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A network model to assist 'design for remanufacture' integration into the design process

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ABSTRACT

Remanufacturing is the process of returning a used product to a like-new condition with a warranty to match. It is widely recognised as an environmentally preferable end-of-life strategy for many products, as it is a process that saves materials from landfill and retains more intrinsic energy than similar end-of-life strategies such as recycling or repair. The concept of 'design for remanufacture' (DfRem) originates from the understanding that decisions made during the design process may have a considerable effect upon the efficiency and effectiveness of the remanufacturing process. Much of the DfRem literature to date has focused upon the identification of technical DfRem factors (such as material choice or fastening methods), and the subsequent development of design methods and tools. However, the literature has overlooked how DfRem practices may be integrated into a company design process, and has not considered the operational factors that may influence DfRem integration decision-making and practice. This paper presents the findings from industrial case study research with three original equipment manufacturers (OEMs) from the UK mechanical industry sector. The research has identified significant external and internal operational factors that influence DfRem integration, including management commitment, OEM-remanufacturer relationships and designer motivation. This paper also presents a 'DfRem integration network model' which maps the identified relationships between the various operational factors, providing practitioners with an enhanced understanding of DfRem and a portfolio of options when seeking to integrate DfRem into the design process.

1. Introduction

Over the past few centuries, global consumption of material goods has risen at an alarmingly rapid rate, with little evidence of our enthusiasm for consumerism waning in years to come. At the same time, manufacturers are presented with a whole range of increasing challenges and pressures, from materials scarcity to increasing energy costs, from meeting environmental requirements to meeting customers' needs during a global financial recession. Manufacturers are seeking ways to reduce costs, meet increasingly stringent environmental legislation and provide customers with quality products at a price they can afford to pay. Whilst 'design for environment' or 'ecodesign' has traditionally focused upon the redesign or development of new products with a reduced environmental impact, manufacturers are now beginning to move towards the design of new product-consumption systems (Manzini and Vezzoli, 2008) for example the development of product-service systems (PSS). PSS is an emerging concept in with the original equipment manufacturer (OEM) will retain ownership of the physical manufactured product, and instead focus upon the sale of the service that product provides. In such models the customer may benefit from reduced responsibility whilst the OEM may benefit financially whilst prolonging the lifecycle of manufactured goods, therefore reducing environmental impact (Coley and Lemon, 2008).

One possible strategy for a company seeking to move towards a sustainable product system is remanufacture: the process of returning a used product to like-new condition. Used products are collected by the original equipment manufacturer (OEM) or a third party and disassembled, inspected and cleaned. Worn parts are reprocessed, and those which cannot be returned to a like-new condition are replaced. The product is then reassembled and tested, and the remanufactured product can then be sold with a warranty that is equal to that of a newly manufactured equivalent (Ijomah, 2002). This differentiates remanufacturing from similar product end-of-life strategies such as reconditioning (when the

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product is returned to an acceptable working condition), or repair (when worn or broken parts are simply replaced) (King et al., 2006). Although remanufacturing typically requires more work and cost input than these two options, the result is a higher quality product with a longer extended life in use. Because the products are being recycled at a component level when remanufactured, much of the intrinsic energy within that product is retained, saving a manufacturer both energy and materials when compared to new manufacture. As a result, remanufactured products may be sold to the customer at a lower price, typically 30–40% less than a newly manufactured equivalent (Giuntini and Gaudette, 2003).

Of course, not all products are suited to remanufacturing. Remanufacturable products can typically be characterised as containing high-value parts (worth investing in) and durable materials (able to withstand both the remanufacturing process and multiple lifecycles). Crucially, there must be market demand for the remanufactured products. Commonly remanufactured products include automotive parts, medical equipment, pumps and compressors, off-road equipment and office equipment (Charter and Gray, 2008). Less durable, less technologically stable products such as consumer ICT equipment are challenging to remanufacture and more typically recycled due to processing barriers and a lack of sufficient market demand (Hatcher et al., 2013a).

Furthermore, the efficiency and effectiveness of the remanufacturing process has been found to be highly dependent upon how that product was designed: technical issues such as material choices, fastening and joining methods and component accessibility are considered to be some of the biggest barriers to successful remanufacture (Ijomah et al., 2007). It is from this understanding that the concept of 'design for remanufacture' (DfRem) has emerged, and as a result research has been dedicated to identifying these technical issues and ways in which product designers may address them.

Remanufacturing is compatible with sustainable product systems because it is a process that can create multiple lifecycles from one manufactured product. It has therefore been suggested that DfRem and PSS go hand-in-hand: when an OEM is involved in service-selling through remanufacture, it should have greater incentive to incorporate remanufacturing considerations into its design process, to ensure the efficient and effective extension of a product's life-in-use, therefore reducing new-manufacturing requirements (Mont et al., 2006; Sundin and Bras, 2005; Sundin et al., 2009).

However, little consideration has been given thus far to how DfRem principles may be integrated into an organisation's existing design process, an issue that is particularly significant when considering the fact that remanufacturing will likely always be a low-priority issue when compared to issues such as function or cost (Hatcher et al., 2013b). Some papers have discussed the opportunity to integrate DfRem into sustainable product systems (Sundin and Bras, 2005; Sundin et al., 2009), however discussions are limited to product redesign challenges rather than the required changes to an organisational system.

The overall aim of this research was to gain an understanding of the operational factors (as opposed to technical factors) that enable design for remanufacture (DfRem) to be integrated into a company design process. To achieve this, three research objectives were set. Firstly, to determine the *external* operational factors which influence the decision to design for remanufacture. 'External factors' refers to those factors which were identified as having or potentially having a direct and identifiable influence upon a company's decision to design for remanufacture in the first instance, i.e. 'kickstarting' integration. The second objective was to determine the internal operational factors which influence DfRem integration into the design process. 'Internal factors' refers to the more specific factors relevant to a design engineering department or team which were found to potentially influence the actual process of integrating DfRem into a company design process. These factors would be within the control of design engineering management, or immediate DfRem stakeholders such as aftermarket management or remanufacturing management.

However, a simple listing of operational factors is of limited value to industry. Product design can be described as a 'human-activity system', meaning that the identified operational factors are not likely to stand-alone; relationships will exist between them. Therefore the third research objective was the development of a 'DfRem Integration Network' model. An understanding of the relationships between the identified factors will provide OEM design teams with a view of the 'bigger picture', enabling a more effective approach to DfRem integration decision-making. If a company were to address one of the identified factors in isolation, the outcome would likely be insignificant.

This paper will focus upon the development of the DfRem integration network model. The next section provides a brief overview of DfRem research state of the art, and an overview of ecodesign integration factors found in the literature (a closely related research field which has influenced the direction of this research). Section 3 will explain the methods which were used to gather information on DfRem integration factors. Section 4 will provide details of the identified external and internal operational factors that influence DfRem integration, and Section 5 will present the DfRem integration network model that was developed as a result of these findings. Section 6 discusses the significance of this research, firstly through the comparisons between our research findings and the ecodesign integration literature, demonstrating that the two fields are not inter-changeable. The section then goes on to discuss the theoretical contributions of this research and practical implications for industry. Section 7 includes our concluding remarks and identified issues for future research.

2. State of the art

This section will provide a brief overview of previous research published on the subjects of design for remanufacture and integration operational factors.

2.1. DfRem state of the art

Much of the previous DfRem literature is focused upon the development of DfRem-specific design methods or tools. Some of these methods and tools are quantitative in nature, for example Bras and Hammond's remanufacturability metrics (Bras and Hammond, 1996), whilst others are intended to provide more qualitative guidance, such as DfRem guidelines (Ijomah et al., 2007) or the 'RemPro Matrix', which links design considerations with particular stages of the remanufacturing process (Sundin and Bras, 2005). Other researchers have proposed the use of existing design methods or tools, adapted to DfRem requirements. For example, Lam et al. (2000) propose the use of Failure Mode and Effect Analysis (FMEA) to assess common failures during the remanufacturing process and provide DfRem feedback to designers, and Yuksel (2010) proposes the use of Quality Function Deployment (QFD) to address the 'voice of the remanufacturer' when outlining design requirements. A detailed literature survey of DfRem research can be found in (Hatcher et al., 2011).

However, there is little evidence to suggest these methods and tools are currently in use by industry. A reason for this could be that the proposed solutions only address the technical design issues associated with DfRem, with little consideration of how these