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Remanufacturing Quality Uncertainty in Robert Bosch Ltd

Relatore:
prof. Maisano Domenico Augusto Francesco

Tutor aziendale:
Ziaul Rouf

Candidato:
Marina Barone

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Acronyms and Abbreviations

IoT	Internet of Things
ESC	Electronic Stability Control
AA	Automotive Aftermarket
OEM	Original Equipment Manufacturer
CSR	Corporate Social Responsibility
OES	Original Equipment Service
OE	Original Equipment
IAM	Independent Aftermarket
EOL	End-of-Life
CLSC	Closed Loop Supply Chain
FSC	Forward Supply Chain
RSC	Reverse Supply Chain
JLR	Jaguar Land Rover

Introduction

There is a growing need for organizations to be responsible socially, environmentally and economically. As a part of an integrated solution to these dynamic challenges, this thesis is focused upon describing remanufacturing as a sustainable solution for the German leading company Robert Bosch Ltd, supplier of original equipment parts (OE) which is also involved in providing OE services (OES) and the independent aftermarket (IAM).

The remanufacturing industry produces goods that are partially comprised of components recovered from end-of-life products combined with new components in place of certain worn or damaged parts that are no longer useable. The process transforms the recovered components into “like-new” goods. This reuse of inputs yields important economic and environmental benefits. Remanufactured goods in Bosch have the appearance, performance, and life expectancy of new goods. They meet the same performance requirements as, and enjoy the same two-years-warranty, of the original equipment parts.

In short, remanufactured products are intended to be identical to, and indistinguishable from, products manufactured entirely from raw materials, new parts or components.

The strategic decision-making for reman automotive aftermarket products (OES and IAM) is complex with numerous uncertainties on core availability, market potential, product design considerations, and supply chain capabilities. The success of a reman business model depends heavily upon a comprehensive, strategic, decision-making framework that addresses the company’s roles as OE suppliers service parts providers and aftermarket providers of service parts. These types of businesses require integrated approaches of the corporation throughout the full value chain.

In this thesis work production planning of remanufactured products when inputs have different and uncertain quality levels is considered. The objective of this thesis is, therefore, to focus on remanufacturing as a sustainability option for the aftermarket, to examine the remanufacturing process starting from the Core Acquisition Management performed by CoremanNet. In particular, the implementation of the Bosch eXchange Program in JLR for remanufactured starters and alternators will be described and analyzed.

This dissertation is organized as follow.

The first chapter gives a general overview of the Bosch Group and in particular of the automotive aftermarket division (AA), in which the student has served the internship. It follows an introduction on sustainability and on the key objective of the company: to provide its customers with technologies that are "Invented for Life". Bosch takes a strong position with respect to the environment and decide to offer products that are sustainable throughout remanufacturing.

The second chapter deepens better the meaning of remanufacturing and outline the main difference between remanufacturing and recycling. Bosch offers to its customers the possibility to be part of its reman eXchange program that will be discussed within this chapter. The remanufacturing process and in particular the reverse logistic process are presented. Later on, the challenges that usually are recognized during remanufacturing will be delineated.

The third and last chapter of this work describes what was done during the internship period. The implementation of a reman eXchange program for one of the biggest customer of Bosch in United Kingdom, Jaguar Land Rover, is described. The major problem faced within this process is recognized in the core acquisition process phase, that comprise a big portion of uncertainty in the quality of returns. The solution proposed by our team to partially solve this problem will be described.

1 The Working Context

1.1 Robert Bosch GmbH: a Culture of Innovation

One of the largest companies in Germany, Robert Bosch GmbH is best known as a world leading multinational engineering and electronics company headquartered in Gerlingen, near Stuttgart, Germany. In 1886, Robert Bosch founded the "Workshop for Precision Mechanics and Electrical Engineering" in Stuttgart. This was the birth of today's globally operating company.

Now, Bosch has operations in more than 50 countries on every continent through its subsidiaries and associated companies and right from the start, it was characterized by innovative strength and social commitment.

Robert Bosch gained a reputation for innovation in industrial relations. He instituted an eight-hour workday (which was uncommon at that time) and paid employees at a higher standard rate, in the belief that superior working conditions would encourage better employee performance. Bosch readily acknowledged ability and creativity in his employees, assigning the most talented among them to positions in the most promising areas. He also recognized the need for a diverse, high-quality product line as the most direct means to growth.

1.1.1 The beginnings

Bosch entered the automotive industry in the early 1890s, when the company introduced a hand-crank motor starter. From 1897, Bosch started installing magneto ignition devices into automobiles and became the only supplier of a truly reliable ignition. In 1902, the chief engineer at Bosch, Gottlob Honold, unveiled an ever better solution, the high-voltage magneto ignition system with spark plug. This product, represented in Figure 1, paved the way for Bosch to become a world-leading automotive supplier.

During the 1950s, Bosch began a cautious program of long-term diversification. For example, household appliances were added to the company's product line in 1952 with the introduction of Bosch kitchen appliances. In 1958 washing machines were added, then dishwashers in 1964. In 1952 Bosch also began to manufacture hydraulic equipment and do-it-yourself power tools.

BOSCH

Figure 1: Bosch logo, designed in 1918 by Gottlob Honold, embodies a magneto armature inside the magnetic casing, the brand's most known product.

1.1.2. Invented for Life Technologies

The Group's strategic objective is to deliver innovations for a connected life, by improving quality of life worldwide with products and services that are innovative and that spark enthusiasm.

In short, Bosch creates technology that is "*Invented for life.*"

Today, as a leading IoT company, thanks to its teams of expertise in sensor technology, software, and services, as well as its own IoT cloud, Bosch offers to its customers innovative solutions for smart homes, smart cities, connected mobility, and connected manufacturing.

It continues to drive new innovations through creative ideas. It is worth remembering that Bosch has been the creative force behind important innovative vehicle technologies such as Electronic Stability Control (ESC) and the common rail system for diesels.

1.1.2.1 Worldwide Modernization Projects

In addition to its leading role in the automotive industry, Bosch should be also appreciated for the realization of several modernization projects for some of the most famous icons of the world.

From London to Paris, from Moscow to Machu Picchu, Bosch has made available its experience to the modernization of drive and control technology, to the update of hydraulic equipment, to the installation of security systems and much more.

Among them are of particular interest the Bolshoi Theatre in Moscow for which Bosch has installed stage technology equipment that is worldwide among the most modern and most complex.

Figure 2: Tower Bridge of London opens to let tall boats pass thorough.

Furthermore, Bosch, as experienced system partner for the modernization of historic facilities, has updated the hydraulics of the elevator of the Eiffel Tower, an icon for Paris for now more than 130 years. In doing so, the company maintained the original construction idea of an indirect hydraulic drive and implemented it with current engineering, by developing a sustainable solution that reduces the energy consumption by approximately 25 percent.

In London, Bosch keeps the giant Ferris wheel of the London Eye turning, actuate the opening mechanism for Tower Bridge and raise the gates of the Thames Barrier, which protects the city against storm and spring floods from the North Sea.

The Tower Bridge, in Figure 2, is a London landmark that has been on the scene for much longer. As part of a modernization project, Bosch planned the drive and control solution for the opening mechanism for the sections of bridge, which weigh around 1000 tons. The modern hydraulics also protect the historic structure against damage caused by heavy goods traffic. Hydraulically adjustable wedges ensure that any forces and vibrations that occur are dissipated evenly.

1.1.3 Mobility Solutions

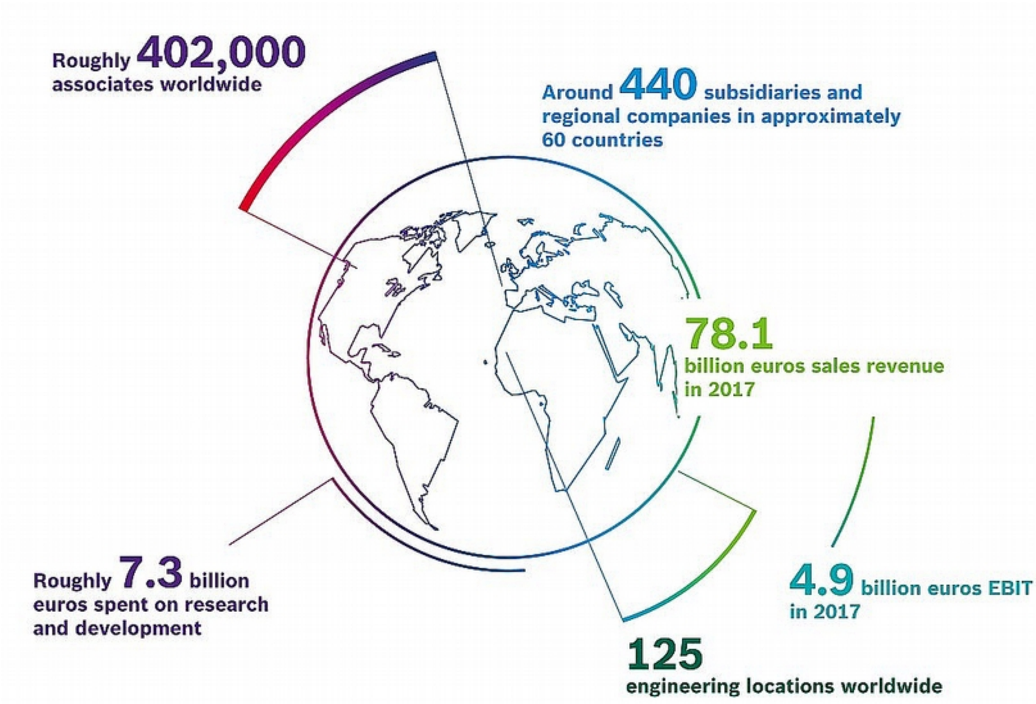

Figure 3: Bosch at a glance.

The Bosch Group is a leading global supplier of technology and services. It employs roughly 402,000 associates worldwide (as of December 31, 2017). The company generated sales of 78.1 billion euros in 2017 (see Figure 3 above).

Bosch operations are divided into four business sectors: mobility solutions, consumer goods, industrial technology and energy and building technology.

The Mobility Solutions business sector, one of the world's largest automotive suppliers, accounts for 61 percent of total Bosch Group sales (see Figure 4).

Figure 4: Sales by Business Sector and the Divisions in the Automotive Sector.

The sector combines the group's expertise in three mobility domains, automation, electrification, and connectivity, and offers its customers integrated mobility solutions that allow cars to interact with other means of transportation such as bicycles, trains, and buses.

At the beginning of 2018, the sector restructured itself by bringing its Gasoline Systems and Diesel Systems divisions, as well as the electromobility unit, together under one roof in a new Powertrain Solutions division. This allow it to serve its customers with the optimum combination of technologies, since even with electrification increasing, efficient gasoline and diesel engines will continue to play a significant role for a long time to come. In addition, the newly-formed Connected Mobility Solutions division brings together the connected mobility solutions and services that had previously been spread across various units within the Mobility Solutions business sector.

Its main areas of activity are injection technology and powertrain peripherals for internal-combustion engines, diverse solutions for powertrain electrification, steering systems, safety and driver-assistance systems, technology for user-friendly infotainment as well as vehicle-to-vehicle and vehicle-to-infrastructure communication, repair-shop concepts, and technology and services for the automotive aftermarket.

1.2 Sustainability and CSR

Conventional businesses have assumed in the past an inexhaustible supply of raw materials from nature. They have used a “take-make-waste” model, in which, virtually, all materials are eventually deposited in landfills from which they cannot easily be used by future generations. Materials will continue to improve, but this model is not sustainable for the longterm. Moreover the eco-system disruptions, caused by the increasing human population and the millions of tons of carbon dioxide and other greenhouse gas emissions that are being released every year, threaten present and future human generations with disease, famine and extinction (Goldman, 2009).

Sustainability, on the contrary, is based upon the concept that resources are finite, and therefore, that all natural resources should be used with care while ensuring sustainable yield within the eco-system's limits, so that human societies and the eco-system can co-exist forever.

It requires integrated emphasis upon closed-loop, cyclical thinking rather than linear, short-term and goal-oriented thinking. This is important for sustainability-focused companies to function and to succeed within the society where the companies provide goods and services. Sustainability decision-making for companies requires an integrated focus upon the triple bottom lines: profitability, people and the planet.

Porter et al. (2006) proposed a new way to look at the relationship between CSR and society. Corporate Social Responsibility (CSR) represents a mixed picture across companies, with some setting high standards for themselves and their sector.

The Porter Value Chain Model (Porter, 1985) is used to identify and prioritize the specific initiatives that corporations should take to build that relationship. It highlights the fact that a strategy has to be implemented at the process level because a company's competitive advantage has its origin in the way the core and support activities are performed and coordinated. CSR should be linked to core business objectives that are leveraged for increased economic and social values.

Many of the operational CSR initiatives from the Porter Value Chain Model like recycling, conservation of raw materials, transportation impacts, emissions and waste, energy and water usage and disposal of obsolete products, can be addressed with an integrated remanufacturing strategy.

1.2.1 Sustainability in Bosch

For Bosch, sustainability means securing the company's long-term success while at the same time protecting the natural environment on which present and future generations depends.

The company's "Invented for life" ethos not only applies to its core business, but also to the subject of sustainability: it wants its products and services to improve quality of life for people around the world and to conserve natural resources.

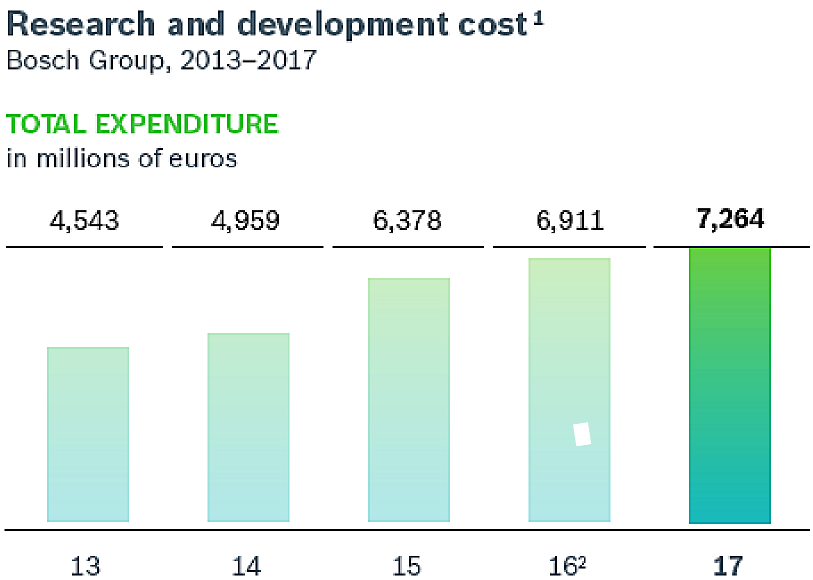

Figure 5: R&D budget from 2013 to 2017.

In other words, Bosch aims to make renewable sources of energy more efficient, mobility emissions and accident-free, and, in all its fields of business, to develop eco-friendly products. It regards a green mindset as an engine of innovation and a pillar of the company's success. From

Bosch Report of 2017, it is possible to see that the company recognize huge opportunities in the areas of connectivity, electrification, and energy efficiency and therefore it plans its capital expenditure accordingly (see Figure 5, of the 2017 R&D budget of 7.3 billion euros, 54 percent went into products in the environmental and safety portfolio).

On the basis of its endeavours to bring economic, ecological, and social concerns into balance, Bosch has identified four fields of sustainability-related action: environment, products, associates, and society.

Within these fields, the company has set five specific targets in the areas of resource conservation, supplier audits, equality of opportunity, and occupational health and safety and again in 2017, Bosch successfully achieved significant improvements here (see Figure 6).

Figure 6: Bosch Sustainability Targets in 2017.

1.2.1.1 A cross-sectoral Sustainability Organization

The company is pursuing several qualitative and quantitative sustainability targets at some 300 locations. These include further reducing packaging waste, optimizing logistics processes, and implementing energy management systems.

Bosch strongly believes that its sustainability targets can only be reached if sustainability related issues and tasks, as well as the corresponding monitoring duties, are made an integral part of processes and business activities.

At Bosch, the range of tasks is based on the product life cycle, and includes the area of materials procurement as well as engineering, manufacturing, logistics, and product use and disposal.

In brief, organizing sustainability is a cross-sectoral task based on comprehensive sustainability management, with clear roles and responsibilities.

1.3 Aftermarket Integration: a Total Product Systems Solution

Emerging responsibilities and management of the ‘End-of-Life’ (EOL) phase increase the importance of the integration of aftermarket activities within a product life cycle stages. Based upon a number of European EOL directives for management of vehicles, and electronic products, new requirements have been placed upon producers, sellers and buyers to properly manage these products at the EOL phase.

The remanufacture of products or parts makes the most significant contributions in saving of resources and energy in the aftermarket system.

Reprocessing to extend the life of products or parts is viewed as a step toward “closed-loop industrial systems.” Such efforts encounter challenges such as: dealing with the uncertainty in the quality of components or parts from EOL sources, and the organization of reprocessing. The challenges multiply with the proliferation of product variants associated with product customization. Meeting these challenges requires dedicated organizational facilities and management.

Similarly, separate logistical networks are needed to recover EOL products, to distribute them to reprocessing centers and to route remanufactured products to the purchasers. Logistical and reprocessing arrangements are organizationally different from mainstream product supply and distribution. There is increased interdependency that is reflected in the pressures on product designers to reduce the scale and costs of product variations and more generally, to reduce materials and energy use by improving product manufacturability and remanufacturability.

Product designers should also take account of issues in the aftermarket and EOL phases.

Design engineers need to include aftermarket considerations within design briefs to reduce the inventory bloats that can impact remanufacturing. Similarly, the designers need to avoid compound materials that cannot be recovered (Seitz and Peattie, 2004).

In the current management and practice, however, the aftermarket and EOL phases are loosely connected to mainstream production. That is why the integrated management of total product systems is needed; additionally such integration will provide significant competitive advantage.

Impacts of external factors linked to growing concerns about environmental impacts further reinforce the need for an extended management of supply chains towards the total product system.

The changing context of supply chain organization relates to the issues that other forms of waste from the production processes are developed. These are the liquid, solid and gaseous wastes and emissions that result from energy use and materials processing in every stage of the product life cycle.

These wastes and emissions were largely ignored earlier in the single-bottom line vision of short-term, cost conscious industries, where the natural environmental systems (atmospheric, hydrological etc.) were treated as dumping grounds as they were, in effect, "free goods," that were largely free of charge to the polluter (Rhodes, 2006).

As society increasingly demands that such previously externalized costs of production, must be internalized within the corporate management system, new regulations are being developed and in some cases implemented and enforced via fines and taxes.

Consequently, at least some corporate leaders are seeking to reduce, at the source, all such wastes and emissions. The companies that will be successful in the future will reduce their supply chain costs from cradle-to-cradle (it is a holistic economic, industrial and social framework that seeks to create systems that are not only efficient but also essentially waste free) and will seek to go beyond regulatory compliance across the entire network (Veleva and Sethi, 2004).

1.4 The Automotive Aftermarket Division

The Automotive Aftermarket (AA) is the secondary market of the automotive industry, concerned with the manufacturing, remanufacturing, distribution, retailing, and installation of all vehicle parts, chemicals, equipment, and accessories, after the sale of the automobile by the Original Equipment Manufacturer (OEM) to the costumer.

OEMs and independent remanufacturers rework worn out or defective engines back to original equipment performance specifications or maybe to even better than new quality by incorporating state-of-the-art technology into these cores (Cores are used products that are returned by or collected from the customers. But returned products can also come from production facilities within the supply chain.) that was not available at the time the initial products were designed and produced.

The Aftermarket support refers to activities associated with products (e.g. spare parts) and services (e.g. engine overhauls), after initial sale of a product.

In the automotive aftermarket business, there is Original Equipment Service (OES) product support with warranty and Independent Aftermarket (IAM) product support that is outside the warranty period.

The AA division, that comprises around 14,000 associates in 140 countries, as well as a global logistics network, manages the supply, logistics and sales of automotive spare parts and Bosch products for retrofitting. In addition, it offers customer service for automotive products and systems.

The division manages 24 warehouses around the world. One of the tasks of the distribution warehouse is to supply Bosch customers that includes automotive manufacturers' headquarters, wholesalers and workshops with a wide and diverse range of spare parts, which are shipped from Karlsruhe to 140 different countries (see Figure 7).

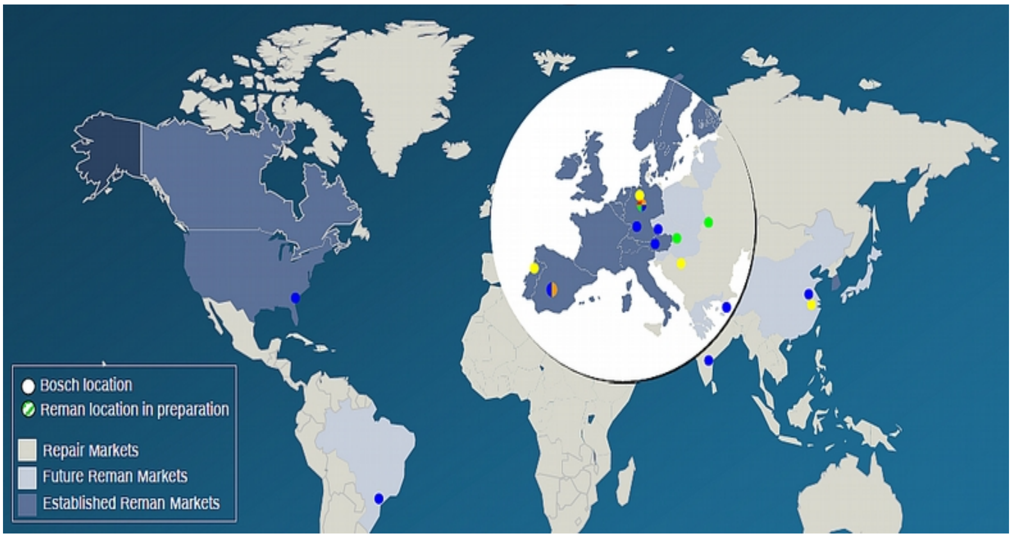

Figure 7: Bosch AA Remanufacturing Location.

1.4.1 AA distribution channels

Automotive parts are defined as either original equipment or aftermarket parts. Original Equipment parts are used in the assembly of a new vehicle or are purchased by the manufacturer for its service network.

Aftermarket parts includes two distinct supply chain distribution channels (see Figure 8): the Original Equipment Service (OES) and the Independent Aftermarket (IAM).

The OES channel is for products within the company's product warranty and they are specific for each customer, while the IAM channel, with the Bosch logo, serves the end customers after the warranty expires.

OES parts are made on the same assembly line as the IAM but they undergo through a couple added steps. Branding of the part with the customer logo and then gets wrapped and labeled in the customer packaging. Remanufactured products serve both channels with different complexities in reverse logistics.

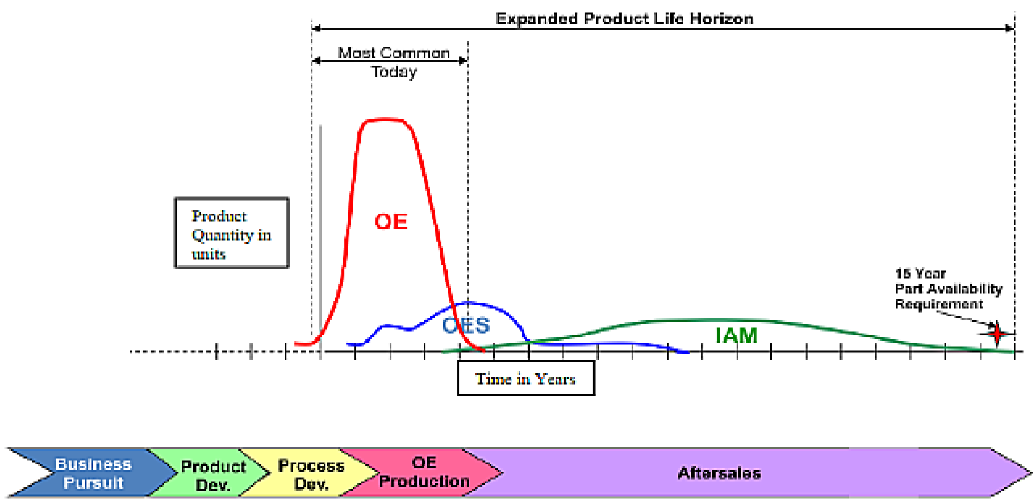

Figure 8: Time after product launch vs. product quantity compared for OE, OES and IAM automotive aftermarket business channels.

1.5 Remanufacturing as a Beneficial Solution for Companies and Costumers

As a first step before analyzing the supply chain weaknesses and to seek to provide strategic reman solutions, one must understand the economic and ecological benefits of remanufacturing products.

Products take-back is one of the activities that many enterprises are obliged or encouraged to do in today's industrial environment. There are many motives that encourage the process of take-back such as: profitability, ethical responsibility, environmental legislation and social benefits.

1.5.1. Cost-Effective and Environmentally-Friendly Alternative to New Products, With the Same Warranty

Remanufacturing of used parts requires much less energy than manufacturing new parts. Reman offers to Bosch the opportunity to cut costs in the production and re-supplying of its customers, since a Reman engine preserves 85% of the energy involved in the production of a new engine, remembering that each core can be remanufactured up to five times, and that the profit margin on a Reman product is profitably high.

A remanufactured spare part is approximately 30 to 40% cheaper for the end customer than a new part, and has the same two-year warranty.

In addition, exchange parts protect the environment and prevent CO2 emissions. By remanufacturing vehicle parts, Bosch reduced its CO2 emissions by approximately 25000 metric tons in 2017 compared to the figures that would have been produced if new parts had been manufactured.

Kim et al. (2008) did an environmental assessment of a remanufactured alternator from Bosch. The environmental evaluation consisted of an assessment of material consumption, energy consumption, waste generation and greenhouse gas emissions (GHGE).

The part was completely disassembled, to the material level, in order to determine the material composition of different components. The environmental impacts were assessed from the material extraction phase to the manufacturing phase.

Remanufacturing of an alternator has the following advantages compared to its new production:

- it required only 19% of the material required for new production;
- energy consumption was 14% - 16% of the respective values for new production;
- GHGE was 11% - 35% of the new production value;
- waste generation was 21% of what it would have been if new products were used instead of remaned ones.

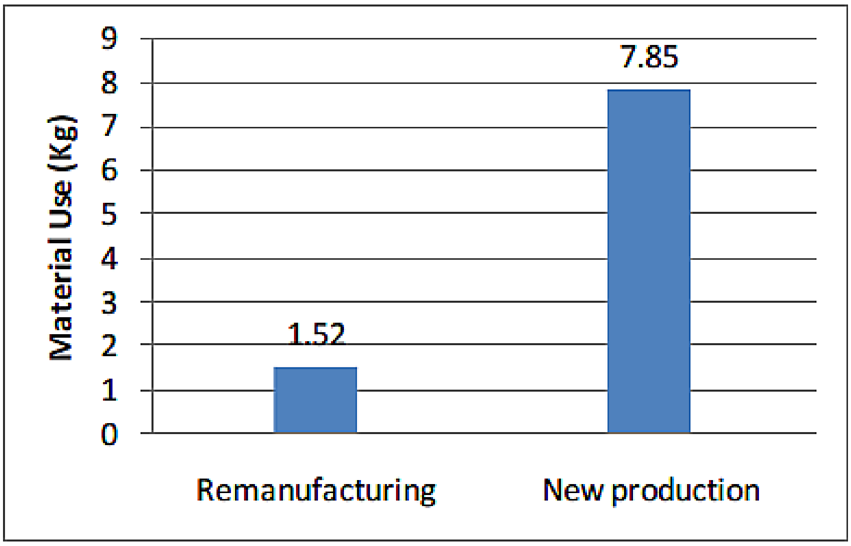

Figure 9: Material usage comparison for producing a new vs. a reman alternator.

Figure 9 above and Figure 10 below represent, respectively, the material usage and the energy consumption for the production of a remanufactured Bosch alternator with respect to a new product.

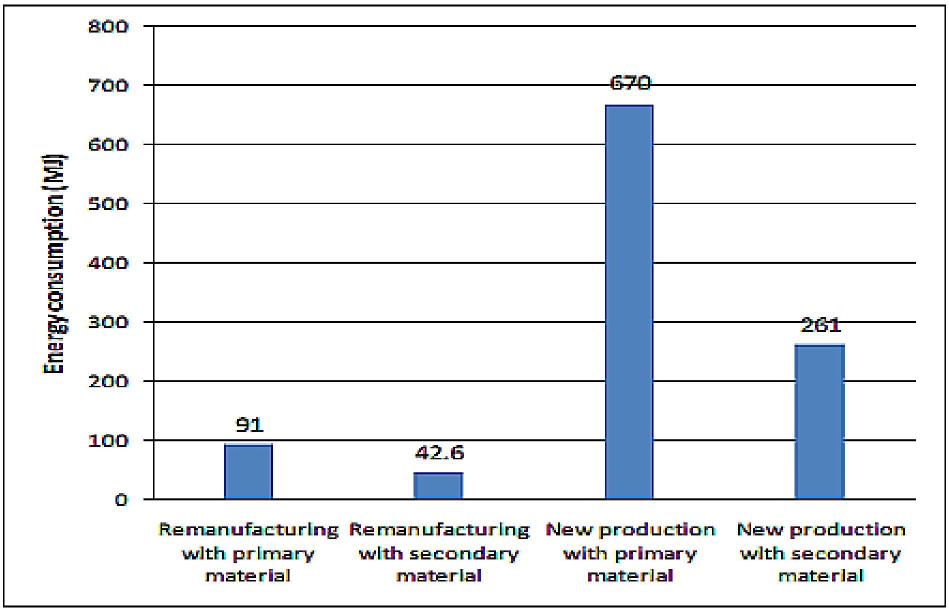

Figure 10: A comparison of the energy and materials usage for producing a remaned alternator vs. a new alternator.

1.5.2 Highest Quality Standards

In Bosch, manufactured and remanufactured product are perfect substitute, since the customer is supplied with a product with the same high quality level than the new one.

So far, industry standards for the worldwide remanufacturing business have not yet been regulated in a standardized fashion.

Bosch supports various initiatives to establish a standardized quality standard, and itself applies the same high quality standards to remanufacturing as it does to the manufacture of original equipment products, and for this reason, Bosch offers the same two-years warranty on the remanufactured spare parts as it does on new parts.

Remanufactured products are typically upgraded to the quality standards of a new product, so that they can be sold in a new product markets.

Furthermore, Reman program offers the best value for its customers, providing them the latest version of Reman components modified in order to accomplish the technical improvements that have been introduced in production.

2 Remanufacturing: process and criticality

2.1 What is Remanufacturing?

The growing awareness of sustainability issues by consumers, businesses, governments and the society-at-large, is driving many industries to undertake environmentally conscious policies for their product development, manufacturing, distribution, service and end-of-life management. As a consequence of the increased awareness in producer as well as consumers regarding remanufacturing outcomes, the market for the secondary use of remanufactured products has increased drastically in the last two decades.

While conventional manufacturing is unsustainable because of its significant adverse environmental impacts, remanufacturing turned out to be a valid solution for those companies that are trying to achieve a sustainable manufacturing by saving costs via reductions in consumption of natural resources. It can also help to reduce environment burden by decreasing landfill wastes and reclaim resources and energy already consumed in the original manufacturing of the products.

Besides the environmental benefits, remanufacturing also provides economic incentives to firms by selling the remanufactured products and extending the life cycles of products. Therefore, it is correct to consider remanufacturing as a profitable solution.

Remanufacturing is defined as “an industrial process to recover value from the used and degraded products to ‘like-new’ condition by replacing components or reprocessing used component parts” (Lund, 1984).

To understand one of the purposes and the importance of remanufacturing, it is helpful to relate back to the Bosch Group's mission, "develop products that spark customers' enthusiasm, improve quality of life, and help conserve resources".

This should all be integrated in Bosch products.

The significance of remanufacturing is that it would allow manufacturers to respond to environmental and legislative pressure by enabling them to meet waste legislation while maintaining high productivity for high-quality, lower-cost products with less landing filling and consumption of raw materials and energy.

A typical remanufacturing system includes disassembly, sorting and cleaning, refurbishing, and reassembly. The process of product remanufacturing is usually less expensive than producing a brand new unit because modules and components can be reused, thus avoiding the need to procure new components from suppliers (Ferguson, 2009). Therefore, a good remanufacturing strategy will contribute to the sustainability of the automotive industry.

2.1.1. Remanufacturing vs Recycling: the Value Added

Remanufacturing of failed products are very different from the simple waste recycling.

According to a statement by Professor Robert T. Lund of Boston University in his book, "The American Edge: Leveraging Manufacturing's Hidden Assets", remanufacturing differs from recycling because remanufacturing 'recycles' the value originally added to the raw material.

According to Lund (2000), "Remanufacturing most importantly differs from recycling because it makes a much greater economic contribution per unit of product than recycling”. Therefore, the essential difference arises in the recapture of value added.

Value added is the cost of labor, energy, and manufacturing operations that were added to the basic cost of raw materials in the manufacture of the product. For all but the simplest durable goods, value added is by far the largest element of cost.

By remanufacturing, residual value of the durable components can be recaptured and some fraction of the original manufactured value is preserved. For example, for a product such as an automobile, the value of the raw materials that can be recovered by recycling is approximately 1.5 percent of the market value of the new car.

Value added is embodied in the product and recycling destroys that value added, reducing a product to its elemental value, its recoverable raw material constituents.

Further, recycling requires added labor, energy, and processing capital to recover the raw materials. When all of the costs of segregation, collection, processing, and refining are taken into account, recycling has significant societal costs. Society undertakes recycling only because, for all nondurable and many durable products, the societal costs of any other disposal alternative are even greater.

Remanufacturing is generally the preferred option, because of the environmental gains, compared to new products and recycling. Additionally, as mentioned in the previous chapter, remanufactured products cost consumers less and are economically beneficial for the company.

2.2 Bosch eXchange Program: a Strategic Decision

Bosch is a leading provider of industrially remanufactured vehicle parts and, with its exchange parts program, is represented locally within all global markets. Bosch eXchange comprises approximately 11000 vehicle parts from the starters, alternators and electronics product sectors, as well as from brake, gasoline and diesel fuel-injection systems.

Reman offer is part of a strategy to take a share of the customer support market, which is often occupied solely by workshops and not by the original manufacturer. It represents a potentially large part of total sales, thus why manufacturing firms should aim to transform their own after sales support into a necessity for the customer.

Many manufacturing firms offer Reman program, and those who don't offer an equivalent alternative may lose customers to competition.

By offering this product, customers are unlikely to move elsewhere.

Reman has therefore become an industry-essential for any company wishing to compete efficiently at the top of the market.

Customers appreciate an efficient after sales support for their products. Price and range of Reman products, as well as the quality greatly affects a customer's buying decision, considering this happens in a market where Reman is a known product.

This strategic decision is also important for Bosch in its pursue of environmental preservation.

Reman customers already own a Bosch product, and can therefore adhere to the Bosch eXchange program offer through a "swing" system.

A “swing” system is where an old product is exchanged by a remanufactured product.

Bosch eXchange offers the unique benefits of certified industrial remanufacturing. At certified Bosch factories, all wearing parts and critical components are replaced by original Bosch parts, incorporating the latest production technology and the know-how gained from original equipment manufacturing (see Figure 11).

Figure 11: Bosch eXchange product. Old and remanufactured Bosch Rotating Machine.

Bosch pays particular attention to a product's capacity for remanufacturing right back at the new product development stage. To this end, the company uses the “Design for Environment” approach, a systematic approach that is applied even in the early stages of product development, and which takes the entire product life cycle into account.

Developments in original equipment are also incorporated into the remanufacturing process, ensuring that when Bosch eXchange products are supplied to customers, they are of the best possible technological standards and high levels of quality.

Without providing Bosch with a used component or engine core, a customer cannot expect to receive a Reman products, as his used/worn parts and cores feed into the life cycle of the swing system.

This offer suits customers who see in Reman products the possibility of good performance with a remanufactured used-product at a lower price (30 to 40% cheaper) than of a new product.

2.3 Remanufacturing Process

Remanufacturing is the process of transforming or restoring the condition of the used product to its original condition or as good as new without performing structure destructive processes.

The remanufacturing process (see Figure 12) starts with the collection of the used products. A product will pass through operations like disassembly, cleaning, inspection, repairing, reassembling, and quality testing to get the remanufactured product.

Typically, bad quality products are recycled after reliability testing and inspection. Recycling is not only a good way to earn profit, it also preserves the raw material in the earth’s crust. It is not necessary to recycle all the parts during the remanufacturing process, one can also recycle unusable parts and the remaining parts can be used to replace the parts in other products.

At the start of the remanufacturing process, technical specialists dismantle the used part into its separate components. The components are then individually cleaned which helps to investigate their condition, taking environmental legislation into account.

Depending on the quality of the components, the value of the components (cost of remanufacture compared to cost of a new component), and safety restrictions, the parts are remanufactured or rejected from the process and replaced by new parts.

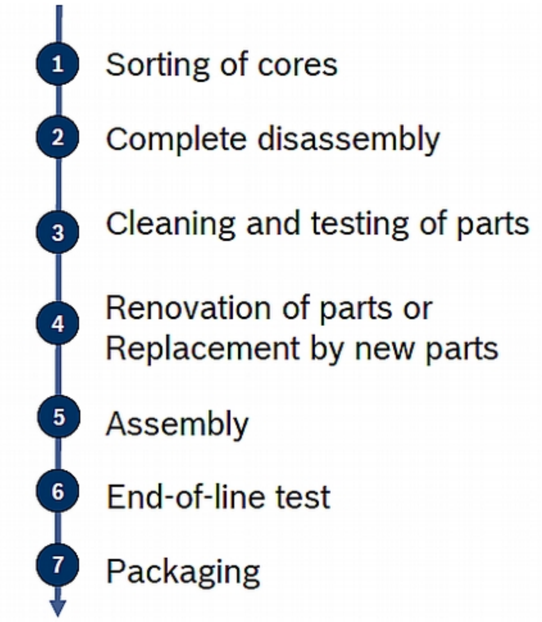

Figure 12: Detailed Remanufacturing Process

When all required components are collected (including remanufactured parts and new components), assembly kits can be organized and the product reassembled.

After this, the entire product passes a final test to ensure that quality is at least equal to a newly manufactured, equivalent product. Only spare parts tested to Bosch quality levels are used in this process. In some cases, products can be upgraded to the latest version.

Each component is subjected to a strict testing procedure, including a visual, dimensional and electrical inspection, and once the quality control process is complete, the remanufactured product is packaged and sent back to the customer.

2.3.1. Reverse Logistic: the Closed Loop Supply Chain

Since certain products are to be returned or taken back to certain collection points, a type of management has emerged. This management is called Reverse Logistics, because it manages the flow of products from the end customers to the collection points.

Reverse logistics is a systematic process of planning, implementing and controlling the backward flow of raw materials, in-process inventory, packaging and finished goods, from a manufacturing, distribution or use point, to a point of recovery or proper disposal.

A reverse logistics network for reman deals with how products are collected from the end user and returned to a facility for reman.

Reverse logistics is being recognized by many organizations as an opportunity for adding value. While global environmental concerns have been the motivation for initiating the field of reverse logistics, businesses have discovered that valuable commercial opportunities are embedded in reverse logistics. The management of customer returns of previous purchases, a common type of reverse logistics, may be a last frontier of competitive advantage. Interest in the field of reverse logistics is growing rapidly as many types of businesses recognize it as a vital part of the overall supply chain.

The added value could be attributed to improved customer service leading to increased customer retention and sales. The added value could also be through reduced cost and/or reduced cycle time. So while environmentalism is and will continue to be a driver behind reverse logistics, it is by no means the only one.

Reverse Logistic and reprocessing arrangements for reman are organizationally different from mainstream product supply and distribution.

According to Akcali and Cetinkaya (2011), “the purpose of the Forward Supply Chain (FSC) is to provide value to the end consumer in terms of products, whereas the purpose of the Reverse Supply Chain (RSC) is to recover economic and environmental value from used products in a cost effective manner”.

If the traditional forward product flow is integrated, coordinated or harmonized with the reverse product flow, the enterprise will create what is called a Closed Loop Supply Chain (CLSC). As the Closed Loop Supply Chain is characterized by recovered material, component, and product flows between the FSC and RSC, the CLSC’s objective, in turn, is to supply the recovered value to the end consumer in a cost effective manner.

2.3.1.1 Easy Return of Used Parts: The CoremanNet Returns System

Bosch handles the return of used parts using the “CoremanNet” returns system (represented in Figure 13 below), which is characterized by the fast and secure return of used parts with deposit return. Bosch has agreed with its customer a Company Buy-Back Return. Used products or components are returned after use by the customer in exchange for a new remanufactured part and in addition he will receive an economical compensation.

Planned return is more predictable than other types of returns due to the additional information that is available to the remanufacturing company. It is much easier for the organization to know what is coming back and when.

CoremanNet offers qualified core return solutions for the automotive spare parts market. The customer has just to let them know as soon as their cores are ready for pick up and they will take care to collect them.

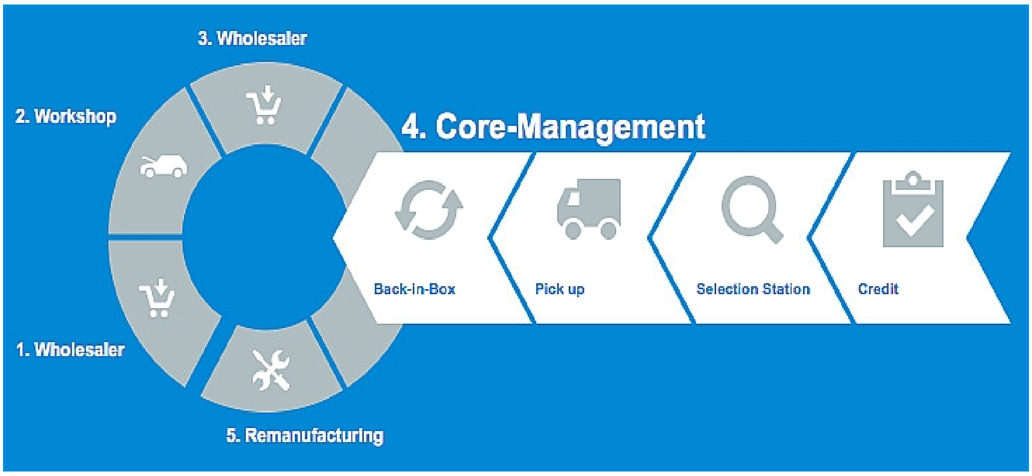

Figure 13: The “CoremanNet” returns system for Bosch Aftermarket.

For its contribution to conserving resources by means of the effective and comprehensive management of used parts, CoremanNet was the only product in the “IT & Management” category to be included in the “Green Directory” at the Automechanika 2017 trade fair in Frankfurt. The “Green Directory” only lists those selected products that make a particular ecological contribution with their innovations and services.

Cores reach CoremanNet selection stations through four steps. When the customer receive the new reman part, the core will be returned in the same original product-package in which the reman part has been delivered to the customer (Back-In-Box) at the retailer and it will be picked up by the forwarder according to customer demand and delivered to the so called selection stations.

There the cores will be validated according to technical criteria, listed below:

- The core is identifiable and listed in the exchange assortment;
- The core corresponds to the minimum technical requirements to ensure the usability for remanufacturing. The minimum technical requirements are in general 4 principal points:
  - complete (accordingly to the delivered reman unit);
  - not dismantled;
  - no mechanical damage at the housing;
  - no heavy corrosion.

- You bought the corresponding reman unit in the given time. Basis for acceptance is your core balance. The balance shows the amount of cores that can still be returned.

If the cores match these technical criteria, if the part numbers are in the return list and if the customer have bought an assigned exchange unit, he will be immediately compensated in order to make it more attractive for customers and to make an important contribution to environmental protection.

Anyway CoremanNet accept all cores, even when they are not usable in the remanufacturing process due to: missing identification, not part of the return list, not corresponding to technical minimum requirement. The customer will receive a basic value for these in accordance with the material value of the core.

2.4 Remanufacturing Challenges

The strategic decision-making for reman automotive aftermarket products (OES and IAM) is complex with numerous uncertainties. There are particular characteristics of the remanufacturing industry that create problems when the traditional production planning methods are used to plan a remanufacturing process. Two of the main characteristics that differentiate remanufacturing from new product production are uncertainty in the number of returned products and uncertainty in the quality of the returns.

To overcome these problems, the remanufacturers must have good control over the product's design and use phases, i.e. the life cycle phases that precede the remanufacturing process. This type of control can be most effectively performed by the OEMs.

2.4.1 Product Design

There is increased interdependency that is reflected in the pressures on product designers to reduce the scale and costs of product variation, and more generally, to reduce materials and energy used by improving product remanufacturability. In Bosch, Product Designers also have to take into consideration issues in the aftermarket and EOL phases. Including aftermarket considerations within design briefs will reduce the inventory fluctuations that can negatively impact reman.

Within design for remanufacturing, many aspects must be considered, such as ease of disassembly, sorting, cleaning, refurbishment, reassembly and testing. Product design that facilitates any of the steps involved in remanufacture will also facilitate remanufacture.

Naturally, it is possible to remanufacture products that are not designed for this purpose; still, it is preferable to have them designed for remanufacture.

Upgrading the functions of the products in accordance with customer requirements can prolong their functional life. Such a product life design strategy is crucial for optimization of product usage in terms of a closed loop product life cycle.

Furthermore, with design for remanufacturing, money can be earned as a result of decreasing waste management costs, decreasing disassembly times and increasing remanufacturing yield for products re-entering the lifecycle use phase.

2.4.2 Product Time Sensitiveness: Electronic Components

Products are time sensitive in the remanufacturing industry and the value of the used products is continuously decreasing with time.

In the automotive industry, the increased usage of electronics in automotive components has resulted in increased product recovery value but the high speed of technology change (and the resulting disposal costs) is making electronic products obsolete faster. A delay in remanufacturing will lower the selling price of the product and simultaneously, the profit of the firm.

Many electronic products have short life cycles and their value goes down very quickly after a certain age.

Thus, the products with short life cycles need to be remanufactured as fast as possible to get the maximum revenue from remanufacturing. Moreover, delay can also affect the choice of the customer while buying products, and the products with short life cycle are less likely to be sold.

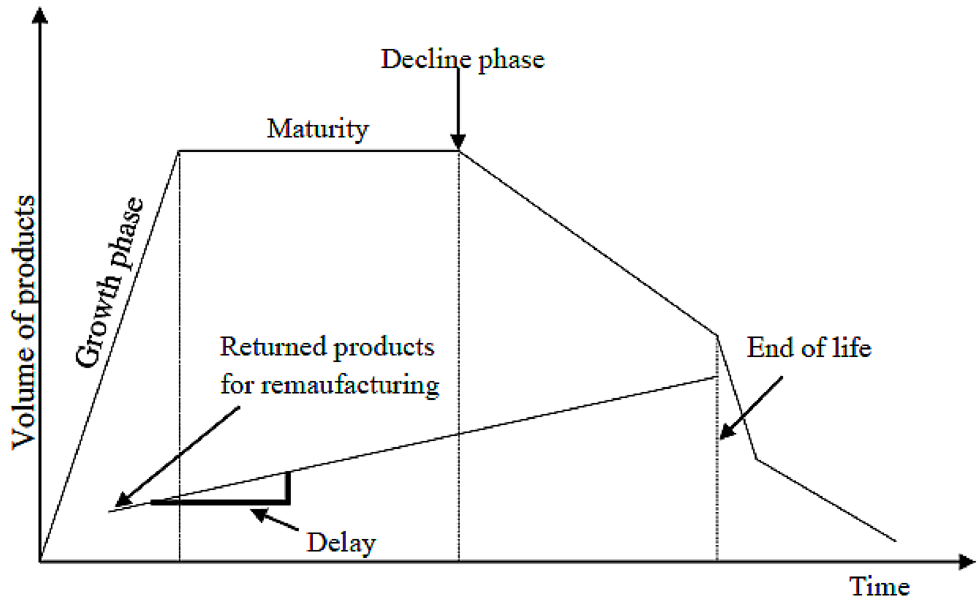

Figure 14: Time value of returned products.

Products lose the 45% of the value due to the delays in the remanufacturing process. In addition, higher congestion levels at the remanufacturing facility can also result in loss of value for time sensitive products.

The time value of the product drops as time passes, and once the product reaches the end of its life cycle, recycling or scrap, is the only way to generate revenue.

Figure 14 depicts the volume of the products in the market with respect to the time.

From the graph it is clearly seen that once reached the EOL, the product is collected and sorted and it passes through the remanufacturing process. At this point, its value is lowered due to delay in the remanufacturing.

Time sensitive products may lose 1% of its value per week and the rate is increased at the end of the life cycle. At this rate, price of the returned products may go down 10% to 20% during evaluation and remanufacturing process (Blackburn et al., 2004).

Therefore one can say that there is a significant amount of decrement in revenue due to delay. The main reason for delay in remanufacturing is uncertainty.

2.4.3 Uncertainty in Quantity and Quality of Returns

Logistics and remanufacturing systems for EOL products in a lifecycle management context differ from traditional forward logistics and manufacturing systems in terms of supply, production, inventory, and distribution. The major difference between the two lies in the supply side. In a remanufacturing system, supply is largely exogenous, i.e., timing, quantity, and quality of returns are much more uncertain than those of a traditional production system are. A significant consequence of these uncertainties is the inclusion of an inspection stage and a corresponding system with variable qualities of supply in a reverse logistics network.

2.4.3.1. Quantity Uncertainty

The amount of returned cores, caused by the uncertainty of the product's life cycle, make the return process most uncertain. In the early phase of a product's life cycle, there are few cores available on the market since few products are returned, making cores expensive. In the later phase, demand and supply become more balanced, and in the end of the life cycle there will be an excessive supply of cores and the price will fall.

These problems should be suppressed by activities such us core deposit systems, which generate a core when a manufactured product is sold.

Many firms who are actively involved in remanufacturing recover their used cores by either leasing their new products (ensuring the used units will be returned at the end of the lease) or by offering buy-back return of an old unit when a new reman product is purchased.

As explained in the previous paragraph, Bosch has agreed with its customer a Company Buy-Back Return. This reduces the uncertainty of quantities returned since provide a more predictable return stream also because the quantity of returned cores is highly correlated with the sales forecast for the firm’s new products.

The main issue that firms still struggle with is the variation in the quality of the cores once they arrive. The uncertainty in the quality of the returns presents a much larger problem than the uncertainty in the quantity of returns.

2.4.3.2. Quality Uncertainty

Quality variation in returned parts is one of the principal sources of uncertainty in a remanufacturing system, and it is mainly caused by different “customer-use” stages and thus leads to different levels of degradation of individual parts and components.

Quality variation adds complexity and challenges to the EOL decision-making framework. More specifically, it complicates the EOL decisions and management of the remanufacturing system by increasing inventory variability, and reduces the precision, with which firms can control remanufactured product quality, balance component inventories, and make decisions on reassembly.

The imbalance of inventories of modules at different quality levels could lead to shortage of certain modules while excessive inventories of other modules.

The quality variation of the returned products also increases complexity to reassembly operations because the final remanufactured products could be assemblies of various combinations of the modules with different quality. But it is worth to say again that Bosch aims to provide its customers with high quality standard parts and with the same two-years warranty as for new products.

3 How To Reduce Quality Uncertainty of Cores: a Bosch Case for Jaguar Land Rover

In this chapter will be analyzed in deep the Core Acquisition Management System of Bosch, applied to the case of Jaguar Land Rover (JLR), one of the biggest customer for this company in United Kingdom.

During the internship served in Robert Bosch Ltd, the implementation of the Reman eXchange Program for JLR, regarding specifically Starters and Alternators, was carried on.

Our Bosch team for JLR, composed by Sales Managers, Supply Chain and Logistic Managers, followed this process from the beginning of the negotiation, until the delivery of the remanufactured products.

Bosch offers to its customer the unique benefits of certified production reconditioning, providing them with the best quality reman products. Wearing parts will be placed by original Bosch exchange parts, incorporating the latest production technology and the know-how gained from original equipment manufacturing.

3.1 Core Acquisition Management: the Market-Driven System

As explained in the previous chapter, remanufacturing is an important product recovery option that benefits our sustainable development. At the start of the remanufacturing process, core acquisition provides the main resource for remanufacturing production to meet the market demand, thus it is critical for the success of remanufacturing business.

Due to different environmental conditions, time lengths and intensities of how the products are used, the returned cores are usually quite different in quality conditions. Instead of suffering from these uncertainties passively, Bosch can actively manage the process of core acquisition.

Despite the importance of Core Acquisition Management and the increasing research interests in it, to our knowledge, there has not been a systematic literature review study focusing specifically on this subject. The existing literature review studies in remanufacturing related subjects are either in general perspectives such as closed-loop supply chains (CLSC) research, reverse logistics or in operational perspectives such as production planning and control (Akcali and Cetinkaya, 2011), disassembly, scheduling, aftermarket strategy, and design for remanufacturing.

In order to coordinate, monitor, and provide an interface between reverse logistics and production planning and control activities, Guide and Jayaraman (2000) firstly build up a framework for Product Acquisition Management based on their survey conducted among North American remanufacturers. They viewed the Product Acquisition Management as "*a complex set of activities that requires careful coordination to avoid the uncontrolled accumulation of core inventory, or unacceptable levels of customer service (insufficient cores to meet demand)*".

Guide and Van Wassenhove (2001) further explain the concept of Product Acquisition Management and describe two approaches in it: the waste stream approach, and the market-driven approach. In a waste stream system, the firms accept the returns passively due to legislation requirements. Such system is unable to control the quality of returns in the first place. As a result, usually a large number of units have to be disposed of, and additional facility and operations are needed for inspecting and grading. Consequently, operation complexity and cost become high.

In a market-driven system, the customers are given financial incentive, such as deposit, credit or cash, to encourage the returns according to related quality standards. This will provide positive impacts on decreasing the variations of return quality, quantity and timing.

While "Product Acquisition Management" in Guide and Jayaraman (2000) deals with all kinds of product recovery options, such as reuse, repair, refurbishment, remanufacturing and recycling, the Core Acquisition Management is specifically related to the remanufacturing area.

Core Acquisition Management is defined as "*the active management of the core acquisition process in remanufacturing to achieve a better balance between return and demand, by dealing with the uncertainties in terms of return volume, timing and core quality*".

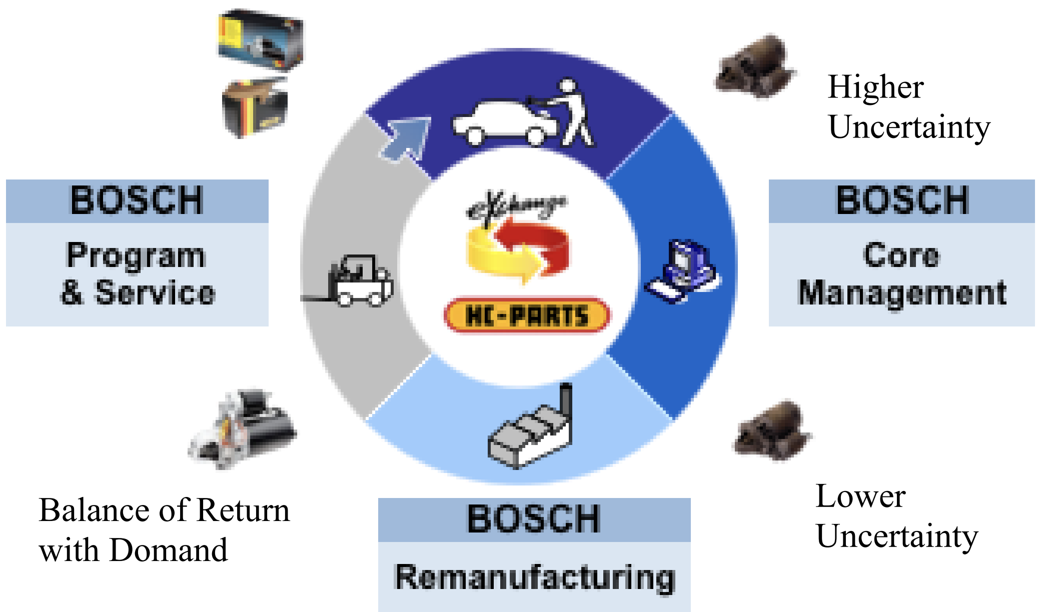

Figure 15: Core Acquisition Management as an interface to reduce uncertainties of return and balance return with demand.

It acts as an interface between the product market and remanufacturing operations, with the aim to achieve the balance between return and demand by managing and reducing the uncertainties in core acquisition processes.

As discussed in the previous chapter, Bosch uses a third party, CoremanNet, in order to ensures the quantity and quality of the returned cores. CoremanNet, with its international logistics network and its innovative IT solution, allows a systematic circular economy for Bosch used parts. It retrieves the cores from the market, identifies them and checks them based on technical criteria. Afterwards, selected cores are sorted and provided to the remanufacturers with the required quality and on time for the remanufacturing. All these activities are parts of the Core Acquisition Management.

3.2 CoremanNet Return Selection Criteria: The Regional Selection Station

The Core-Management system, CoremanNet (Core-Management Network) is a well-established logistic network with more than 10 collection stations in all European markets (see Figure 16). Time and cost efficiency is ensured with regional selection station, placed close to the customers. This allows high frequency of returns and shortest lead-time for evaluation and refunding.

JLR return old and used Starters and Alternators to Bosch throughout CoremanNet. Its Core Acquisition Management System bundle used goods within the respective market, so that later only, full transporters are sent directly to the remanufacturer in the central selection station. This preserves valuable resources and limits transportation costs.

From the operational perspective, the decision on accepting or rejecting a core depends greatly on how the cores are evaluated by the remanufacturer's. To control the quality of returned cores, quality selection criteria are usually pre-established, based on the remanufacturer know-how. Usable cores are an important precondition for the remanufacturing plants. Inspection, therefore, plays an important role in order to sort the cores. During inspection, the remanufacturing suitability of a core is estimated and the processes to be used are evaluated based on the inspector's knowledge and scheduling constraints.

Figure 16: Network of Local European Collection Station.

At the CoremanNet selection station, the cores are identified and it will be checked whether they are part of the Exchange program. For this purpose, CoremanNet searches for the remanufacturer's reman number by using the corresponding core number. If the core number is not legible, it will be identified the old one based on a specific algorithm, technical data or samples. CoremanNet will also check if the customer bought this Reman unit in the given time and if they want back the rejected parts.

In the next step it will be checked if the core complies with the technical criteria for a return or not. As already mentioned in the previous chapter, the core must be completed, not dismantled and not mechanically damaged (as practical examples see Figure 17).

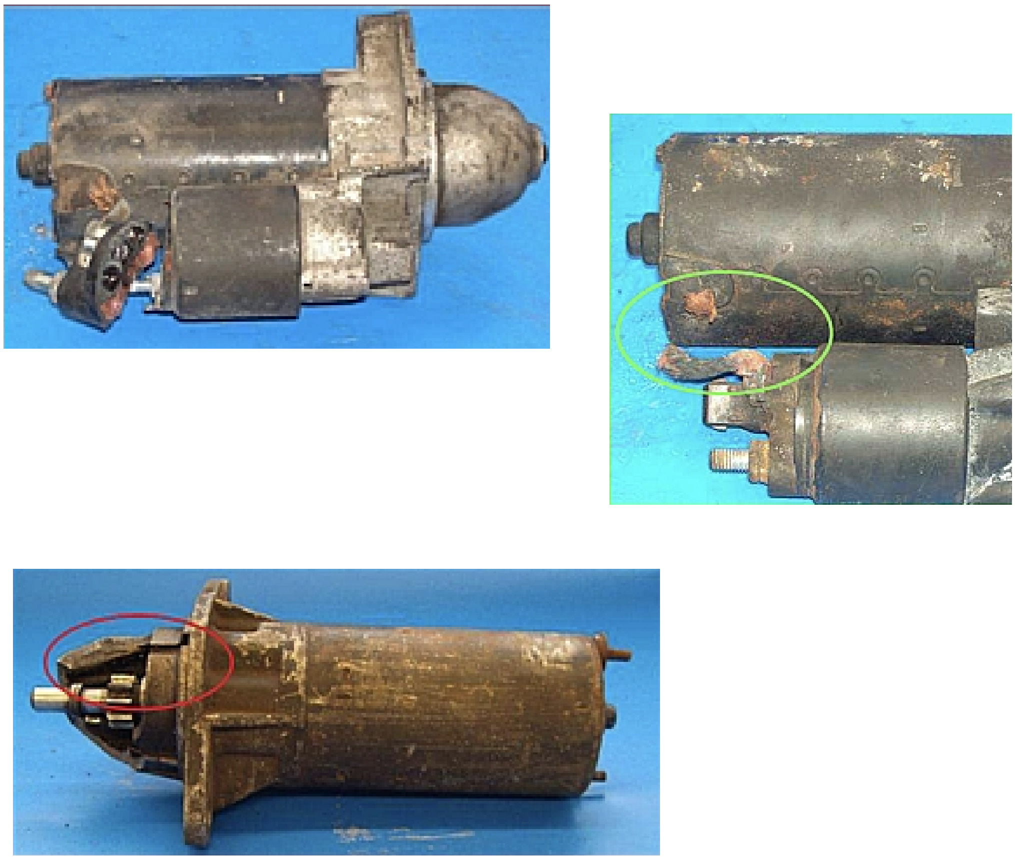

Figure 17: Rejected cores because the part is not in one piece, the house is broken and it is mechanically damaged.

By purchasing an eXchange part and paying the cores surcharge, the customer automatically receives the core return option for a matching core. In the event of a core return, CoremanNet checks whether a return option is available for the corresponding eXchange part.

The CoremanNet core balance provides a detailed overview of the return options per exchange number. It shows the balance period, the open returns options, the amount of exchanged parts purchased and the amount of ordered exchange parts returned, the booking of return this parts, the overdelivered amount of returned cores without return option.

The results of the identification are documented in the Core Selection Report. It shows the amount of accepted cores with direct credit, the accepted cores booked on the core bank, the amount of cores that did not pass the technical inspection and cores which are not part of the eXchange programme.

Figure 18: Returned products, once sorted, are then stored in the Core Warehouse.

After this, the core is labeled and now can be precisely identified and sorted by product family, remanufacturing plant, cooperation partner and acceptance or rejection. Subsequently, the cores are stored (see Figure 18). Upon request, they are delivered to the remanufacturer. This ensures a continues and fast inflow of cores to Bosch Remanufacturing Plant.

3.3 Central Selection Station and Remanufacturing Process for Starters and Alternators

The comprehensive Bosch range of Starters and Alternators includes not only completely newly-manufactured original spare parts, but also remanufactured spare parts from the Bosch eXchange Program: the ideal solution for cost effective maintenance in the work shop.

Once used parts are retrieved from the market and the first selection process is performed, the accepted cores are delivered to the Remanufacturing Plant. The work shop receives first class quality at a good price. The old parts were sorted by type, temporarily stored and then brought to the dismantling area.

Here, a second selection is conducted, but while the first selection is based upon an external inspection, this time it will be carried out according to a deep and internal inspection. The quality condition of the recovered cores is now assessed in details (see Figure 19).

We deals with an industrialized and standardized process in which all cores are treated equally, no matter their age, defects or other conditions.

Figure 19: A recovered core is subjected to a detailed inspection from a Bosch operator.

In the dismantling area, used starters and alternators are expertly disassembled into their component parts (see Figure 20). The operator need to know exactly where and when to use the screwdriver and the mandrel, in order to properly disassemble the part without damaging.

During intensive cleaning, oil, dirt, rust and paint residues are all completely removed. The cleaned component are then carefully examined for their suitability (see Figure 21).

With Bosch Remanufacturer only important components that are subject to wear are replaced by corresponding new parts in Bosch quality, other components, for example the drive end shield or the slip ring end shield of the alternator, are maintained and simply reworked to bring them again back to their original condition. All these components need to successfully pass the dimensional and functional tests in order to go trough the Bosch eXchange Program.

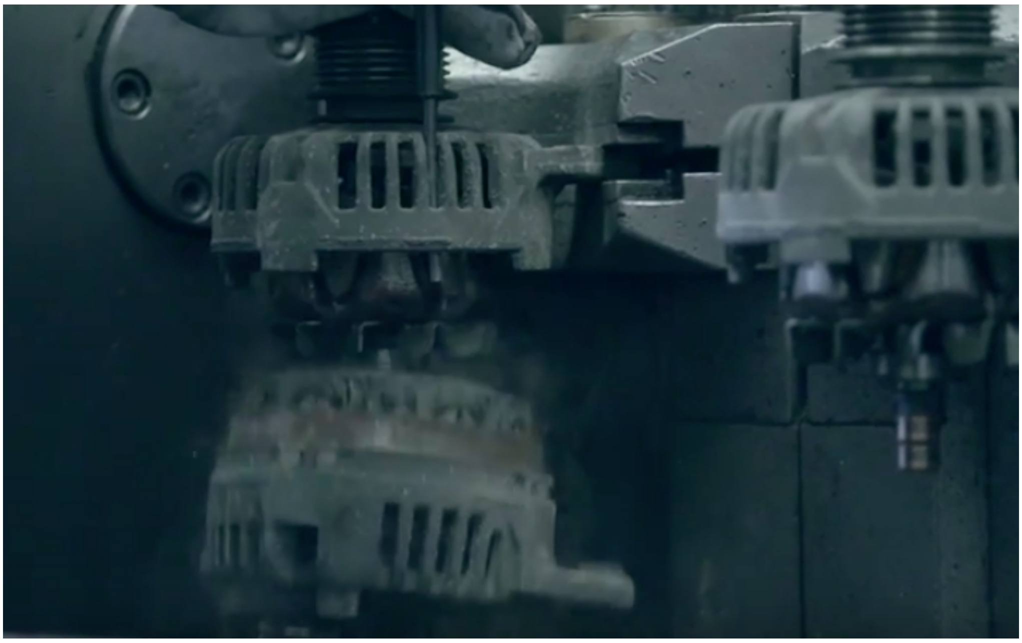

Figure 20: An old alternator is dismantled in its component parts.

After the components test, it comes the assembly process. This is carried out to the cores with the latest originally equipment specifications. Each step is clearly defined and documented. This ensure consistently high quality throughout the entire process. Bosch incorporate, in all products, improvements from the production of new components. Products are on the cutting-edge of technology.

During the final testing, remanufactured parts must prove 100% functional and perform efficiently. Throughout extensively repair and final testing, it is possible to ensure the high quality standards of Bosch eXchange.

In addition, quality is strictly controlled by a random individual test. Conducted according to original equipment standards, this test simulate years of use in the vehicle.

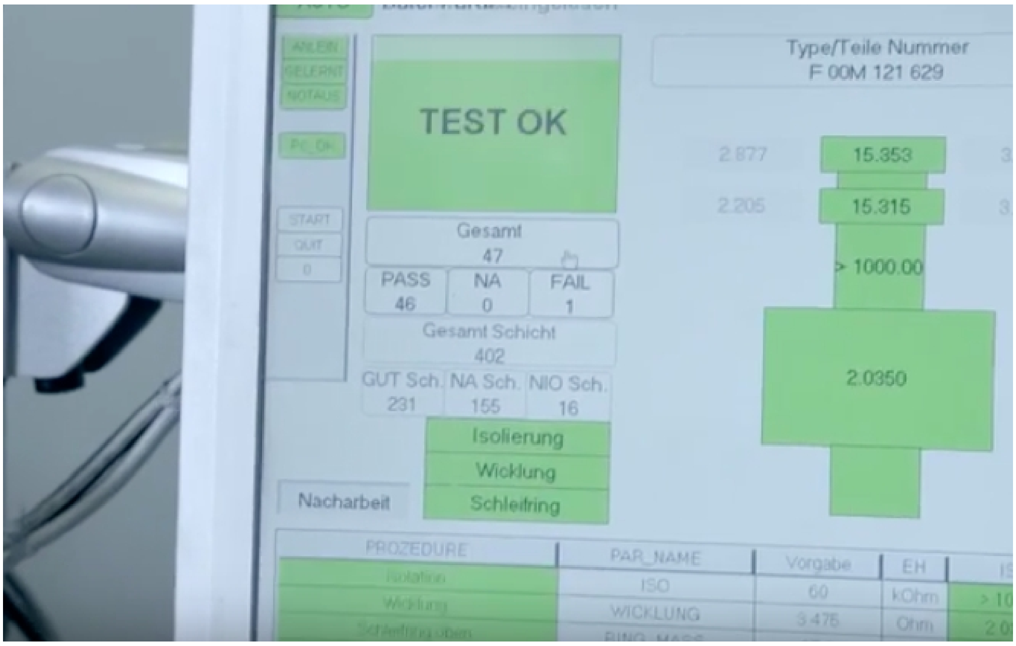

Figure 21: The components once cleaned will be tested in order to confirm their suitability.

The result of this process, it is a premium product, that has the same warranty, feature the latest cutting-edge technologies and simply work efficiently.

3.4 Quality Uncertainty of Returns: a High Scrap Rate

The quality of a reman product is determined by two major factors: the production process and the quality of returns. The uncertainty on the quality of returns is a critical factor. It is difficult for a company to control directly this external uncertainty element, as it is based on customers and on the efficiency of the supply process. Imposing on the customer to perform a pre-selection of cores, before send them to the remanufacturer, can result in an optimal solution for Bosch.

In addition to the two selection processes described in the paragraphs above, a further screening procedure should be performed by the customer. This will also result in minimizing the inspection efforts, therefore also time and costs, and will also leads to a more efficient use of cores transportation from the customer to the Regional Selection Station.

The CoremanNet Core Acquisition Management System keeps trace of the amount of cores accepted and scrapped among all the parts returned by the customer JLR. The histogram below (see Figure 22), gives us informations about the scrap rate registered by CoremanNet during the months in which the internship was served (from February 2018 to August 2018).

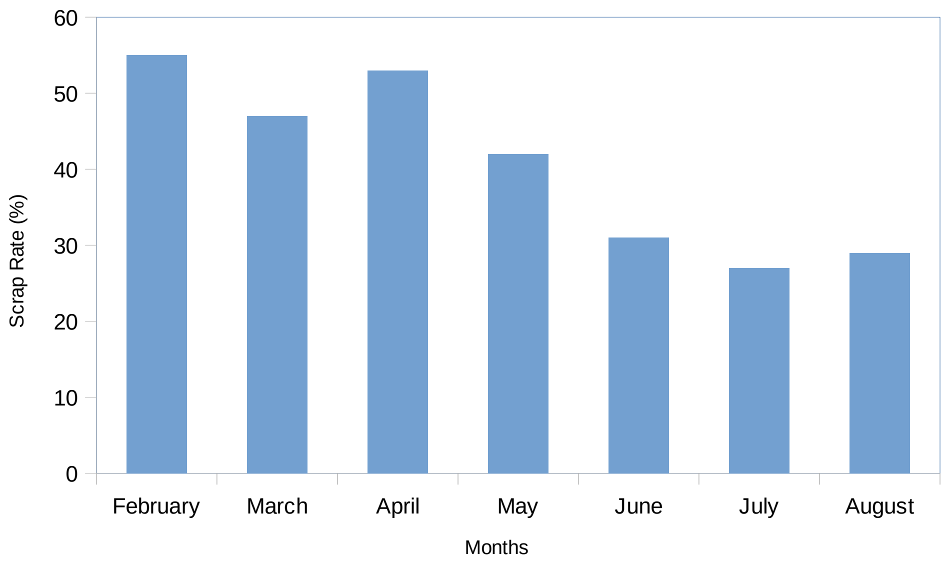

Figure 22: Scrap Rate of JLR on Starters and Alternators, data provided by CoremanNet for the period February 2018 – August 2018.

During the firsts three months of implementation of the Bosch eXchange Program in JLR, a relatively high scrap rate of about 50% (on average) on all returned parts was observed. An analysis on the whole remanufacturing process was, therefore, needed.

The student and the sales person for JLR were authorized by the company to investigate on the cores selection process directly at the customer warehouse and then in Germany, Nuremberg, where is located the Bosch remanufacturing plant for Starters and Alternators.

The contribution of the core analysis has highlighted that the customer often returned used cores without complying with any shared criteria. This resulted in an unnecessary usage of resources, additional and unjustified operational and logistic efforts and thus, consequent higher costs.

Thanks to the analysis conducted and to a subsequent negotiation of the sales person with the customer, an agreement was reached. Bosch will partially outsource its quality inspection operation, asking to the customer to firstly check the parts before send them back for remanufacturing. In order to gather a certain quality used products a market-driven channel is carried out by paying an acquisition price to the end users, which is an effective incentive mechanism to collect usable cores for remanufacturing. Furthermore, since higher the quality level of the used products, higher will be the deposit payback gained by the customer, Bosch grants itself a partial control on used product returns.

The Figure 23 below summarizes the external selection criteria that should be satisfied so as to decrease the used product scrap rate. The customer will be then compensated with an amount proportional to the core value returned.

Full Credit:

- Acceptable part number.
- Fully assembled and complete.
- No non operational damage such as excessive rust, corrosion, mishandling, torch marks, or fire damage.
- Not cracked or damaged.

Partial Credit:

- Housing or shaft cracked or damaged.
- Non operational damage such as excessive rust, corrosion, or pitting.

No Core Refund

- Unacceptable part number.
- Disassembled.
- Fire damage.
- Unsuccessful attempt to salvage.

Figure 23: Alternator core acceptance criteria and consequent credit offered to the customer.

And again, by looking at the Figure 22, as a final result of the implementation of a market-driven system, in the conclusive months of the internship period it was possible to monitor a lower scrap rate, now reduced to the an average value of 30%.

Conclusion

Quality uncertainty and its effects on remanufacturing systems are among the hot topics that need great attention due to their immense financial impact. This thesis work has described how Bosch attempt to reduce the quality uncertainty of returns, referring to a specific case for the remanufacturing of Starters and Alternators.

The remanufacturing enterprise should be able to thoroughly inspect each return based on its condition. Checking the quality of returns and applying a relatively strict selection process, will provide cost savings that will lead the company to reach higher profit related to the aftermarket sector.

From the analysis carried out in the third chapter it appeared advisable to make the customer firstly perform a quality inspection itself before deliver the used cores to the supplier. This will result in decreasing costs related to both the subsequent inspection processes and to the transportation costs from the customer to the regional selection station, driving, as a direct consequences, to a positive increase of the company profit.

Limitations and Future Research

We have noticed that the literature concerning remanufacturing lacks the involvement of quality uncertainty and its effects on systems' behaviour. Thus, this subsection highlight some limitations of the current study and suggests several topics to be further analyzed in order to better understand quality in the remanufacturing context.

The influence of returns' acquisition price on quality could be further investigated. For example, in the literature concerning remanufacturing, higher acquisition prices are associated to both higher quantity of returns and better quality of returns. Therefore, it could be interesting to examine in deep the relation between different acquisition prices of used cores and their returned quality. This will be another input to better control the Core Acquisition Process.

Moreover, the study previously developed, refers in general terms to the remanufacturing of mechanic components, in this specific case it deals with Starters and Alternators. Their economic lifetime extends increasingly, 15 years and more are often reached. But electronic components are characterized by a short life cycle which could end in an extreme case after only two years.

With reaching the maximum storage time, a test with the finished electronic components in stock has to be done. That kind of test is very expensive, as the test equipment needed for it is very complex and often unique to a single part number. Furthermore, technologies of the product itself or the production of electronic components develop quickly and old technology is no longer supported, as a consequence, high scrapping costs arise.

Therefore, a possible extension of this work could be an analysis for the remanufacturing of time sensitive products, whose quality is quickly eroded over time.

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