Development of a Methodology to Establish a Component Hierarchy for Remanufacturing Solutions for Complex Mechanical Assemblies

Abstract

Research into effective remanufacturing is recently new and is often concentrated on ensuring that the design of new products to market considers the reuse and reclaim after use. However, the pressure on landfill is already high and remanufacturing solutions are required for products currently at the end of their useful life. The vast majority of these items were produced without consideration of an end-of-life strategy. Remanufacturers are often not the original equipment manufacturer (OEM) but may be third-party contract remanufacturers or independent remanufacturers. OEMs are often very protective of their intellectual property and will not share information even with their contracted partners [1]. Consequently, successful remanufacture is often complicated by the need to “reverse engineer” (often by the disassembly and measurement of new purchased core) a product owing to a lack of available technical information. This can have a significant impact on the speed to market of a remanufactured product. Research [1] has shown that one of the key indicators for remanufacture is a short lead-time to market. This has been partly addressed by research into establishing the viability of remanufacture, however the complex mathematical models developed [2, 3, 4, 5], usually based on remanufacturing costs, do not seem to have been widely adopted by industry. There is a paucity of research into the business of remanufacturing once the initial decision to remanufacture is made and in particular into the order in which remanufacturers should concentrate their efforts. Empirical evidence together with the author’s experience working for a remanufacturer, who is both an OEM and contract remanufacturer, suggests that timely remanufacture of complex assemblies is often jeopardised by the unexpected need to develop remanufacturing solutions for individual components. These components are often relatively minor in the overall assembly but their importance is elevated when a new remanufacturing solution is required. The majority of focus is usually placed onto large, high-value components, although this may not always be the most efficient use of resource. Remanufacturers have grown used to developing innovative in-house solutions to problems but the time taken and the cost involved can threaten a viable remanufacturing programme.

2. Thesis Objective

The aim of this research is to improve remanufacturing by providing an effective method of targeting the development of remanufacturing solutions within existing complex mechanical assemblies by providing a methodology that can be used to establish a hierarchy of components requiring tailored remanufacturing solutions. This will enable a quicker response to demand and shorten the lead-time to market for remanufacturers.

3. Theoretical Background to the Research and Knowledge Gap

Remanufacturing is the process of returning used products to at least OEM original performance specification from the customers' perspective and giving the resultant products warranties that are at least equal to that of newly manufactured equivalents [6]. It has been estimated that manufacturing generated in excess of 65% of annual UK waste in 2002 of which almost half went to landfill [7]. Whilst remanufacturing helps divert a significant proportion of production waste from landfill, recycling remains the usual method of reuse. DEFRA research [7] estimates of the waste diverted from landfill, between 2% and 9% is returned for remanufacturing and other reuse methods whereas 44% is recycled. Remanufacturing is a more efficient reuse strategy than recycling as, in addition to the reduction in landfill and the use of virgin material, it also reduces the amount of energy used in production by removing the need for raw material production and the subsequent shaping and machining processes thus increasing profitability for the remanufacturer [8, 9, 10, 11, 12] Lund [8] suggested that up to 85% by weight of a remanufactured product may come from reclaimed components, and that remanufactured components have a comparable quality to new whilst requiring between 50% and 80% less energy to produce. This, as a whole, can produce manufacturing savings of between 20% and 80%. Remanufacturing can also slow or reduce the production of greenhouse gas emissions such as CO_2 as it eliminates the need for the majority of raw material production, shaping and machining processes where the majority of such emissions occur.

Remanufacturing also offers benefits to society; firstly through the wide range of jobs it creates, particularly for semi-skilled and unskilled labour – sorting, disassembly and cleaning tasks do not usually require skilled labour – research by Mähl and Östlin [13] demonstrated no increase in material recovery from the use of skilled labour in the sorting, disassembly and cleaning phases. Secondly remanufacturing provides quality products at lower prices, typically between 30% and 40% lower [14], than the new equivalent. Remanufacturing is defined under "reclamation" and "reuse", the top two preferred waste management options identified in the European Union's (EU) Fifth Environmental Action Programme.

Environmental and legislative pressures now demand consideration of reuse and remanufacture as part of the design process, however there is still a pressing need to develop remanufacturing solutions for existing products, developed before consideration of their end-of-life state was a factor. The Basel Convention prohibiting EU member states from exporting their waste outside of the EU, escalating landfill taxes and end-of-life directives are all driving manufacturers towards reusing existing products, reclaiming as much as possible for its original purpose and diverting products from landfill.

These products, ranging from diesel engines through to domestic appliances and office equipment, are often not remanufactured the original equipment manufacturer (OEM) [6] but either an individual remanufacturer who identifies a marketplace or by a third party remanufacturer under contract from the OEM. It should be noted that even when remanufacture is carried out under contract, engineering information and support is often limited. This is confirmed by research findings [14]. The researcher's experience is of OEM engineers being suspicious of the quality of remanufactured goods despite repeated functional testing. Timely remanufacture of complex assemblies is often jeopardised by the unexpected need to develop remanufacturing solutions for individual components. These components are often relatively minor in the overall assembly but their important is elevated when a new remanufacturing solution is required, for example, a recent new remanufacturing programme at Caterpillar Remanufacturing Limited was put on hold until a remanufacturing solution had been found for a drive belt tension adjuster. The customer (an OEM for whom remanufacturing is carried out under contract) had expressed a desire for 100% replacement of this item owing to previous failures in the field. The engine in question is no longer in current production and a different, incompatible component used in current OEM production. A supply was initially identified from a single source that indicated quickly that the volumes required were not viable after existing products has been exhausted. Research [3, 15] has indicated that aftermarket sourcing of parts, both new and from used core, is one of the greatest barriers to remanufacture.

The cost of the part, together with the customer's preference would normally ensure that during the introduction phase the component would not normally be considered for remanufacture, however the supply difficulty, discovered relatively late during the remanufacturing programme introduction, forced a decision to remanufacture. The resultant remanufacturing process involved a high level of engineering input identifying, specifying and manufacturing small component parts, both in-house and by third party manufacturers, sourcing fixing components and an assembly process. The development of this one remanufacturing solution increased the overall cost of the component threefold and, more importantly, delayed the engine introduction by six weeks.

Research into remanufacturing is still relatively new and consequently the majority of remanufacturing is carried out on the basis of locally established assumptions and practice [6]. Remanufacturing research that directly concerns the processing of individual components is unusual. Rugrungruang [15] gives a comprehensive guide to identifying the potential for the remaining life of electronic components being longer than the expected life of the remanufactured assembly, however this requires a level of knowledge as to the initial life of the component. This information is often not available and, in the case of a product like a diesel engine, may vary considerably dependent on the application (an engine used in a tele-handler or fork lift application would experience much less stress than an identical one used in a generator). Anityasan [2] assigns economic factors to societal and environmental benefits of reuse and remanufacturing but once again this is a mathematical model that requires an understanding of the typical life of the product.

Research [1] has already identified that the four criteria that are used to decide whether to remanufacture or not. These are:

- The remaining value in the product is high;
- Demand for the remanufactured product must exist;
- The quality must be at least as good as the original whilst the purchase cost remains lower; and
- The lead-time to market must be short.

Existing research does not address the fundamental remanufacture or buy decision at component level except when considering the disassembly process. Lee, Cho and Hong [3] consider the benefits of considering remanufacturing, reuse, recycling or disposal options for an individual component or group of components based on the economic advantage but their work assumes that the remanufacturing decision at component level is made purely on what is economical to remanufacture. This research argues that there may be more factors than purely economic ones, particularly as the uneconomic remanufacture of an individual component may allow the economically beneficial remanufacture of a complete assembly. A purely economic view also ignores the many factors that contribute to the ability to remanufacture a component – engineering, quality and logistic considerations.

Existing research concerning logistics is similar in nature to that concerning the viability of remanufacturing in that it also often uses complex mathematical models that are not widely known and understood in industry. Tang et al [16] and Bao et al [17] provide very comprehensive models for establishing component lead-times and optimal inventory levels, however the skill level required to understand and apply them is not always available in industry and consequently makes them much less likely to be taken up. The varying need for new parts, dependant on the quality and quantity of the cores received for remanufacturing, is not directly addressed by this research save only where difficulties in supply require new remanufacturing solutions to be developed.

Research to identify the critical factors and their weighting to inform a robust decision-making process to remanufacture or replace could not be found and as such is the basis for this research.

4. Research Objectives

In order to fulfil the overall aim of the research and develop a methodology that can be used to establish a hierarchy of components requiring tailored remanufacturing solutions, the following research questions will be answered:

i) What are the current factors that inform the remanufacture / replace decision for components within a complex assembly? Understanding the decision making process will facilitate the categorisation of components in objective ii) and will ensure that the resultant hierarchy applies all criteria to each decision.

ii) What categories can be established to enables initial sorting of individual components within a complex assembly with regard to:
   a. Components that the customer or the limits of technology require are always new;
   b. The anticipated work content of the required remanufacture;
   c. The anticipated rate of salvage for remanufactured components; and
   d. The availability of current, established remanufacturing solutions.

   This sorting will enable a focused approach to the development of remanufacturing solutions by identifying the items that require the most input in terms of remanufacturing process design.

iii) What is the impact of the new cost, availability and lead-time of individual components? These factors may change within the life of the programme and consequently alter the remanufacture / replace decision and so their understanding is critical to a dynamic methodology.

iv) What is the impact of suitable used core availability, particularly with regard to the possibility of additional disassembly to support remanufacture?

v) What is the appropriate weighting of all of the above in the resultant methodology?

5. Research Methodology

The researcher is currently employed by Caterpillar Remanufacturing Services as a production manager and consequently the majority of the research will be carried out at the Caterpillar Rushden facility in the UK. Caterpillar is both an OEM and third party contract remanufacturer. The researcher is fully involved in the remanufacturing process on a day-to-day basis and fully acknowledges that this makes truly independent research almost impossible. This interdependence in the remanufacturing process has shaped the research methodology.

There is an established view that quantitative and qualitative research methods are incompatible [18] because of the assumption that the paradigms from which they originate are disparate, Knox [19] and Brannen [20] argue that it is acceptable and also desirable to use a combination of quantitative and qualitative paradigms to provide a complete picture of the research subject. Brannen [20] theorises that the phase of the research dictates the particular paradigm being used and it is that consideration that is crucial to the design of the research rather than which overall paradigm is selected. The fundamental nature of this research is of a quantitative paradigm collecting data from live remanufacturing programmes, however it will, particularly in the phase 2 case study phase, include qualitative research carried out among experienced remanufacturing practitioners.

The research will use a case study based approach as recommended by Eisenhardt [21], Yin [22] and Glaser and Strauss [23] for it's usefulness in understanding complex relationships and building theory and also as it allows in-depth consideration of data. This quantitative case-study approach will bring objectivity to the research and active remanufacturing projects will be used to develop these hypotheses and test their validity. Yin [22] particularly recommends a case study approach when investigating in a "real-life" context where there are variables that are not all directly data-driven. Case studies also give the advantage of being able to triangulate from the various data sources to confirm findings. Yin [22] also argues that in order to gain the most from case studies, it is necessary to first develop the base theories to guide data collection and analysis.

A participatory action research method (PAR) will be used for this research. This is because PAR is a collaborative approach to research, building theory from direct experience and progressively testing it. A team-based approach to problem solving is very familiar in industry and Caterpillar uses SixSigma methodology for all its operational functions. As a consequence of this influencing the process through a participatory research stance is both useful and desirable.

Action research, as identified by Lewin [24] has been criticised [25] for a lack of creditability [26, 27], however, Whyte [28] argues that PAR can deliver academic rigour and valuable insight particularly where local experience is a key component of the existing body of knowledge. This is the case in remanufacturing [6] and this research will use PAR to capture existing practise and experience and test against the developing theory. The SixSigma methodology employed by Caterpillar in all of its operations is based around examining a process to capture all the available knowledge, building a theory about improving the process and implementing the agreed changes before monitoring to gauge whether the theory accords with practice. This methodology converges with PAR and consequently using this strategy will not only accord with current practice within Caterpillar but also be familiar to, and therefore comfortable with, the workforce enabling a more productive relationship to develop.

The research will develop initial theories from existing research, and use them to develop the preliminary methodology. This will be tested in a live remanufacturing environment and refined as required following practitioner feedback and analysis of the data collected. This will be an iterative process until the researcher and practitioners are satisfied that the methodology is fully developed and understood. The resultant methodology will be peer reviewed outside of Caterpillar to validate it and establish its generic credentials.

Initial data collected from practitioners throughout Caterpillar has identified the factors currently used to make the remanufacture decision and initial theory building has begun.

6. Expected Results and Contribution to Knowledge

Examination of existing literature has shown that no specific research to support the development of remanufacturing solutions for existing complete mechanical assemblies is available and this research will provide a novel methodology that will enable the identification of priorities for a remanufacturing solution within a complex assembly. Moreover existing work does not consider all the actual inputs into an individual remanufacturing decision, often assuming it is purely an economical decision. The omission of wider factors – engineering, quality and logistical – limits the usability of any given solution.

This research will identify all the factors that inform the remanufacture or buy decision when remanufacturing a mechanical assembly and provide a novel robust methodology that will enable remanufacturers to evaluate an assembly, particularly one where design for remanufacture has not been considered. This decision-making tool will prioritise efforts to develop new techniques and processes, thus facilitating a quick and effective response to the customer.

It is intended to make this research accessible to industry via a system capturing the new information in a manner that facilitates its usability primarily through a tool to This tool will allow remanufacturers to assess a bill of materials and quickly identify components that require additional effort at the beginning of a remanufacturing programme, thus enabling a more competitive response whilst supporting sustainable manufacturing.

7. References

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