P, Brissaud D. *A Tool to Implement Sustainable End-of-Life Strategies in the Product Development Phase.* Journal of Cleaner Production. 2008;16:566-76.
[10] Kimura F, Kato S, Hata T, Masuda T. *Product Modularization for Parts Reuse in Inverse Manufacturing.* Annals of the CIRP. 2001;50(1):89-92.
[11] King A, Burgess S. *The Development of a Remanufacturing Platform Design: a strategic response to the Directive on Waste Electrical and Electronic Equipment.* Proceedings of the IMechE. 2005;219(Part B):623-31.
[12] Lam A, Sherwood M, Shu L. *FMEA-Based Design for Remanufacture Using Automotive-Remanufacturer Data.* Toronto: Department of Mechanical and Industrial Engineering University of Toronto; 2000.
[13] Yuksel H. *Design of Automobile Engines for Remanufacture with Quality Function Deployment.* International Journal os Sustainable Engineering. 2010;3(3):170-80.
[14] Johansson G. *Success Factors for Integration of Ecodesign in Product Development* Environmental Management and Health. 2002;13(1):98-107.
[15] McAloone T. *Industrial Applications of Environmentally Conscious Design.* London: Professional Engineering Publishing, Ltd; 2000.
[16] Bras B. *Design for Remanufacturing Processes.* In: Kutz M, editor. Environmentally Conscious Mechanical Design. Hoboken: John Wiley & Sons; 2007.
[17] Charter M, Gray C. *Remanufacturing and Product Design.* International Journal of Product Development. 2008;6(3-4):375-92.
[18] McIntosh M, Bras B. *Determining the value of Remanufacturing in an Integrated Manufacturing-Remanufacturing Organization.* Proceedings of the DETC98 ASME Engineering Technical Conferences. Atlanta1998. p. 1-12.

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