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The Impact of Product Variety on Closed-Loop Supply Chains: An Automotive Perspective

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Abstract

Remanufacturing is not new to the automotive industry, neither is it to the academic debate of product take-back. However, there is limited empirical research on business aspects of closing the loop in the automotive sector. Since academic research has largely focused on theoretical models and problem solving, the underlying research has taken a business-oriented perspective on remanufacturing in the automotive sector.

The article is based on extensive case study research with regard to car engine and electronic component remanufacturing. It identifies issues within the management of these recovery processes. Thus, the research provides an empirical account for further quantitative work in the area and complements as well as extends existing theoretical research.

Since the management of remanufacturing operations is significantly different from managing ‘conventional’ manufacturing, the underlying research demonstrates these differences and identifies sources that inhibit the creation of successful product recovery in the automotive sector. A particular emphasis will be put on the impacts of mass
customisation on the automotive remanufacturing sector. Mass customisation is characterised by the manufacturing of individualised products for individual customers at mass prices. However, this strategy contains two conflicting aims. On the one hand, designers create product platforms, which are applied to facilitate the manufacturing process and aim at broadening the application of the product. On the other hand, there is the need for product differentiation in order to address individual customers. The article shows how remanufacturing needs to address these two contrary aspects.
Introduction

The academic field of product take-back and recovery embraces a variety of aspects. Many contributors focus on the take-back process (reverse logistics), for example De Brito and Dekker, (2002) as well as Fleischmann et al. (1997). Others investigate individual recovery operations, such as recycling (e.g. Wiedemann, 2001; Moyer, and Gupta, 1997) or remanufacturing (e.g. Ferrer, 1997; Guide, 2000; Lund, 1996). Despite increasing publications in the area, few publications take a holistic view. Tibben-Lembke and Rogers (2002), for example, outline the differences between ‘forward’ and reverse logistics. Guide (2000), on the other hand, defines the seven complicating characteristics of recoverable manufacturing systems. However, there is still the need for an all-embracing view, which considers empirical research (problem identification), a review of appropriate approaches to problem-solving and the improvement or elimination of real-world issues. Guide et al. (1999) argue that one of the major weaknesses of previous research on remanufacturing is that there are insufficient contributions which present industry practices in case studies or surveys. Moreover, “future research must be grounded with industrial data to ensure that it is relevant to actual concerns” Guide et al. (1999, p.229).

Hence, this article considers two aspects of remanufacturing. On the one hand, it seeks to identify real-world challenges within automotive remanufacturing. Moreover, it will ask for appropriate tools and techniques in order to solve these problems. The research focuses on the automotive remanufacturing sector. It aims at outlining issues and obstacles observed within case study research. The results demonstrate which issues are found within passenger car engine remanufacturing and the sources of these obstacles are identified. The paper therefore portrays the differences and similarities
between manufacturing and remanufacturing. The question will be asked if tools and techniques applied in ‘conventional’ research on manufacturing operations may be suitable for automotive remanufacturing.

The paper shows that there are certain characteristics of remanufacturing operations which would indicate that current tools utilised for the improvement of manufacturing operations, which focus on ensuring steady volumes and some variety, are unsuitable for automotive remanufacturing. A particular role plays the need for mass customisation within the car industry. Mass customisation is characterised by the manufacturing of individualised products for individual customers at mass prices. Pine (1993) further specifies the term mass customisation as the supply of products at such variety that customers are able to find the exact product they are looking for and at a price they can afford.

**Methodology**

The underlying paper is based on research carried out in conjunction with a doctoral thesis. Overall, the research has taken a case-study approach. In the course of two years, more than one hundred and thirty interviews were conducted within the facilities of OEM (Original Equipment Manufacturer) remanufacturers, remanufacturers subcontracted to OEMs and independent remanufacturers. Interviews were semi-structured and structured and ranged in duration from twenty minutes to several hours. Interviewees came from all functional levels, including executives (centre manager; head of department), middle management (planners; administrators) and workers (assembly-line staff; warehouse operators). Interview data was
supplemented with (process) observation, business process mapping and secondary data gathering.

The insights presented here derive from detailed case study focusing on the engine remanufacturing operation of a major European vehicle manufacturer. Three levels of the case study’s supply chain were investigated, the remanufacturing plant, the main distribution centre and the company’s headquarters (administrative centre). Within the remanufacturing plant, the research focused on the analysis of operational processes, while research at the headquarters and the logistics centre considered the whole supply chain for recovered engines. However, most of the information presented in this article relates to observations which were made within the vehicle manufacturer’s remanufacturing facility.

**The Typical Automotive Engine Remanufacturing Process**

The typical engine remanufacturing process, as it is performed by the case company, is pictured below. The actual parts recovery consists of the following phases: the disassembly of the used engine, the so-called ‘core’, the cleaning of the parts, the identification and control of parts, the chemical cleaning, the quality control as well as the actual parts recovery. Afterwards, parts are either put on stock or directly re-assembled into a (remanufactured) engine.

Within the remanufacturing plant, engine disassembly takes place at ten single workstations. About 50 engines are dismantled every day. Disassembly may take up to three hours (in the case of complex V-engines), since some of the joinings are difficult to loosen. Moreover, engines are often rusty or oily, which complicates the disassembly process. There are a large number of engine variants, hence workers are
skilled in order to avoid damage to parts and components. According to Steinhilper (1998), disassembly is very challenging, because this process involves more than the reverse of conventional assembly processes. As a matter of fact, there are no simple reverse operations for gluing, pressing or welding. The disassembly process is carried out manually, even in relatively large remanufacturing plants, such as the plant observed within the underlying research. One of the reasons for that is the fact that experiments of automating disassembly processes remained unsuccessful. Although it is technically feasible a considerable amount of investment is required (Steinhilper, 1998). Feldman et al (1999) therefore claim that a large amount of these problems could be avoided by incorporating a ‘design for environment’ into the product.

The cleaning process is divided into two parts. Some components are cleaned with water and detergents. Others, like the cylinder head, undergo a deep chemical cleaning process, which usually incorporates the ‘soaking’ of the part in an acid bath. Thereafter follows the identification process, which is of significant importance. Parts and components are manually sorted by part numbers so that they can be stored appropriately.
The actual parts recovery takes place at single workstations or within machines and includes honing and lapping as well as machining processes. Most of the activities are carried out manually, which is also due to different wear patterns of individual parts. The recovery process of the cylinder block includes the replacement of the cylinder liners as well as the boring of cylinders. Within cylinder head recovery, valve seats are reworked and valve guides replaced. For other parts, like the crankshaft, remanufacturing includes machining of the main bearing as well as the big end bearing of the crankshaft. Furthermore, oil ways are re-bored and bearing points lapped. The final inspection with a pneumatic gauge ensures that bearing shells harmonise with the crankshaft.
After recovery, all parts, except for the cylinder block, are put on stock. They are re-assembled order-related. Cylinder blocks are fed into the re-assembly process directly. Re-assembly of the engines takes place at a short assembly line with about 16 main work cycles. These cycles strongly resemble those of conventional engine assembly (new engines) with the only distinction that one worker tends to spend up to 10 minutes for one process cycle. Workers are also responsible for pre-assembly of engine components, such as the pre-assembly of pistons and connecting rods.

After the re-assembly process, the remanufactured engines undergo a cold test. Within the cold test, the engine is not fired, but tested for leakage. In addition to the cold test, 20% of the highly demanded diesel engines are run and tested on a dynamometer (hot test). After the tests, the remanufactured engines are packed and shipped.

There are two aspects, which are essential to the understanding of an engine remanufacturing process. On the one hand, it has to be noted that engine cores are disassembled to parts level. Parts of one engine are not kept together. Instead, the remanufacturing output (re-assembled engine) could hypothetically consist of parts of several hundreds of engines, since the aggregate comprises around 500 different parts. Moreover, it is noteworthy that engine remanufacturing operations always take place in separate plants. In other words, remanufacturing does not take place within a manufacturing or assembly plant for new engines.

**Players in the Automotive Remanufacturing Sector**

An overview of players in the North American remanufacturing sector has been given for a variety of products by Lund (1984a, 1984b, 1996). However, this section
contributes to the understanding by presenting an industry-specific, European and historic point of view in order to meet the needs of the underlying research.

**OEM Remanufacturers**

According to Lund (1984b), OEM remanufacturers are original equipment manufacturers, whose focus is on the production of new parts, but remanufacturing is an added business (non-core business activity). Applied to the underlying research on automotive remanufacturing, an OEM remanufacturers may therefore be either a vehicle manufacturers or a first tier parts and components supplier. With regard to the size of the businesses, OEM remanufacturers tend to be larger in terms of sales and employment (Schwarck, 2003; Sherwood and Shu, 2000).

Independent remanufacturers on the other hand “tend to be small, usually operating on a hand to mouth basis competing in a complex and uncertain environment” (Ferrer, and Whybark, 2001, p.113).

It can be assumed that vehicle manufacturers, whose core competence has always been the manufacturing/assembly of new vehicles, have entered the market relatively late compared to independent remanufacturers. In 1984, Holzwasser (in Waters, 1984) reports that the remanufacturing industry needs the support of the OEMs in order to get more recognised and approved, however, vehicle manufacturers perceived the industry as ‘alien’, ‘threatening’ and ‘vaguely déclassé’. However, it can be claimed that the original manufacturers of parts and components may find remanufacturing comparatively easier, since they have access to design information. Independent remanufactures on the other hand, often need to ‘reverse engineer’ a product in order
to identify its design characteristics and to conclude necessary remanufacturing processes.

...the original equipment manufacturer has an advantage over the independent firm. The remanufacturing process is fairly easy for the OEM because it is responsible for the original vehicle design and its assembly. Access to data, such as dimensions, material, performance, and other specifications, removes the need to research the information. Many OEMs refuse to share this information with independents forcing them to do the research. Often costly and inefficient, some information may not even be obtained in this way.

(Schwartz, 1995, Past Chairman of the Automotive Parts Rebuilders Association (APRA))

Guide (2000) claims that in the United States, original equipment manufacturers remain largely disengaged and account for only 5% of the total industry. In the European automotive sector, however, car manufacturers possess a larger market share than US remanufacturers (Schwartz, 1995). This relatively higher share of OEM remanufacturers in Europe may be a result of the increase in European take-back laws, in which OEMS are responsible for product take-back, recovery and the coverage of all costs (Fleischmann et al., 2000).

Independent Remanufacturers

Lund (1984b) defines independent remanufacturers as those businesses, who solely focus on the remanufacturing of products produced by others. An independent
automotive remanufacturer may therefore be characterised as a remanufacturer who has no connection to the vehicle or the original manufacturer.

Sherwood and Shu (2000) have observed that OEM engine remanufacturing working practices differ from remanufacturing procedures undertaken by independents. Their research has shown that the priority of independent remanufacturers is the saving of a particular part, whereas OEMs tend to scrap parts that are uneconomical to repair or would take longer than average to be remanufactured. As a matter of fact, independent engine remanufacturers have developed special repair methods in order to utilise as many parts from a used product, the so-called core, as possible. This observation has been confirmed by Szuhy, who claims that within independent remanufacturing plants “only with great reluctance are pieces ever thrown out” (in Waters, 1984, no page given). Sherwood and Shu (2000) furthermore explain that lower scrap rates for independents are the result of a rather selective core-buying process. Where OEMs tend to take back all of their products, independents “are more selective about the pieces they buy and they avoid discarding parts” (p.89).

With regard to the re-assembly activities, products are generally produced in small batches. OEMs also have small batch sizes, but still larger than the independents. Szuhy (in Waters, 1984), who has expertise with OEM and independent remanufacturing explains that in an independent remanufacturing environment, a thirty minute batch is considered a ‘long run’.

However, independent remanufacturers depend on new parts to be included in the remanufacturing operation. In some cases, these parts are only available from the
original manufacturers or their OEM suppliers. This dependency can be critical with regard to delivery times or prices, hence, some independent players manufacture their own parts – frequently incorporating modifications of the original design so that it may fit several cars or upgrade existing technology (Waters, 1984). Moreover, a whole business sector has developed around remanufacturers, providing them with new parts such as cylinder liners, new pistons or bearing shells, since vehicle manufacturers have tried to exclude their independent competitors from access to (new) replacement parts.

Compared to the OEM remanufacturer who tends to mainly remanufacture products from the own brands, an independent remanufacturer selects whose parts they buy and remanufacture. Independent players therefore often provide a whole range of remanufactured brands. One of the largest independent players in the world, VEGE-Motoren in The Netherlands, for example, offers remanufactured engines, engine parts and gear boxes from 16 different brands (VEGE-Motoren B.V., 2002). According to Sherwood and Shu (2000), the throughput at independent outlets is only a few engines a day. This statement is true for the largest share of independent remanufacturers, but not for the biggest independent players which achieve sales and employment figures comparable to major OEM remanufacturers.

However, in many cases, independent players do not just undertake remanufacturing activities, but have extended their product range by related business activities, such as the production of new parts which are used within remanufacturing. Many of them also offer non-remanufacturing services to OEMs, such as testing or machining of new parts. However, as soon as they provide remanufacturing activities for other
parties, the independents may be rather classified as subcontracted remanufacturers (see section below).

**Remanufacturer Subcontracted to the OEM**

Within this research, a subcontracted remanufacturer is defined as a business contractually bound to an original equipment manufacturer. This may be a business which is solely providing services to vehicle manufacturers or an original equipment parts manufacturers. In most cases, however, subcontracted remanufacturers provide remanufacturing services for an OEM while remanufacturing for their own purposes as independent players. A major advantage of subcontracted remanufacturers is the access to specification sheets and design information which is provided by the OEM so that quality levels and product specifications can be met. “In some cases, the independent remanufacturer may be operating under a franchise from a major OEM such as Ford or GM’s Detroit Diesel/Allision Division, in which case technical assistance and parts are available from the OEM” (Lund, 1984b, p.12). However, not just technical specification sheets but also equipment and machinery is provided by the OEM. Mostly, this machinery comprises the outdated equipment from the original production line.

**Differences between Manufacturing and Remanufacturing**

This article solely focuses on OEM engine remanufacturing, which is undertaken by a vehicle manufacturer. Several of the above characteristics for OEM remanufacturers could be confirmed within the underlying research. The remanufacturing plant is a comparatively large with between 350 and 400 employees. The annual output of remanufactured engines around 13,000 and the vehicle manufacturer performs this
activity in a separate plant. As a matter of fact, the case company may have facilitated access to specification sheets and design information from its original production of new engines. However, the processes in plant still cannot bypass characteristics, which are typical for automotive remanufacturing. As has been outlined in the section describing the engine remanufacturing process, many process steps are carried out manually. Amezquita and Bras (1996) confirm that most automotive remanufacturing operations resemble craft production systems. This section therefore outlines typical issues observed within the automotive engine remanufacturing plant.

**Product Diversity and its Impact on Parts Recovery and Inventory Levels**

Wolff (2000) explains that nowadays, 80% of all cars are customer specified. As an example, each car model can be painted in 25 standard colour and 300 customer specified colours. He furthermore argues that customer specified mass production and the historic evolution of production structures are the main contributors for complexity. Many vehicle manufacturers, particularly those of luxury cars, experience a ‘model explosion’, which not only refers to the increase of car models. Satisfying customer demand by offering personal customization of mass products has lead to an explosion of variants within car parts and accessories, but also with regard to engines. Each car model is available with a variety of engine specifications regarding horsepower or fuel type, which creates and increasing number of variants. As the underlying research will show, the necessary service for the customer within the battle for new car sales, transfers the complexity onto the remanufacturing sector.

The following table shows how the worldwide engine variety has developed over time. The source of the data does not capture minor rating variants and also generalises by subsuming engines with the same power and the same ‘kit’ (parts,
which are needed to fit the engine into a vehicle, e.g. alternator, exhaust manifold or starter motor) hence the true picture is much more dramatic. The table shows that between 1980 and 2003, the number of (new) engines produced world-wide has increased by nearly eight times. The volume of engines has expanded from an annual output of over 12 million in 1980 to an estimate of over 54 million by the end of 2003. In the same period of time, however, the output per engine model has dramatically decreased from an average of 76,000 (1980) to just 42,000 engines per model in 2003.

<table>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine Models</td>
<td>163</td>
<td>790</td>
<td>865</td>
<td>1,095</td>
<td>1,281</td>
</tr>
<tr>
<td>Volume</td>
<td>12,413,351</td>
<td>39,199,466</td>
<td>40,648,374</td>
<td>48,960,172</td>
<td>54,441,178</td>
</tr>
<tr>
<td>Volume/Model</td>
<td>76,156</td>
<td>49,620</td>
<td>46,992</td>
<td>44,712</td>
<td>42,499</td>
</tr>
</tbody>
</table>

Table 1: Engine production over the years world-wide for cars, minivans and sport utility vehicles (source: Power Systems Research, Brussels, Belgium)

Within the underlying research, product diversity (variation) has been identified as one of the main barriers to the establishment of a successful remanufacturing operation. Wells and Nieuwenhuis (2000) explain that mass manufacturing is characterised by the making of identical products in large numbers. However, remanufacturers deal with two types of product diversity. On the one hand, the quality of returned engines may range from ‘hardly any damage’ to ‘practically unusable’. On the other hand, a remanufacturer recovers engines from a large number of models and from many engine generations. Some of the engines may return after decades. Hence, these two types of product diversity have impacts on the inventory management as well as the recovery operation. This section firstly explains why and how product diversity is an obstacle within remanufacturing and secondly demonstrates how current industry practice tries to manage the issue.
As a matter of fact, ‘parts proliferation’, as it is often called, impedes the remanufacturing process. Parts proliferation is hereby defined as the making of “many variations of the same product – differing only in one or two minor areas. However, these differences (such as electrical connectors) are distinct enough to prevent interchanging similar products” (Amezquita and Bras, 1996, p.36).

Within a typical (new) engine manufacturing process, the manufacturing of different engine variants can be managed by producing one family of engines with the same core block, crankshaft and cylinder head in order to put the engine family through the same machining lines. Hence, the aim is to design one engine platform which may be transformed into as many engine variants as possible, in order to facilitate manufacturing.

However, within remanufacturing, product diversity is multiplied. Due to large product diversity, low batch sizes were observed at the case company’s remanufacturing plant. Amezquita and Bras (1996) confirm that current remanufacturing processes are heavily batch oriented. Due to low remanufacturing volumes and high product variety, current remanufacturing practice resembles a craft production system. The underlying research has confirmed that although Amezquita and Bras’ research was undertaken in 1996, craft production is still common practice.

Most automotive parts remanufacturers (and other remanufacturers) still rely on craft production systems to handle the variability in the number of parts to be remanufactured and the variability inherent in refurbishing operations due to wear differences.

(Amezquita and Bras, 1996, p.38)
Moreover, the underlying research has discovered that for many automotive remanufacturers, high automation is not feasible. On the one hand, vehicle manufacturers who undertake remanufacturing activities hesitate to invest in non-core activities, since all resources are needed for the company’s core business. On the other hand, smaller, often independent remanufacturer, do not possess the financial means for high automation. However, (Steinhilper, 1998) has discovered that high automation within remanufacturing is also not feasible in technical terms. Hence, for the disassembly process, for instance, “manual or moderately mechanized disassembly will remain the adequate solution for the future” (Steinhilper, 1998, p.45-46).

The second problem resulting from high product diversity is a high inventory level across the whole supply chain. The OEM engine remanufacturing case company holds significant inventory levels at various places in the supply chain. 13,000 used car engines, the equivalent to an annual production (remanufacturing) output, are stored at the remanufacturing plant. Moreover, there is a parts warehouse with 31 million parts (recovered, new and used but not yet recovered). As opposed to conventional engine manufacturing which deals solely with new parts, inventory management of a remanufacturing operation needs to consider new, remanufactured and used parts. Hence, there is not just more variety with regard to product characteristics (e.g. new or remanufactured), but also volumes are larger since one particular part may be on stock in different conditions at the same time (e.g. new, remanufactured or used).

The second cause for high stock levels in remanufacturing plants refers to the constructional level of the product. Johannes (1995) explains that in a traditional
manufacturing environment, there is just one constructional level of the product, whereas within remanufacturing there are several constructional levels of one product or model, due to previous generations of the product. The underlying research has observed the difficulties of parts proliferation among OEM engine remanufacturers. With regard to the independent sector, Amezquita and Bras (1996) as well as Hammond et al. (1998) have outlined parts proliferation as a major issue within independent automotive remanufacturing.

Current Industry Practice
As a result of highly manual product recovery and high product diversity, there are low batch sizes and high tool changing times. A potential approach to problem-solving could be an even stronger emphasis on platform design of engines so that parts may become more interchangeable and tools as well as machinery could be utilised for more parts. However, there are several aspects which interfere with significant engine design changes. Firstly, the underlying research has found that there is no communication between engineers and designers for new engine manufacturing and engineers for remanufacturing. Designers of new parts do not consider remanufacturing or aftermarket issues, as one developer confirms: “we develop for the series – not for the aftermarket”. Hence, design strategies such as ‘design for environment’, as proposed by Carlson-Skalak et al. (2000) and Feldman (1999), or ‘design for remanufacturing’ (e.g. Sherwood and Shu (2000) are currently not applied within automotive engine design.

Moreover, for vehicle manufacturers who undertake remanufacturing, such as the case company, there is no intention to changing current industry practice. As previously
outlined, remanufacturing is a non-core activity. Its importance has not grown in the past decade. Case company A’s manager of the remanufacturing plant has explained that despite the vehicle manufacturer’s overall increases in (new) engine production, engine remanufacturing has produced consistent output over the years. For remanufacturing plants owned by vehicle manufacturers, this may indicate no significant changes of their current practices.

The accumulation of high inventory for buffering is also a strategy which is often applied to eliminate the uncertainty incorporated within product returns. As it has been outlined by Guide (2000), there is a strong uncertainty within the quality, quantity and timing or product returns.

Safety stock in this environment does provide some limited protection against material recovery variation, but not the amount of coverage expected. Hence, the benefits of using safety stock to provide stability to remanufacturing schedules may be limited.

(Guide, 1999, p.228)

Amezquita and Bras (1996) have therefore found that there is significant scope for the application of lean practices within remanufacturing operations. These authors have identified ‘waste of overproduction’, ‘waste of inventories’, as well as ‘waste of transporting’ within automotive clutch remanufacturing. Hence, there is the need for the more detailed identification of non-value added activities within engine remanufacturing in order to eliminate ‘wastes’.

A second approach to achieve improvement of the above issues is the development of a specific demand forecasting tool. As it seems, too many parts for which no real
demand could be identified are stored at the remanufacturing plant. Moreover, the research has discovered that no forecasting was practiced within the case company at the time of the research. Interviewees gave several reasons for that. They were asked why future demand for remanufactured products could not be based on the number of cars on the road. One interviewee explains that forecasts for remanufactured engines which are based on the current car park are too complex and time-consuming. Furthermore, the determination of cars on the road is difficult in itself, considering the migration of cars into foreign countries, for example.

**Discussion and Conclusion**

This article has portrayed real-world insights into automotive engine remanufacturing. It has given an overview of the diverse practices between independent and OEM remanufacturing, but mainly focused on the differences between new engine production and remanufacturing. The following table illustrates the causes for issues identified within automotive engine remanufacturing. These aspects are further outlined below. It has to be noted that the result of one issue (effect) may also represent a cause for further obstacles.
Table 2: Cause and effect analysis for issues identified within OEM engine remanufacturing

<table>
<thead>
<tr>
<th>Cause</th>
<th>Effect</th>
<th>Current OEM Practice</th>
<th>Suggestions for Future Research</th>
</tr>
</thead>
</table>
| • High variation in quality of returned products | • Uncertainty with regard to scrap rates | • High inventory buffers  
• ‘Over-stripping’ (disassemble more than needed in re-assembly)  
• Integration of new parts | • Computer system support that is able to distinguish between the various ‘states’ of parts: new, used, remanufactured  
• Forecasting tools that predict quality of returns  
• Identification and elimination of ‘waste of inventories’ |
| • Personal customization (horsepower, fuel type)  
• Different engine generations  
• Technological updates over time | • High engine core levels  
• High part stock levels  
• High product variation within one shift | • Scrapping of excess cores  
• Batch orientation  
• Skilled labour in order to cope with variety | • Identification and elimination of ‘waste of inventories’  
• Identification of an appropriate remanufacturing philosophy |
| • Large amount of manual labour | • High throughput times | • Aim to replicate mainstream engine production | • Identification of a more efficient remanufacturing process layout |

Product variation within the automotive sector has been identified as one of the main sources leading to obstacles within OEM engine remanufacturing. A large number of product variants in a remanufacturing plant results in two main management obstacles. On the one hand, it requires the plant to adopt craft production with a large amount of manual labour involved. However, this approach enables the remanufacturer to deal with large numbers of product variants while customising products according to customers' needs. Although it seemed as if the vehicle manufacturer sought to replicate mainstream engine production in a remanufacturing environment by, for example, establishing a re-assembly process similar to engine mass manufacturing, there were two drawbacks to this approach. On the one hand, there is a lack of automation and therefore standardisation within a remanufacturing environment, which is essential to obtaining the benefits from mass manufacturing.
systems. Moreover, a replication of a mainstream engine manufacturing system is complicated by product variation.

On the other hand, the increasing amount of engine variants leads to very high inventory levels. There are 13,000 cores and 31 million parts on stock at the remanufacturing plant, whereas the main distribution centre stores 8,000 complete (remanufactured) engines. Whereas the large product variation and the various conditions of parts are two reasons for that, the disassembly of an engine to parts level may further increase stock movements.

Future research should therefore seek to improve the two problems outlined above. Previous attempts to identify the ‘appropriate manufacturing philosophy’ for remanufacturers have been made by Amezquita and Bras (1996) for automotive clutches. From a more empirical point of view, attempts have been made to apply lean practices on remanufacturing operations (e.g. Fargher, no date given). However, future research should consider the industry-specific issues outlined above in order to improve parts recovery of automotive parts.

With regard to the second issue occurring within remanufacturing facilities, the high inventory levels, there is a large body of academic literature. Since inventory management for remanufacturing has been identified as a major challenge, a comprehensive body of operations management literature has been developed for this topic. However, there are various points of criticism for current models. De Brito and Dekker (2003) argue that contributors in the area of inventory control generally take simplified assumptions in inventory control management for product returns. These
simplified assumptions include the demand and the return flow being a homogeneous Poisson Process and the presumption that return and demand processes are independent from each other (ibid). In their work, De Brito and Dekker (2003) therefore examine the empirical validity of these assumptions. They conclude by arguing that there is the need to adapt these assumptions to create models suitable for non-stationary (real) situations, such as the seasonality of certain products. Further concerns of a limited practical applicability have been raised by Debo et al. (2001), who argue that the current quantitative literature assumes that prices, demand rates and the level of remanufacture are exogenous.

In addition, it is assumed that consumers do not distinguish between new and remanufactured products. This perspective is clearly too general and may only be applicable to certain industry sectors, but not to the automotive sector. Ferrer and Whybark (2001) confirm that in the automotive sector, consumers clearly differentiate between new products destined for vehicle assembly or the aftermarket, and remanufactured products, which are exclusively distributed as spare and replacement parts. As a result, more specific tools and techniques have to be developed for the above problems. Future models need to consider the product diversity within inventories, such as different product generations, different conditions of inventory (new, remanufactured and used) as well as the range of qualities of returned products.
References


Fargher, J.S.W., (no date given). *Lean Remanufacturing*. Missouri Enterprise, Bridgeton, MO, USA.


