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REMANUFACTURING AT XEROX: EVALUATING THE PROCESS TO ESTABLISH PRINCIPLES FOR BETTER DESIGN

Andrew King[1], Stephen Barker[1] and Andy Cosgrove[2]
[1]University of Bristol, UK
[2]Xerox, Dundalk, Ireland

ABSTRACT
This paper explains and illustrates the process Xerox uses at its factory in Ireland to return old document equipment (including photocopiers and printers) to an "as new" product. Through a series of industrial processes in a factory environment, a discarded product is completely disassembled. Usable parts are cleaned and restored to their "as new" condition before the product is reassembled with some new parts to produce a unit fully equivalent to the original new product.
Although Xerox has made a profitable business from remanufacturing, there are many barriers to its wider development. This paper outlines some of these barriers to remanufacturing and outlines the development of a design method to enable better design for remanufacturing.

Keywords: Remanufacturing, Design Platforms, Sustainable Development

1 INTRODUCTION
Remanufacturing is the term given to the process of returning products to their as-new standard and form. It is a process that has become increasingly relevant and important given the need to ensure that future economic and manufacturing growth is sustainable - that is "a development that meets the needs of the present without compromising the ability of future generations to meet their own need" [1]. The difference between sustainable and industrial agenda was defined by Stahel [2], who described the former as "a long-term societal vision, concerned with the stewardship of natural resources (stock equals wealth) in order to safeguard the opportunities and choices of future generations"; the latter, meanwhile, is described as a "short-term optimisation of throughput in monetary terms". The need to move manufacturing closer to a sustainable vision is evident given that virgin development uses high levels of both energy and raw materials, and the current primacy of purchase cost means that it is often cheapest simply to discard an old product and develop again from new – thus producing waste.

This situation has led to a focus on "Extended Producer Responsibility (EPR)" and its application in respect of End-Of-Life (EOL) product take-back [3]. There have been several recommendations and directives issued in this regard. Example items of legislation include: EOL requirements for the automotive sector [4], the provision of guidance for governments on how the EPR issue should be addressed [5], and the regulation of the disposal and reuse of waste from electrical and electronic equipment (WEEE). The European WEEE Directive [6] is intended to achieve three key objectives:

1. Reduction of waste arising from EOL electrical and electronic equipment (defined as being any equipment powered via either mains electricity supply or batteries);
2. Improvement and maximisation of recycling, reuse, and other forms of recovery of EOL electrical and electronic waste materials;
3. Minimisation of the impact upon the environment from the treatment and disposal of electronic and electrical EOL equipment.

In order to achieve these goals, it is necessary to gear products toward the EOL scenario. Duflou et al. [7] identified two significant tasks: whole product reuse, and product disassembly with optimal reuse of parts and components. There will be various ways of achieving these aims. Stahel [8] differentiated between a "fast-replacement" system, or 'open-loop' approach, characterised by short-life, incompatible goods and products lacking 'repairability', and a "self-replenishing", or 'closed-loop' system, characterised by the ability to extend product life expectancy, and the reduction of product waste. The principle methods associated with the closed-loop approach are: repair, reconditioning, remanufacture, and recycling. These are shown in figure 1.

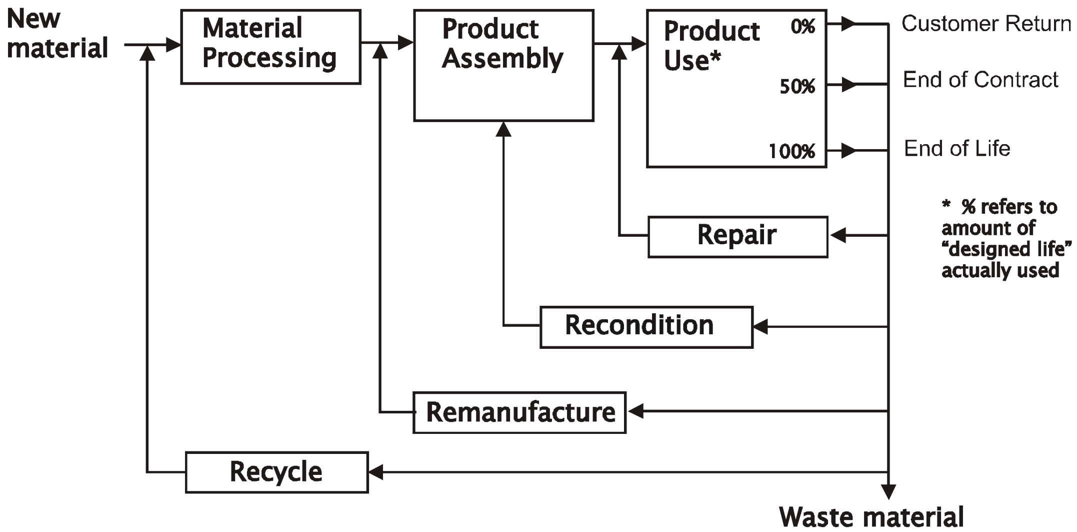

Figure 1: Closed loop design through repair, remanufacturing or recycling

1.1 REPAIR

Repairing a product is the process of rectifying a number of given faults with a product and returning it to useful service. King and Burgess [9] describe it as the most logical approach to closing the loop on product use. Stahel [8] describes it as elimination of secondary damage such as worn components, or cosmetic damage (i.e. dents). Repairing a product minimises the energy and material needed to keep it in use at the expense of not offering an updated or improved functionality. However, the quality of a repaired item tends to be inferior to a newly produced, remanufactured, or recycled version. Warranties for repaired items are also shorter and less comprehensive than those for other methods of EOL reuse, and may cover only the repaired components of the product, rather than the product itself. Additionally, it is suggested [10] that consumer decisions on whether to have a product repaired, reconditioned or disposed of are based on age of product, service life remaining, and cost. Inexpensive products are perceived to have a short in-service life remaining, and the consumer is unlikely to have it repaired. This is reflected in a four-fold increase in repair costs over as-new purchase costs in the 1980s and 1990s.

1.2 REMANUFACTURE

This method of reuse is the only one in which the performance of a used product is returned to at least the Original Equipment Manufacturer's (OEM) performance specification. In addition, remanufactured items possess a warranty which is equal to that of equivalent new products [9]. Nasr [11] states that remanufacturing is "the process of disassembling, cleaning, inspecting, repairing, replacing, and reassembling the components of a part or product in order to return it to like-new condition"; Sundin [12] describes it as: "an industrial process whereby products referred to as cores are restored to useful life. During this process, the core passes through a number of manufacturing steps, e.g. inspection, disassembly, cleaning, part replacement/refurbishment, reassembly and testing to ensure it meets the desired product standards". It is a process that is particularly relevant to the reuse of complex electronic equipment, which tends to have a core, which, when recovered will possess an added value that is high in comparison to their actual market value, and to their original value [9].

1.3 RECYCLING

"Recycling involves the separation and collection of materials for processing and remanufacturing into new products, and the use of the products to complete the cycle" [13]. This is the method of reuse most clearly established within the public consciousness, where it is inextricably linked with the concept of waste reduction. In some product families, recycling rates have reached as far as 80% [6], and recycling is the most easily understood of waste reclamation strategies by the public. However, designers tend to be wary of reusing recycled components because such items can have variable quality issues attached [14].

1.4 WHICH RETURN LOOP?

Effective end-of life strategies are often dictated by product characteristics and will therefore vary from product to product [15].

However, Stahel [16] states that the smaller the loop, the more profitable it is. Thus, according to Stahel, repairing or remanufacturing products ought to be more common (if it is more profitable) than recycling. And yet, the reality is the opposite: recycling is far more common than repair or remanufacture.

With the introduction of legislation such as the WEEE directive in Europe, manufacturers are now liable for their products through and beyond their end-of-use life. Whilst a strategy to ensure recycling would meet their obligations, many manufacturers see that this is an additional cost with little or no financial benefit (scrap values are often less than recycling costs). Thus, interest in repairing or remanufacturing products is increasing because the potential profits from these smaller loops will be the most "value adding" way to discharge extended producer responsibility. They also have the added societal benefits of providing gainful employment for low to medium skilled labour because much of their tasks are simple to learn.

Repair or remanufacture? In terms of environmental benefit, repair is clearly the better option because less energy is needed and virtually all material is kept. However, the barrier of consumer behaviour (and manufacturers' demand for future new sales) is huge. To change the present culture of fashion obsolescence driving new sales is a macro-level activity. However, if products can be remanufactured such that the second-life product is made up-to-date to the market, then this could be both economically viable to manufacturers (an essentially new product is made) and desirable to consumers.

The essential characteristic from an environmental aspect is that remanufacturing preserves the embodied energy (emergy) that has been used to shape the components for their first life. Lund estimates that a remanufactured product only requires 20-25% of the energy used in its initial formation [17]. Thus, as well as reusing the material, the energy required to produce a new product is significantly lower. Although the environmental advantages are clear (and meet the intentions of extended producer responsibility even if not the legislation) there are other benefits from remanufacturing. Bras & McIntosh state that, by receiving back old products, manufacturers can obtain feedback on reliability and durability information and can also resell into lower-priced markets, typically costing 60% of the original production cost [18].

2. REMANUFACTURING AT XEROX

One well known (and certainly well referred to) example of remanufacturing is that of copiers and printers made by Xerox. By retaining ownership through leasing, or other direct links with the users, they have been able to work towards their environmental goal of making "waste-free products in waste-free plants to help customers attain waste-free workplaces".

In 1987, Xerox started a new programme called "asset recovery" and created a new facility within, its manufacturing plant in The Netherlands. *(Changed for consistency with point 1 on page 6)* Its aim was two-fold: firstly, to remove old copying machines from the waste stream and, secondly, to process these machines for resale. This was called the Asset Recovery Operation (ARO). In 1989 5% of scrapped machines were remanufactured; by 1997 this had risen to 75% of the 80,000 printers returned. At the beginning of 1993 landfill accounted for 41% of manufacturing waste but by 1995 this was only 21%. To encourage return, an incentive scheme was introduced in The Netherlands, and although the remanufactured printers compete with new Xerox machines, the company claimed to have saved $65million by 1996 [19]. By 2001, Xerox had remanufacturing facilities in the USA, the UK, The Netherlands, Australia, Mexico, Brazil and Japan [20]. These facilities not only ran at a profit, they also enhanced Xerox's environmental image and reputation all over the world. In Europe, Xerox remanufacturing facilities are located in three factories: Venray (NL), Mitcheldean (UK), and Dundalk (IRL) respectively.

- At Venray a mid sized multifunction product is fully remanufactured and sold back into the European market. Production is approximately 1000 units per annum.
- At Mitcheldean, the Fuser Manufacture Centre remanufactures high value fuser roll components alongside new manufacturing. Separate studies by the authors have assessed the environmental impact of this operation and found remanufactured rolls can have a little as ¼ of the impact of new build [20, 21]. Remanufactured production is approximately 400,000 units per annum.
- At Dundalk both large industrial printers (the Docutech range) and multifunction products are remanufactured. A Docutech product (the focus of this paper) is shown in figure 2. Production is approximately 650 units per annum. In addition, 400 smaller DC12 machines are also remanufactured at the Dundalk site.

Figure 3: Xerox's Docutech Printer remanufactured at Dundalk

The new products are built and shipped from Xerox's Webster factory in New York State, USA to Dundalk to supply the European market. The original Docutech product has now been replaced by the Nuvera range, which will begin to be remanufactured at the end of 2007. Before original sale they are customised to suit the final destination country (in terms of language & software settings etc) and then shipped for first life use. A team of 50 people manage this operation. This sale is managed through a network of Xerox Operating Companies (OpCos) who deal directly with the customers.

2.1 The Dundalk Remanufacturing Process

Acquisition

Except for excellent condition "Category 1" customer returns (which are immediately resold by the OpCos) Xerox has a reverse logistics process to take all other End of Use (EoU) products to their Surplus Equipment Warehouse in The Netherlands. In order to incentivise the OpCos, the Xerox Warehouse "buys back" each product at a given rate, dependent on demand. At the warehouse, staff make an initial assessment of the condition of Docutech products as:

Category 2 – good condition, suitable for return to Dundalk
Category 3 – damaged condition, still suitable for return to Dundalk
Category 4 – written off (as salvage) and recycled in the Netherlands

If Xerox Dundalk has an order (or likely order) for a remanufactured Docutech product then it is shipped back to Dundalk via TNT logistics. Once acquired, the main process flow for remanufacturing at Dundalk is shown in figure 3.

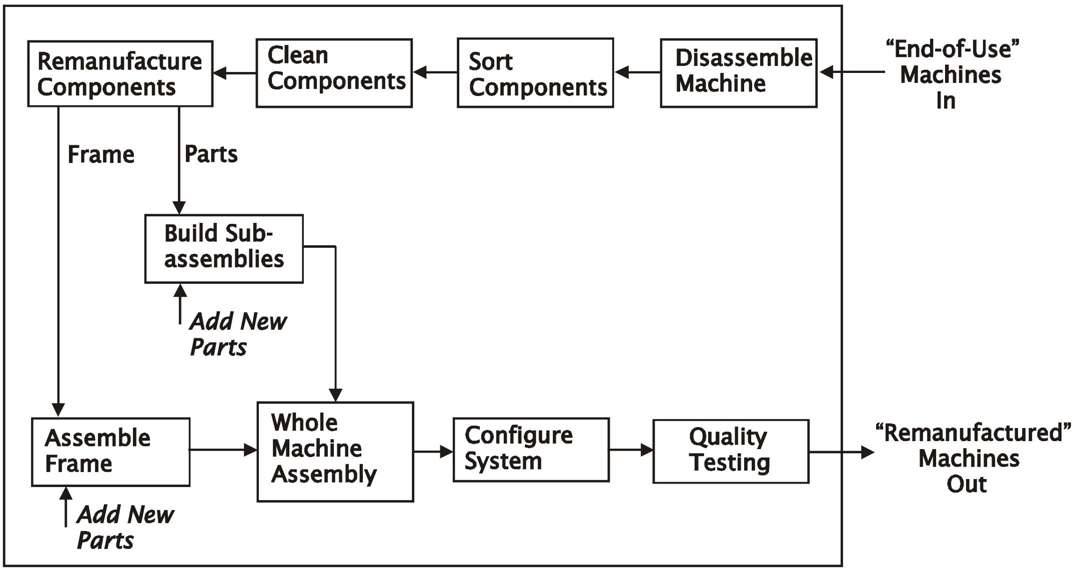

Figure 3: Xerox Dundalk's Remanufacturing Process Flow

Disassembly

When an old machine is received from Venray it is fully disassembled according to standard OICs – Operator Instruction Cards. This makes the process traceable and fully auditable for Quality Inspection purposes. It also allows the factory to operate with workers who have not had experience of building the original new products. Thus, the process operates as a full "manufacturing" factory.

All Outer panels are removed and re-sprayed by a local sub contractor). Dry Ice cleaning is undertaken for many parts (CO_2) together with ultrasonic bath cleaning and hand cleaning using brushes etc.

Remanufacture & Assembly

The Dundalk factory floor space is 15,000 m^2 and is laid out like a modern manufacturing operation with 300 people directly involved in the operation. Thus, individual cells of workers concentrate on the remanufacture of individual sub-assemblies of the product. Certain components such as bearings, gaskets, seals etc are replaced. A fully inspection is made of each sub assembly. Then a team of workers will rebuild a product from its original frame and sub-assemblies. Figure 4 shows a worker reassembling a particular sub assembly.

Figure 4: Docutech Sub-Assembly

Although the clear majority of component parts are reused, some are replaced with newer, higher specification components to reflect the most up-to-date standard. Thus, a remanufactured product may have more efficient components and enhanced functionality (such as faster print speeds or a colour print rather than mono). All remanufactured products will have the latest operating software installed.

Customise, Test & Package

The product is customised to suit its new owner involving setting the exact specification and operating language. After this, final panels are added and a full test operation is undertaken to the same standard and specification of a brand new machine. Once completed, the product is packed and shipped out to the customer in the same fashion as it was originally when it was a new product.

Xerox standard practice is to give a 100% customer satisfaction guarantee with each remanufactured product and therefore offer the same warranty conditions as a brand new machine.

2.2 Evaluating the Dundalk Remanufacturing Operation

Xerox has made remanufacturing a profitable business through a mixture of strategic intent and close process monitoring. After a number of years of investment, the current operation reaps the benefits of products designed <u>for</u> remanufacture, and the closely monitored supply & production process is finely tuned to deliver lean manufacturing practice.

Strategic Intent

Arguably the single most important aspect of Xerox's remanufacturing strategy has been the decision to design products for remanufacture. This has enabled the disassembly, inspection and remanufacturing operations to be more efficient as decisions made at the start of the design process have allowed for eventual remanufacturing. Through other studies with different remanufacturing companies (particularly 3rd party remanufacturers) a consistent issue has been that of product design that has not facilitated easy disassembly, inspection and remanufacture. Whilst the consideration for remanufacture may seem simple, a number of important features of Xerox's strategy are important:

1. The same business teams assume full responsibility of a product for new build and remanufacture. Thus, there is no "handover" of workload to a distinct remanufacturing arm of the company. Instead, the designers & planners who develop a new product take responsibility for remanufacture. Rewards and incentives are therefore built into the New Product Development process and allow trade-offs between assembly and disassembly issues to be more objectively considered.
1. The same production equipment, operator instructions and quality assessment procedures are developed for new build and remanufacturing. In this way, the company is well able to guarantee that at least the equivalent specification, reliability, quality and appearance will be given to the remanufactured product as the new one. This aspect is seen as key to overcoming customer hesitation at buying a remanufactured product. In addition to ensuring the same quality, the identical process operations allow economies of scale to be achieved with suppliers and staff training/expertise. [Indeed, outside the European Union , Xerox manufactures and remanufactures the same products in the same factory. Inside the EU, the recent Restrictions of Hazardous Substances (RoHS) Legislation requires operations to separate products that do and do not contain RoHS restricted substances. As remanufactured products are older, most of these do contain such substances].
2. Due to the same quality standard, Xerox uses remanufactured products to provide a product portfolio mix to customers. Thus, a customer is offered a mixture of new and remanufactured products to suit the particular operating conditions and budget. In this way, Xerox sells the remanufactured products through the same network of sales staff with the same incentives, bonuses and rewards as new products. Again, comparative studies with other remanufacturing companies has shown that incentivising sales staff is a very important part of the operation.
3. At the heart of the Xerox design strategy is the use of a Modular Product Architecture build on stand design platform. The standardisation of parts allows for cost savings to be realised or additional costs to allow for remanufacture to be absorbed. This has been a key aspect of the strategy where design decisions that would add cost for a single life strategy are reduced through standardisation over a number of product varieties. In addition, the use of a design

platform has allowed Xerox to build in future upgradability as key modules can be replaced without the need to remove other components. This has been seen with new technologies for fuser and toner components which are now added to remanufactured products too. By establishing long-life platforms (typically 10+ years) the incremental improvements are realised on both new and remanufactured models, thus maintaining the saleability of otherwise outdated equipment. In addition, the stock levels required to service remanufactured machines is reduced and can be modified as suppliers phase out older variants.

In short, Xerox has made remanufacturing a long-term strategy for many of its printing products. By so doing, both the business and design process is aligned with this strategy allowing decisions to consider multiple-life assembly & upgrade.

Process Monitoring

In addition to having a long-term strategy, Xerox has also developed a number of more practical techniques to enable the remanufacturing operation to be more effective. These techniques enable both a stable supply of products to be returned and ensure that the quality of remanufactured machines is to the same standard as new.

1. In order to ensure a stable supply of category 2 or 3 products return to Dundalk, Xerox "buys back" the products from the individual country Operating Companies. In effect, this is a cash bonus and ensures that an incentive is in place to pull back the needed assets. From other research, the availability of "cores" for remanufacture is commonly the next highest problem to disassembly issues.
2. The Dundalk factory acts as both the supply route for new and remanufactured products. This brings two practical benefits in that mixed orders can be easily arranged and return logistics are seamlessly linked to forward journeys. The results in a significant cost saving.
3. Partly through a process of learning over time, and partly through design intent, Xerox has developed a Stock Planning database so that exact stock orders of replacement parts can be ordered. This allows single purchasing to suppliers for both new build and remanufacturing operations and again reduces cost. In addition, through direct field maintenance data, the company is able to determine which components need replacement in order to satisfy the demanding "as new" quality level.
4. Signature Analysis is a vital part of Xerox's diagnostic procedure for determining the health of a returned product. During the initial design of a component, a number of key characteristics are set and then test procedures developed to allow these characteristics to be assessed when they return. Thus, certain components are specifically designed to allow for testing as they are known to be of continued value. A particular operating "signature" is developed such that a simple test procedure can determine whether the component is within the acceptable tolerance levels for continued use.
5. As Xerox has designed parts knowing whether they will be remanufactured or replaced, the Dundalk site is able to prepare in advance for new remanufacturing lines. In addition, as it uses the same assembly process as new build, much of the equipment can be pre-installed ready for use. Thus, the company has a well refined launch and closure process for remanufacturing. Again, this is seen as vital in order to deliver the as-new quality level. The process works according to the 3 stages shown in figure 5 where a "Shamrock" phase is employed before and after main remanufacturing. The Shamrock operation involves taking a returned product and undertaking extensive repair & reconditioning but not full remanufacture. Thus, the product is sold clearly at a lower quality level but Xerox learns a lot about the finer disassembly procedures and gathers data on component quality. Once a sufficient number of these have been processed, a full remanufacturing operation is started. Eventually, the demand for this product will fall and thus only the best Category 2 products are returned. As an "as new" quality is much harder to guarantee after several remanufacturing cycles, Xerox returns the product line to a "Shamrock" operation to met final demand on a strictly "refurbished" quality level.

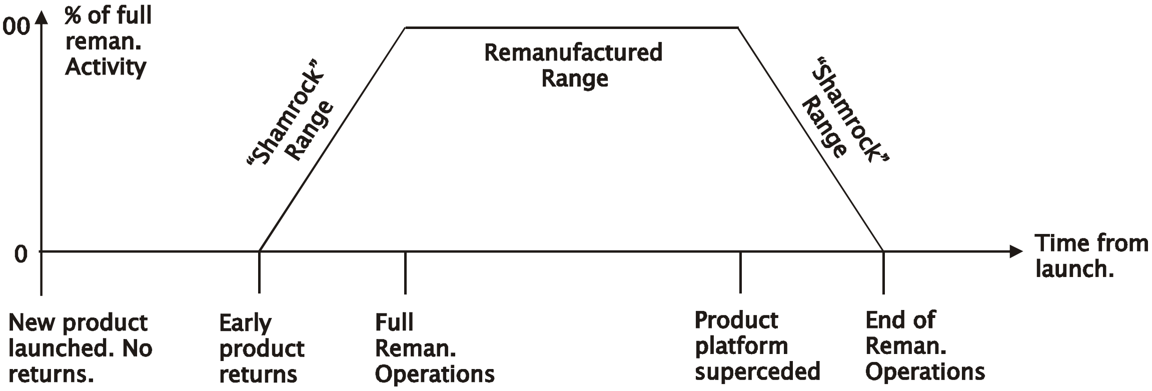

Figure 5: The Xerox Remanufacturing Ramp Up/Down for each Product Line

Therefore, in a similar way as in the strategic matters, Xerox has developed a number of proven process activities both to reduce cost and to ensure 100% customer quality levels from its remanufacturing operations.

2.3 Future Challenges Driving Design Changes

Whilst Xerox has adapted its remanufacturing operation well to suit new technical designs and market conditions, a continual challenge has come from the need to comply with European Union legislation developed to encourage more sustainable development. In a separate paper, the authors cover the issues relating to the WEEE and RoHS directives [20]. However, the planned EuP (Energy using Products) Directive is now presenting further challenges to Xerox's remanufacturing operation.

At the heart of remanufacturing is the recovery of embodied energy within an existing manufactured product. This case has been presented in earlier sections of the paper. However, reused components may not be as energy efficient as new components of more recent design. At present, the EuP Legislation is shaping around the quest to reduce standby and in-use energy consumptions. In so doing, it may become impossible to re-sell a product if its energy consumptions are higher than newer "low energy" models. Of course, this may well be a good thing and yet if a consideration is not made for the manufacturing energy and waste saved through remanufacture, the perceived lower operating energy may not be the best measure of improvement. However, as with most legislation, a simple measure is likely to prevail as an acceptance target because it is both easier to measure and easier to communicate to the general public.

In response to this, the authors are involved in a study to assess the differential energy consumption levels between newer and older image printing products. This is aimed at assessing whether incremental product upgrades do yield high savings in energy. In tandem to this, assessments are being made on the level of manufacturing energy saving needed to negate any higher stand-by and in-use energy levels. Models are being developed to determine whether a remanufactured product used for a shorter second life would use a lower total energy level than a new equivalent.

3 GENERIC REMANUFACTURING DESIGN PLATFORMS

From the study and evaluation of Xerox's operations, the authors conclude that the single strongest way of enabling products to be remanufactured is through the design of a product platform. However, in light of EuP legislation and the continual need to reduce in-use energy, future platforms need to combine both assessments of remanufacturability with future life efficiency. Therefore, the authors are engaged in a longer-term project to develop a generic remanufacturing design platform tool to allow other products to be designed for energy-efficient remanufacturing.

The authors' definition for a Remanufacturing Platform Design is "a strategic architecture of components that forms a platform of components that are remanufactured for multiple lives onto which a series ephemeral or high energy using components are added". This is shown in figure 6.

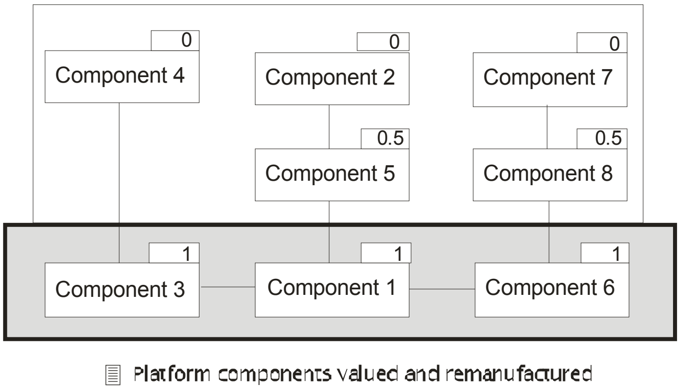

Figure 6: A Remanufacturing Product Platform

Thus, by arranging components that have remanufacturing potential in the platform, the more ephemeral or high energy using components would be built on to this base. At the end of life, these would be removed and recycled leaving the platform available to be remanufactured. Some of the remaining components may still have sufficient quality to allow reuse whilst others may be suitable for remanufacture. Therefore, their utility will lie somewhere between 0 and 1; for example a utility of 0.8 may show the component only needs cleaning before re-use where 0.5 may show the product needs to be repaired and recalibrated. Components with a utility of 0.2 may only be useful when cannibalised to reclaim minor parts. Thus, to a producer, an old product should be seen as a collection of discrete components each with different end-of-life utility values.

The underlying argument is therefore that as individual components and sub assemblies within a failed/end-of-life product still have intrinsic value these should be configured to be more easily identified, removed and thus remanufactured. The principle of Platform Design is thus appropriate in this context as it can allow components with remanufacturable & no/low energy use to be configured in the platform to allow easier remanufacture. In this way, the design would anticipate the updating of energy using components such as motors and heating elements such that the standby and in-use energy consumption of a later life is lower than the earlier life (and thus in line with new models and required targets). This can be a strategic design response.

A generic design platform approach could enable the wider application of remanufacturing. The current research project is therefore investigating how component design, selection and assembly can enable a platform to be designed from components suitable for remanufacturing, with additional consumer aesthetic and single-life obsolescent components forming each derivative. After the first product life, such an arrangement would allow the derivative components to be more easily disassembled for recycling, and a new product to be built from the remanufactured platform. By using the platform approach, it is hoped that a major barrier to current remanufacturing will be removed so that each second-life product could be updated with the latest technologies and customer styles. At present this is the barrier that prevents many consumer products from being remanufactured, as there is no market for out-of-date products.

Current research is gathering a list of design criteria from a number of remanufacturing companies to establish the most important criteria upon which to determine a component's remanufacturing utility.

4 CONCLUSIONS

This paper has described the operation Xerox uses to remanufacture large industrial image printing equipment at its Dundalk factory in Ireland. Both strategic design & business factors and a number of specific process techniques have enabled the company to establish a profitable business that delivers products back in the market at the same quality levels as new.

The authors investigation has found that the single most significant feature of the operation has been the intention and organisation to design these products for remanufacture. The use of a stable design platform has enabled economies of scale, parts variability reduction and an intrinsic ability to upgrade certain modules to reflect newer operating specifications. In the light of the impending EuP Legislation addressing energy consumption levels, remanufactured products may be prevented from resale. Ongoing research is establishing whether savings in manufacturing energy & waste can compensate for higher use-phase energy.

Thus, future design for remanufacture must allow energy-using components to be easily assessed and upgraded. A utility score for these components may be a way of assessing their potential for future use and help to develop a system architecture that allows them to be easily disassembled and replaced.

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Contact: Andrew King
University of Bristol
Department of Mechanical Engineering
Queens Building, University Walk
Bristol, BS8 1TR
UK
+44 (0) 117 928 8213
andrew.king@bristol.ac.uk