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Use of Enterprise Simulation to Assess the Impacts of Remanufacturing Operations

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Abstract

Remanufacturing could become a cornerstone of a future sustainable society and considerable progress has been made towards finding technical solutions for the renovation of products or selected components. Not all the barriers to remanufacturing are purely technical, however; others are related to business drivers, or social factors. The problems anticipated for remanufacturing, as identified by Guide [1] include “stochastic product returns, imbalances in return and demand rates, and the unknown condition of returned products.” In order to investigate the significance of these problems, a simulation model was constructed to explore the costs and benefits of a range of different end-of-life (EOL) strategies. It suggests that environmental harm can be reduced to an extent, when a company is set up to process returned goods, but that this benefit comes at the cost of considerable complications in scheduling and logistics.

Introduction

All products require energy and materials for their manufacture. They perform a role for a time, but ultimately reach a point where they are no longer useful for some reason. At that point the energy and materials they embody can be retained and reused, or they can be squandered. The influences that determine success or failure are complex. It ought to be a good idea, in principle, to make viable products and components serve again, but questions remain about the practicality of this, in terms of capacity requirements, logistic implications and economic impacts.

Individual studies attribute considerable eco-efficiency benefits to remanufacturing in the form of energy savings, reduced greenhouse gas emissions, savings of raw material etc. (e.g. Sutherland et al [2], Ijomah et al [3]) but success in remanufacturing appears to be confined to isolated islands of excellence. There remains considerable potential for remanufacturing to be applied more widely, but there is a need for a better understanding of the circumstances under which significant levels of remanufacturing can be achieved. Our software model was meant to be generally applicable for this purpose.

Model Construction

A generic model of a system was constructed, simulating the purchasing and production activities of an enterprise, plus the behaviour of the market it served.

Rockwell Automation's 'Arena' was employed to produce the model, using stochastic branches to determine each individual product's life cycle. Parameters that were built into the model allowed the probability of key events to be specified. For example, a product might be built with a faulty component, and fail immediately upon installation. Even a viable product might be rejected by a customer who changed their mind. Once in service, a product might be accidentally damaged, it might be used until a key component wore out, or it might be deemed to have become unfashionable or obsolete while still functional. Upon reaching the end of life (EOL) by one route or another, there was a further probability to express the chance that the product would be returned to the manufacturer, who could then reuse or remanufacture components if this was technically and commercially feasible.

Figure 1 shows the basic arrangement within the Arena model. The model also consulted a Microsoft Excel spreadsheet at the commencement of each model run to set key parameters such as probabilities for outcomes of the kinds listed above, the design life of each component type and Boolean variables that stated if a remanufacturing process existed for each. A cost and a simplistic measure of 'points of environmental harm' were also associated with each operation. A second Excel spreadsheet was populated with data during the model run, recording the results. (For the purposes of this paper, the number of products entering service each month and the proportion of them that made use of reclaimed components.)

A variety of alternative EOL strategies could be explored, from a simple 'everything goes to landfill' strategy up to a complex solution that included residual life assessment and a life restoration operation for components that qualified. Constructing a single model that features multiple branches to allow experimentation with different processing strategies (with each option switched on or off with variables in the external scenario definition file) demands additional development effort at first, but greatly simplifies subsequent experimentation and verification, as described in Farr et al [4].

Within the model a simplified product was presented. It consisted of just four composite components, but any of these could represent a whole class of parts found within real manufactured products. Details that were defined included the rate at which each component accumulated wear and when it was likely to fail as a result, whether it was susceptible to accidental damage, and if a remanufacturing process could be used to restore a part-worn component to as-new condition.

For the purposes of this paper, an experiment was performed with the following fictional components defined:

- Component 1 was a motor casing. It could be accidentally damaged (a 0.5% chance each month), causing the product to reach EOL. Occasional quality problems (1% of all products supplied) caused customers to reject the product immediately upon receipt.
- Component 2 was a motor shaft. It was very sturdy, and not subject to significant wear. As such it was an ideal candidate for reuse.
- Component 3 represented the motor windings and brushes. This composite part had a design life of 48 months, although individual usage patterns were subject to some variation. A part-worn motor that came back to the manufacturer would be remanufactured if it had accumulated more than 6 months' usage. Like Component 1, this part was subject to some quality problems, at 0.6% of all products supplied.
- Component 4 was a special case, being the product's packaging. Since our notional product was mostly supplied to trade customers, we specified that there

was a 75% chance of the packaging being returned after delivery. In a general retail context this percentage would most likely have been zero.

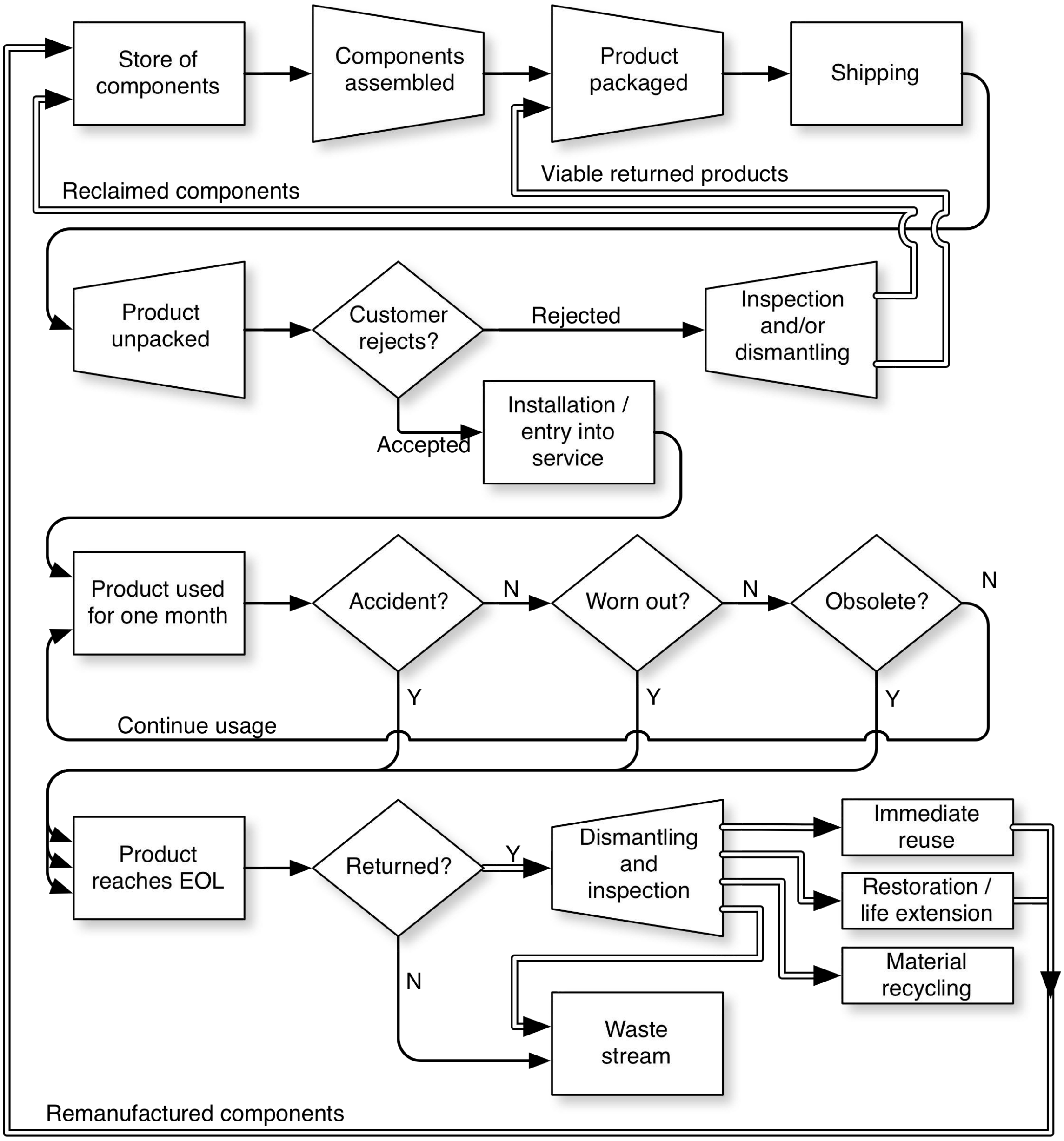

Figure 1: Basic architecture of the remanufacturing simulation

We further specified a pattern of orders for the product, ramping up steadily to a peak rate of 70 products per month, remaining steady for five years and then declining, to settle at a much lower ‘legacy support’ level of five products per month. In terms of the usage pattern, customers were said to use the product steadily and keep it for at least 30 months, but thereafter there was a 10% chance of their choosing to retire the product each month. We also stipulated a 66% probability that any given EOL product would be returned.

All these things could be adjusted by alterations to the scenario definition spreadsheet, the only limit being that we could not model the production of *thousands* of products per month. In simulation terms, each product is a *temporary assembly* of three or four components, and unlike a manufacturing simulation our products do not leave the model once they are delivered; instead they cycle repeatedly around a pattern of usage every month, until they fail or are otherwise disposed of. The computational overhead for numerous, long-lived products simulated in this way can be prohibitive, but we can still obtain indicative results over multiple replications with a reduced set where each product represents a hundred or more real-world equivalents.

Results

The model was run with the parameters presented above, to produce a sample that showed one kind of information that we could obtain from the model. Figure 2 illustrates the results obtained:

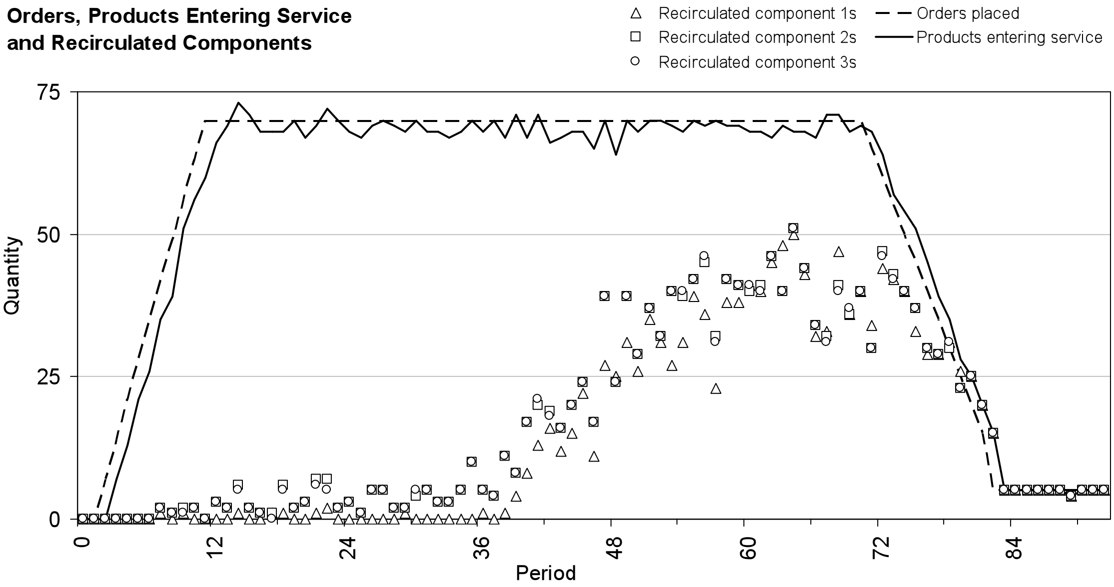

Figure 2: Orders filled and the proportion of recirculated components within them

Here we see how very little remanufacturing is possible at first, as there are few products being returned to the manufacturer. There are only three causes of remanufacturing work in the early stages of a model run, namely:

- Products that were supplied with faulty components, and which can be repaired and sent out again (subject to it being practical to collect the faulty goods),
- Products that have been accidentally damaged, and which are returned to the manufacturer as EOL goods (subject to their containing usable parts), and
- Viable new products that were rejected by the customer (e.g. during a 'cooling off period') but which were received in a questionable condition that demands minor reconditioning before they can be sent out again.

As the model run progresses we can see that the volume of Components 2 and 3 being recirculated increases gradually, while the recirculation rate for Component 1s is virtually flat for the first three years of the simulation. This is because casings have been defined as vulnerable to accidental damage, and accidents are the primary cause for goods reaching EOL until product retirements begin to be seen.

An increase in the accident rate is caused by the steadily increasing size of the installed base for the product, which means more chances of products being accidentally damaged each month. Once each product has been in service for 30 months, it becomes subject to a chance of being retired by its owner. In any event, its design life means it is likely to wear out after approximately 48 months of use, and all kinds of EOL products have been assigned a 66% chance of being returned to the manufacturer. Due to these product retirements, we see a strong increase in the proportion of components being recirculated, beginning in Month 36 or so. From then onwards, recirculated and remanufactured content plays a much more significant role in the company operations, with the proportion of recirculated components approaching the 66% ceiling that our returns rate implies.

At the end of the simulation, as demand falls away we reach a point where recirculated components account for all new goods supplied. In reality the remanufacturer is unlikely to store large quantities of EOL goods simply to provide components for the low-level demands of the legacy phase. Instead many of the later-arriving EOL products would be recycled at best, but no stockpiling constraint for EOL material exists within our model.

Discussion

The amount of remanufacturing that can be done is clearly limited by circumstances that may be beyond the manufacturer's control. Some promising business models exist that can increase the likelihood of the EOL goods being returned in a timely manner, such as leasing arrangements of the kinds described by Baines et al [5], or highly servitized offerings (for example, Rose et al [6] reported Kodak's recycling and/or recirculation rate for single-use cameras to be 92% by weight, but obviously a customer *must* return the camera in order to benefit from their time of ownership). Through parameters defining the timing and variability of product retirements, plus the chance of a product finding its way to the right place for remanufacture, we have provided a means to explore such scenarios.

Geyer et al [7] identified two key constraints that cause the quantity of remarketable product returns to appear as a trapezoidal subset within a plot of all activity, with the size of this trapezoid being constrained horizontally by the inevitable delay before EOL goods begin to arrive, and vertically by the proportion of products that are unfit for reuse. Our results confirm this, with Figure 2 showing just such a trapezoid at the component level.

The experiment presented in this paper illustrates the potential of remanufacturing to make a partial contribution towards a future 'closed loop' system of the kind described by Kerr and Ryan [8], increasing the eco-efficiency of the overall system, but clearly some problems remain. Even with an optimistic 66% probability for EOL goods being returned and a long overall life cycle for the product type (almost six years of volume production) the best-performing component in our system (Component 2, measured in terms of recirculated components as a proportion of all components used) was only a recirculated part in 33% of all cases. This is caused by the unavailability of EOL goods early on. We could experiment with alternative strategies via model parameters, such as compulsory product return after a fixed term (ie a leasing arrangement) or perhaps a buyback scheme where the rate for EOL goods return is improved, at a financial cost. Equally, if the product continued to be sold for a longer period, the overall proportion of recirculated content would increase, but in a competitive world of shortening product redesign cycles remanufacturing may be increasingly disadvantaged. It is to be hoped that future products can be redesigned in such a way as to continue to make use of common components across several generations, such that a late surge in the arrival of EOL goods yields components that are still of use to the remanufacturer. (Ongoing work with our model explores the impact of a successor product type that has one or more components in common with its predecessor.)

Even where designers are sympathetic to the needs of the remanufacturer, however, our model shows a significant problem in the planning of operations. Not only must the level of remanufacturing activity be ramped up to match the occurrence of retirements or failures, but this needs to be accompanied by a scaling back in the production of new-built components, which may cause further disruption in terms of its effect upon established batch sizes and economic order quantities. We expect remanufacturing to be somewhat more demanding than the creation of all-new products, due to the unpredictable condition of products when they are returned, but its further effect upon conventional manufacturing activity may not have been anticipated. Our model shows just how much variability a remanufacturer (or an OEM considering the introduction of remanufacturing) can expect to encounter. While it does not propose solutions, it allows the level of remanufacturing activity to be anticipated over time, such that the capacity implications may be addressed.

Conclusions

This paper has shown how a parametric simulation can be employed to explore the consequences of demand patterns, component life expectancies, product return rates at EOL and strategic remanufacturing decisions such as the level of residual life that is tolerated. Driving a single, flexible model via a simple interface presented in a well-known tool (Microsoft Excel) allows the representation of some very different product and service offerings.

The experimental results reported suggest that even where the expertise and investments necessary to facilitate remanufacturing are in place, the activity is only likely to occur at significant levels where a product or at least some of its components enjoy a period of sustained demand that substantially exceeds the life of a single product, allowing time for products to reach EOL, for their components to undergo remanufacturing, and to be of use once again.

References

1. Guide, V.D.R. (2000) Production planning and control for remanufacturing: industry practice and research needs, Journal of Operations Management, Volume 18, Number 4, June 2000, pp. 467–483
2. Sutherland, J.W., Adler, D.P., Haarpala, K.R. and Kumar, V. (2008) A comparison of manufacturing and remanufacturing energy intensities with application to diesel engine production, CIRP Annals - Manufacturing Technology 57 (2008) pp. 5–8
3. Ijomah, W., Bennett, J. and Pearch, J.(1999) Remanufacturing: evidence of environmentally conscious business practice in the UK, in Proceedings of the IEEE International Symposium on Environmentally Conscious Design and Inverse Manufacturing. IEEE, February 1999
4. Farr, R., Tannock, J. and Almgren, T. (2008) A Parametric Approach to Logistic Control Within Manufacturing Simulation, International Journal of Industrial & Systems Engineering, Vol. 5, No. 3, 2010, pp. 313–326
5. Baines, T. S., Lightfoot, H. W. Evans, S. et al (2007) State-of-the-art in product-service systems, in Proceedings of the I MECH E Part B: Journal of Engineering Manufacture, 221(10): pp. 1543–1551
6. Rose, C.M., Masui, K. and Ishii, K. (1998) How Product Characteristics Determine End-of-Life Strategies, Proc. IEEE International Symposium for Electronics and the Environment Conference, Oak Brook, Illinois, May 1998, pp. 322–327
7. Geyer, R., Van Wassenhove, L.N. and Atasu, A. (2007) The Economics of Remanufacturing Under Limited Component Durability and Finite Product Life Cycles, Management Science, 53(1), pp. 88–100
8. Kerr, W. and Ryan, C. (2001) Eco-efficiency gains from remanufacturing: A case study of photocopier remanufacturing at Fuji Xerox Australia, Journal of Cleaner Production, 9, pp. 75–81