

Revenue management in remanufacturing; key considerations for a firm and future research directions

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Abstract

Remanufacturing is coming up in a big way as an answer to the questions related to sustainable development on one hand and increasing profitability for firms on the other. However, firms are struggling to cope up with challenges that this nascent area is throwing up and there is a need to address these problems from a revenue management perspective. We assess the current literature and summarize the key points that firms need to consider as they assimilate remanufacturing in their operations strategy. We also provide the direction for future research with an assessment of white spaces in this area.

Keywords: Remanufacturing, Revenue management

Introduction

Environmental sustainability efforts have focused around the mantra of “Reduce, Reuse and Recycle” for reducing consumer waste. Amongst these options, “Reuse” entails refurbishing, remanufacturing and parts recovery from used products and there is an increasing amount of legislation to support this from an environmental impact perspective. Some examples include: universal waste regulations act, enacted by New Jersey in 2002 and the European Union directive on waste electrical and electronic equipment (WEEE) act 2005 (Webster and Mitra (2007)). But it is not just legislation which is encouraging firms to engage in remanufacturing operations. Plain economic considerations are also driving up such activities. In this paper, we refer to refurbishing, remanufacturing and parts recovery under the broad umbrella of remanufacturing. Remanufacturing of used hi-tech and consumer durable products is less costly as compared to manufacturing of new products by 40-60% (Mitra et al. 2007) including cost of materials, power etc. It helps to create a segment of customers who opt for remanufactured products which have comparatively lower costs but similar features like new products. Thus it can help increase market shares and increase revenues as well apart from reduction in cost.

Thus now firms are looking at remanufacturing as a profitable option and not just as a legislative compulsion. Hence they need to look at revenue management from both new and remanufactured products. There are multiple problems and issues when one deals with revenue management of remanufactured products and researchers have tried to address them through their work over the last 10-15 years.

Remanufacturing supply chain

Remanufacturing activity is a part of the reverse logistics operations of a company. This can be done either by standalone third party firms which deal with remanufacturing or the OEM. (There are third party companies who remanufacture ink printer cartridges and sell it in the market. (Agrawal et al. 2012) This can also be done by the OEMs (Original equipment manufacturers)) who had manufactured the new products in the first place e.g. Hewlett Packard remanufactures the servers it leases to companies. A typical remanufacturing supply chain includes the activities related to collection of used products, transportation to a remanufacturing facility, quality inspection or sorting, inventory management of used products and remanufactured products and production planning and scheduling of used products. A typical remanufacturing closed loop supply chain is as shown in figure 1. The process starts with a stage to collect used products. The used products are transported to a sorting facility where based on its quality, it is determined whether the product should be remanufactured, dismantled for parts, or scrapped. The products which are worth remanufacturing are processed at a remanufacturing plant and the finished remanufactured products are added to the inventory used to satisfy market demand.

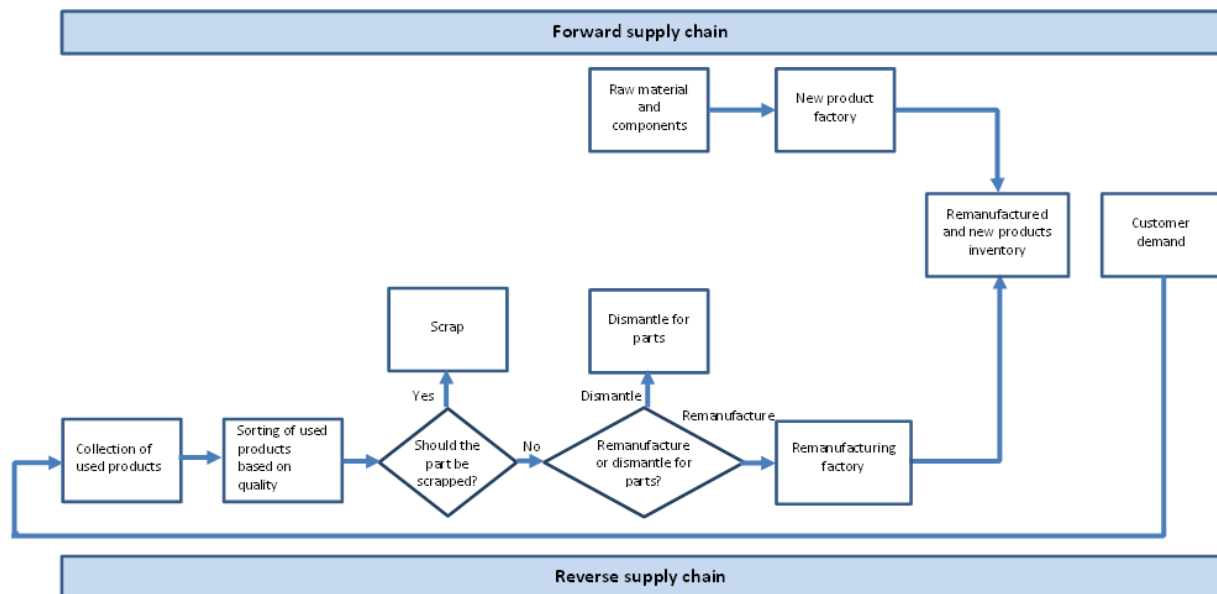


Figure 1- Illustration of the typical remanufacturing supply chain

Problems studied in this context

There are multiple issues that have been dealt with in the research on revenue management in remanufacturing. Product related issues have been outlined in table 1. As can be seen in the table, the number of factors that can affect revenue management of remanufacturing is really lengthy and although we have tried to give an overview on many of them here, we do not claim that this is exhaustive. These issues and factors have been discussed in detail below. In this section we deal with product related issues affecting revenue management of remanufactured products that have been dealt with in the research so far. Details of these are summarized in table 2 and 3. Table 2 gives the product related issues affecting revenue management for remanufactured products and table 3 gives the product pricing related issues.

Table 1 - Elements of revenue management in remanufacturing

Remanufactured only or both new & remanufactured	Consumer behavior
Waste-stream/ market driven used product acquisition	Remanufacturing of only parts versus full products
Quality of incoming used products	Lifecycle issues
Pricing of finished new and remanufactured products	Remanufacturing with and without part upgrades
Demand cannibalization	

What to manufacture? Remanufactured products only or both new and remanufactured products

This issue impacts not only the way cost allocations are done in the supply chain but also impacts trade-offs made by managements between the forward and reverse supply chains. For e.g. if only remanufactured products are considered then the cost of acquired used products is assumed to be zero except the acquisition costs. This is not the case if both new and remanufactured products are considered wherein the initial cost of the material can be assumed to be absorbed by both new and remanufactured products and the optimal decisions are different in such a case. There is also an interesting twist to this when some firms consider both new and remanufactured products to be the same e.g. single use cameras and here there is no need to consider demand cannibalization between new and remanufactured products which is so important in case both of them are considered different products being served to same set of customers.

We find that the current literature in this area addresses issues by considering either remanufacturing products only (Govindan and Popiuc 2014, Mitra 2007, Yu et al. 2012) or by considering both new and remanufacturing products at the same time (Cardoso et al. 2013, Ferguson et al. 2008, Ovchinnikov 2011). We also find that in some papers, authors have considered both the new and remanufactured product to be the same in the eyes of the customers (Qiaolunn et al. 2008, Robotis et al. 2012). Examples of this are leasing of photocopy machines by Xerox, servers by IBM, HP etc. and manufacturing equipment by Caterpillar.

Waste-stream or market driven used product acquisition

A remanufacturing firm needs to acquire used products either from the waste stream process or by incentivizing users to return them for a fee. This gives the firm more control on the quantity and quality of the used products or cores. Both quality and quantity of used products play an important part in influencing the overall profit maximization from remanufacturing business. More specifically, they impact the cost as well as the service level of the customer demand fulfilled by the remanufactured products. Used products generally come into a remanufacturing setup through two methods:

- “waste-stream” method where there is no incentive provided by the remanufacturer to the owners of used products (Chen and Chang 2013, Inderfurth et al. 2001, Robotis et al. 2005).
- “Market-driven” method where the remanufacturer pays a price for the used products (Bulmus et al. 2014, Kwak and Kim 2013, Zhou and Yu 2011).

In the context of the market driven acquisition of used products it is important to determine what price the remanufacturer should pay for the used products. Also in both the waste-stream and market driven acquisitions, another important question is related to how many of these products should be acquired?

Quality of incoming used products

The used products that are acquired need not be of the same quality. This impacts the cost associated with remanufacturing and is very critical for revenue management of these products.

Most of the firms segregate the used products into multiple core classes. For e.g. product returns from retailers which are simply due to wrong shipments have nothing wrong on the product side and can be sold as it is in the market. Those products which have some aesthetic problem like a scratch etc. require very little time and cost to bring them up to the resalable product type. There can be products which are very difficult to remanufacture due to very poor quality level and cost associated here is also very high. Also the yield of either the parts or even the finished goods from used products depends on the quality of the incoming products and some of the papers deal with this issue.

There are papers in which all the used products have been assumed to be of the same quality (Ferrer and Swaminathan 2010, Vorasayan and Ryan 2006, Wu 2013), but there are other papers where they have been considered to belong to multiple quality levels (Galbreth and Blackburn 2010, Mitra 2007, Ovchinnikov 2011).

Table 2 - Product related issues affecting revenue management in remanufacturing

Product type	Waste stream/ Market driven acquisition	Different quality of incoming used products?	References
Both remanufactured and new products	Waste stream	No	Agrawal et al. (2012), Akan et al. (2013), Atasu et al. (2008), Bhattacharya et al. (2006), Cardoso et al. (2013), Chen and Chang (2013), Debo et al. (2006), Ferguson and Totkay (2006), Ferguson et al. (2008), Ferrer and Swaminathan (2010), Inderfurth (2004), Kim (2013), Majumder and Groenevelt (2001), Ovchinnikov (2012), Totkay and Wei (2011), Vorasayan and Ryan (2006), Wang et al. (2011), Webster and Mitra (2007), Wu (2012), Wu (2013)
		Yes, multiple quality levels	Aras et al. (2006), Debo et al. (2005), Ferrer and Swaminathan (2006), Mukhopadhyay and Ma (2009), Ovchinnikov (2011), Robotis et al. (2012)
	Market driven	No	Bulmus et al. (2014), Heese et al. (2005), Kaya (2010), Savaskan et al. (2004)
		Yes, multiple quality levels	Li et al. (2013), Ray et al. (2005), Saadany and Jaber (2010)
Both remanufactured and new products are the same	Waste stream	No	Robotis et al. (2012)
	Market driven	No	Qiaolun et al. (2008), Zhou and Yu (2011)
Only remanufactured product	Waste stream	No	Inderfurth et al. (2001), Zeng (2013)
		Yes, multiple quality levels	Ferguson et al. (2009), Galbreth and Blackburn (2010), Guide et al. (2005), Mitra (2007), Robotis et al. (2005), Souza et al. (2002), Teunter and Flapper (2011), Vadde et al. (2011), Yu et al. (2012), Zikopoulos and Tagaras (2007)
	Market driven	No	Bakal and Akcali (2006), Govindan and Popiuc (2014), Liang et al. (2009)
		Yes, multiple quality levels	Galbreth and Blackburn (2006), Guide et al. (2003), Kwak and Kim (2013), Seidi and Kimiagari (2011)

Pricing of finished new and remanufactured products

The pricing of end products (both new and remanufactured) have a direct impact on the demand for these products and also the different price levels create different segments of customers. This is very important aspect of managing revenues when both new and remanufactured products are involved. New products can be priced higher and profits can be maximized from them from customers who are willing to pay more and perceive the higher priced new products as having better quality. Similarly, the remanufactured products when priced lower will be able to capture

demand from customers who are not willing to pay the price for a new product but still want to get the higher utility from the remanufactured versions of these products.

Some papers where this aspect is dealt with are Debo et al. (2006), Ferrer and Swaminathan (2010) and Vorasayan and Ryan (2006). What should be the optimal prices of either the finished new or remanufactured products? Some of the other issues impacting the pricing of end products (new and remanufactured) are demand cannibalization between them and consumer behavior towards new and remanufactured products. These are dealt with in the sections below. The summary of the pricing related issues is provided in table 3.

Table 3 - Product pricing related issues affecting revenue management in remanufacturing

Pricing of finished products	Lifecycle issues	Demand cannibalization	Consumer behavior	References
No	No	No	Not considered	Aras et al. (2006), Bhattacharya et al. (2006), Galbreth and Blackburn (2006), Galbreth and Blackburn (2010), Inderfurth (2004), Inderfurth et al. (2001), Kim (2013), Li et al. (2013), Liang et al. (2009), Robotis et al. (2005), Saadany and Jaber (2010), Teunter and Flapper (2011), Zeng (2013)
			WTP based	Totkay and Wei (2011)
		Yes	Not considered	Ferguson et al. (2008)
			Inverted U-shape	Ovchinnikov (2011)
			WTP based	Agrawal et al. (2012)
	Yes	No	Not considered	Wang et al. (2011)
Yes, multiple price points	No	No	Not considered	Bakal and Akcali (2006), Kaya (2010), Mitra (2007), Ray et al. (2005), Seidi and Kimiagari(2011), Yu et al. (2012)
			WTP based	Bulmus et al. (2014), Debo et al. (2005), Ferrer and Swaminathan (2006), Heese et al. (2005), Vadde et al. (2011), Wu (2012), Wu (2013)
		Yes	WTP based	Ferguson and Totkay (2006), Robotis et al. (2012)
	Yes	No	Not considered	Guide et al. (2005)
			WTP based	Webster and Mitra (2007)
Yes, single price for new and remanufactured product	No	Yes	WTP based	Akan et al. (2013), Chen and Chang (2013)
			WTP based	Savaskan et al. (2004)
			Not considered	Ferrer and Swaminathan (2010)
	Yes	Yes	Inverted U-shape	Ovchinnikov (2012)
			WTP based	Vorasayan and Ryan (2006)
Yes, pricing for remanufactured products only	No	No	Not considered	Debo et al. (2006)
			WTP based	Atasu et al. (2008)
Yes, single price for the end product	No	No	Not considered	Kwak and Kim (2013)
			WTP based	Ferguson et al. (2009), Mukhopadhyay and Ma (2009), Qiaolunn et al. (2008), Souza et al. (2002), Zhou and Yu (2011), Zikopoulos and Tagaras (2007)
	Yes	No	WTP based	Govindan and Popiuc (2014), Guide et al. (2003), Majumder and Groenevelt (2001)
			Not considered	Cardoso et al. (2013)
			WTP based	Robotis et al. (2012)

Demand cannibalization

Demand cannibalization between new and remanufactured products leads to reduction in demand for new products when the demand for remanufactured products increases. This has an impact on the revenue from new products and also the overall revenues. Also, the pricing of new products determines the extent of demand cannibalization from remanufactured products and vice-versa. Hence it is important to consider this angle while determining the prices for end products and managing overall revenues.

The existence of cheaper remanufactured products with almost similar configurations as a new product; impact the demand for new products. Similarly the new products also impact the demand for remanufactured products as the quality conscious consumers who perceive the new products to be of better quality opt for them. This demand cannibalization has been studied by authors like Debo et al. (2006), Chen and Chang (2013), Ovchinnikov (2011), Vorasayan and Ryan (2006) etc.

Consumer behavior

Consumer behavior towards new and remanufactured products is different, given their perception about the quality of these products being different. This impacts the demand for these products and hence the pricing of the end products needs to be based on the demand for them. Hence it is important to study consumer behavior related issues while dealing with pricing of the new and remanufactured products.

Most of the authors have assumed Willingness-to-pay (WTP) based consumer demand behavior. (Agrawal et al. 2012, Ferrer and Swaminathan 2006, Totkay and Wei 2011, Vorasayan and Ryan 2006). This means that as the price for new or remanufactured product increases, the demand for it decreases and vice-versa. Ovchinnikov (2011) has made a study of the consumer behavior for remanufactured products and found that it is Inverted U-shaped and not WTP based. This study was conducted by them to test the assumption of WTP based customer demand. They found that the number of customers switching from new to remanufactured products first increased, then decreased and then again increased as the amount of discount offered on remanufactured products increased.

Remanufacturing of only parts versus full products

Revenue management of remanufactured products deals in both full product remanufacturing as well as salvaging the parts within the used products and generating revenues from them. Thus it is important to incorporate this issue while dealing with revenue management aspects for these products.

In the automotive industry, end of life vehicles (ELV) are used to procure the parts which are still in useful condition like engines, gear box etc. Thus in the remanufacturing businesses, papers have addressed problems where only the parts are remanufactured (Bakal and Akcali 2006), full products are remanufactured and also there are papers where both parts as well as full products are remanufactured (Ferguson et al. 2008).

Lifecycle issues

When we have both the new and the remanufactured products in the market at the same time, both of them impact the lifecycle of the product. Both new and remanufactured products have their individual lifecycle characteristics and if they are in the same market, then they influence the demand based on their lifecycle stage. Example, if remanufactured products are introduced

early in the lifecycle of a new product, then the cheap variant of the new product can dampen the overall demand for the new product. Also whether the lifecycle of the product is short or long has an effect on the supply of used products. Example, if the lifecycle of the new product is short, there will only be limited availability of used new products in the market. The prices of new and remanufactured products can also be influenced by their lifecycles. Example, for a short lifecycle new product, since the supply of used products would be limited as explained before; the price charged for the remanufactured product can be higher. Thus it is important to incorporate lifecycle aspects while dealing with revenue management aspects for these products. There are papers that consider this important aspect (Chen and Chang 2013, Debo et al. 2006, Robotis et al. 2012) whereas there are other papers where this aspect has been left out of the analysis.

Remanufacturing with and without part upgrades

Although in most of the remanufacturing literature, the underlying assumption is that the used products are brought back to their original specification by remanufacturing, there are also cases where the parts of the used products are upgraded so that they may not become obsolete in the market against the existing new products. Example of this is the Desktop market in the personal computer business. A desktop PC can be remanufactured to its original processor speed level but the original processor may have already become obsolete and hence may not generate any demand in the market. Hence, the desktop can be remanufactured with an upgrade in the processor speed which can increase the chances for its sale. This has a lot of impact on the demand for new products as it reduces the cannibalization between new and remanufactured products. This is because in case there is no part upgrades, then the only difference between new and remanufactured product is the price difference, since the specification is almost the same. However if there is a part upgrade for remanufactured product, then it is as good as new in product specifications or better. There is a paper that deals with this topic and incorporates it in its analysis (Kwak and Kim 2013).

Discussion

Existing problem configurations and research gaps

The current literature on this topic has been mapped in the tree shown in figure 2. The paths which are marked out in dark cells indicate the spaces where work has already been done. The cells which are not colored are the white spaces or research gaps where work has not yet been done. As can be seen, there are still multiple research gaps that provide ample opportunity for future work in this area. The research gaps can be summarized as below:

Combinations of problems with demand cannibalization and lifecycle issues are not covered well. Lifecycle issues in general do not seem to have been studied that well in the context of remanufacturable products especially where a firm deals in both new and remanufactured products and has to deal with separate lifecycles for both new and remanufactured products. Problems with multiple quality levels of incoming used products do not seem to have been studied well. Multiple quality levels can have a big impact on the final supply of remanufacturable products and hence the revenue management for these products.

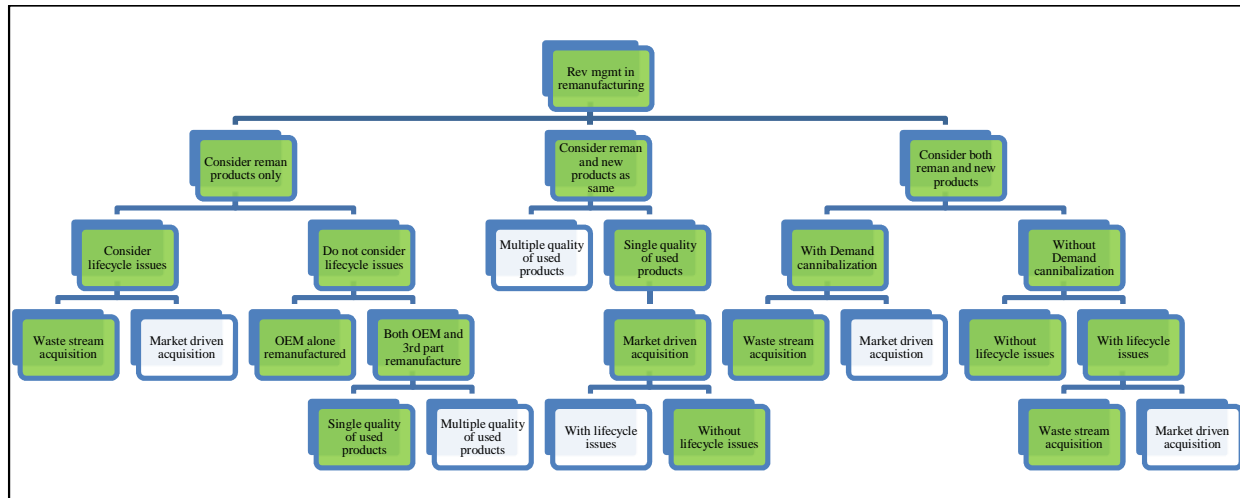


Figure 2 - An illustrative tree of the various research gaps based on the current literature review

Concluding remarks and futures research directions

Remanufacturing as an area is fast becoming an important field as more legislations come in to support it on one hand, and on the other, the sheer economic imperatives make it an absolute necessity. However, when a firm indulges in remanufacturing, revenue management becomes very important as there is cut throat competition in the manufacturing sector and especially in the consumer goods or hi-tech industry segments. Our paper summarizes the key product related factors that firms need to look into while dealing with remanufactured products from a revenue management perspective. We also establish the current research gaps in this upcoming area and find that more study needs to be done on market driven product acquisitions, lifecycle issues and topics with multiple quality levels of incoming used products. These also construe the areas in which future research can be done in this field.

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