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Reverse logistics challenges in remanufacturing of automotive mechatronic devices

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Abstract

The remanufacturing industry as a whole and the automotive sector in particular have, over the years, proven to be beneficial to the environment and economically lucrative to the companies involved as well as to their customers. However, remanufacturing is associated with complicating characteristics, not least to mention the process of core acquisition.

The automotive industry is one of the earliest adapters of remanufacturing. Parts like engines, brake calipers and servo pumps are common targets for remanufacturing. Modern cars also have several embedded computers, often referred to as electronic control units that communicate, share information and verify each other over a Controller Area Network (CAN) bus. Due to their high value and an increasing trend in the amount of CAN bus mechatronic devices, interest in their remanufacture is growing.

Previous research has shown that it is preferable that the remanufacturer is an original equipment manufacturer (OEM), or has a close relation to the OEM, in order to achieve a well-performing remanufacturing business. In the automotive industry, there are many small and medium-sized enterprises (SMEs) that perform remanufacturing; for these enterprises, the challenges to have a profitable business are even harder. This is because the OEMs will not release any information on the communication parameters and therefore will not support the independent remanufacturing business. As a consequence, the independent remanufacturers, often SMEs, have to perform substantial reverse engineering.

This paper presents a qualitative research study, based on interviews at SMEs regarding challenges linked to the reverse logistics of SMEs remanufacturing and trading used automotive mechatronic devices, to identify specific challenges concerning the collection phase of automotive mechatronic remanufacturing. Challenges previously identified by researchers are confirmed, additional challenges within the collection phase are recognized, and challenges expected to arise when remanufacturing and trading automotive electronic CAN bus mechatronic devices are identified. The major concern for the involved companies when commencing future challenges is the handling, transportation and storing of cores. Even though the cores today mainly consist of mechanical devices, these challenges are still present; they are expected, however, to become even more crucial when cores contain a higher degree of mechatronic devices.

Keywords: Reverse logistics, Remanufacturing, Mechatronics, Electronics, CAN bus, Automotive, CAN REMAN, SME

Background

Remanufacturing is considered the ultimate form of recycling [1] and is sometimes referred to as a 'win-win-win' situation compared to traditional manufacturing since the customer pays less, the remanufacturing companies earn more and the environment benefits from less usage of raw materials and energy [2]. The benefits of remanufacturing have been put into figures by Giutini and Gaudette [3], who found that remanufactured products cost 40% to 65% less to produce than new products, are typically 30% to 40% cheaper for the customer to buy, and save globally the energy equivalent of 16 million barrels of crude oil annually. In a study by Sundin and Lee [4], it was noted that 11 of 12 environmental research studies found remanufacturing as a preferable option, at least in comparison to new manufacturing.

The remanufacturing industry has grown recently, and to date, close to 4,000 establishments are confirmed in

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the USA alone, with more than 110 known product areas [5]. The automotive part remanufacturing industry is roughly estimated to be a $85 to $100 billion dollar industry worldwide, where the value of the remanufactured parts was estimated to be $40 billion in the USA in 2009 [6].

A fairly new and interesting area within remanufacturing in the automotive industry concerns mechatronics (e.g. power steering systems, central locking systems and anti-lock braking systems) and electronic systems (e.g. engine control units and distance control units) communicating via a Controller Area Network (CAN) bus. Developed by Bosch in 1983, CAN is a serial communication bus designed to provide robust, simple and efficient communication for in-vehicle networks [7]. The rapid growth in complexity of automotive electronics in the following decades made traditional point-to-point wiring increasingly expensive to manufacture, install and maintain; hence, CAN soon became adopted by all car manufacturers, resulting in a sales growth of CAN nodes from merely 50 million in 1999 to more than 340 million in 2003 [7]. Given the many CAN nodes in a modern vehicle and the high costs associated with replacing a malfunctioning device, ranging between 200 and 3,000 €, there is an economic incitement for remanufacturing such devices and an opportunity not yet exploited [8].

This research was part of a research project called 'CAN REMAN', with the target to develop innovative diagnosis methods and technologies for automotive mechatronics and electronic remanufacturing. The project, funded by the European Union, was conducted by Bayreuth University (Germany), Linköping University (Sweden), the University of Applied Sciences Coburg (Germany), Fraunhofer Project Group Process Innovation (Germany) and eight European small and medium-sized enterprises (SMEs). The aim of this paper is to identify previously unknown, and verify known, reverse logistics challenges experienced by SMEs that are about to remanufacture or trade automotive mechatronics and electronic systems communicating through the CAN bus system.

Reverse logistics challenges - in theory

Remanufacturing differs from traditional one-way manufacturing in several ways. These differences are also associated with manufacturing challenges and are necessities to realize a successful remanufacturing system (i.e. core acquisition, remanufacturing process and redistribution [9]). These challenges have been recognized by researchers, e.g. [9-12], but also have been summarized by Lundmark et al. [13], who also categorized them according to where and when in the remanufacturing system they occur.

In the literature about challenges within the collection phase of the remanufacturing system, there is a lot of emphasis on a lack of control regarding quantity, quality and timing of the returned products. This lack of control is recognized by, for example, [10-12,14-17] and is caused by:

- Reflection of the uncertain life of a product [11]
- Product life cycle stage and the rate of technological change [11,16]
- The dispose behaviour, which results in a stochastic return pattern [14,16]

The lack of control regarding quantity, quality and timing of the returned products (cores) is described as the major difference between a traditional production-distribution network and a product recovery network [18]. The handling of these control issues is stated as the key for creating profitable remanufacturing by Guide and Van Wassenhove [19]. In addition, there is also uncertainty regarding the demand of the remanufactured products. This uncertainty is caused by the following:

- The rate of technical development. The demand for a product might suddenly drop due to the technical development [16].
- Detailed forecasting is not possible to perform due to uncertainties regarding timing and quantities of the eturned products [16].

In order to maximize profit, a remanufacturer must be able to balance the return of cores with the demand from customers for remanufactured products. If not, the remanufacturer faces the risk of building up excessive amounts of inventory (when returns exceed demand) or low levels of customer service (when demand exceeds supply) [11]. The uncertainties in supply and demand make it hard for many remanufacturing companies to balance supply and demand [11]. All companies do not try to balance the supply with demand since the uncertainties in supply and demand makes inventory management and control functions more complicated [11]. The kind of motivation for returns could also affect the situation for the remanufacturing company since a take-back obligation might give the remanufacturing company an abundance of used products [12]. A survey conducted with 48 remanufacturing companies by Guide [11] showed that more than half of the companies had no control over the timing or the quantity of the returns. The remanufacturing companies that do not try to balance supply with demand instead dispose excess used products on a regular basis [11]. Excess used products might cost a lot of money, and the disposal cost might be high [11,15]. The storage area needed to store the excess used products is also often expensive [15]. Another challenge is that a remanufacturing firm typically has a large number of sources which means that a remanufacturing firm has to bring together a large number of small volume flows which increases the complexity [14].

According to Lundmark et al. [13], the uncertainties regarding quantity, quality and timing of the returned products are the main challenges for the collection phase of the remanufacturing system. The uncertainty in timing and quantity of the returned products also make the remanufacturing process less predictable than an ordinary manufacturing process [19]. This uncertainty makes production planning more difficult [12,15]. The uncertainty in quality adds challenges to the remanufacturing process in two different ways. Two returned products (cores) that are identical might yield a very different set of remanufacturable parts which makes inventory planning and control and purchasing more difficult [11].

Reverse logistics challenges - in CAN REMAN

Reverse logistics in CAN REMAN

Reverse supply chains comprise the activities, routes, intermediaries, etc. when transporting products in the opposite way compared to forward supply chains, i.e. from the customer or end user, via possible intermediaries to the remanufacturer, as can be seen in Figure 1. Intermediaries can, for instance, be retailers and repair shops in the forward supply chain and core brokers and scrap yards in the reverse supply chain. How the reverse supply chains are designed, i.e. how used products are brought back to the remanufacturer, plays an essential part in the remanufacturing system as a whole since it is of most importance to receive the right cores in the right quantities at the right time in order to be able to perform successful and profitable remanufacturing.

The designing of reverse supply chains is a delicate procedure with many variables and aspects to take into consideration, and there exists no general optimal supply chain. The number and type of cores (material, value, size, weight, etc.) that are to be transported highly influence the design of the reverse supply chain. In addition, types of core suppliers, types of core acquisition and relationship between remanufacturer and supplier/customer have a great impact.

Core acquisition

A remanufacturer of automotive components normally has the possibility to choose from several core suppliers, as can be seen in the next section. The choice of supplier does not, however, automatically set the guidelines and rules on how the core acquisition is made but may enforce a certain acquisition type or open up for multiple choices. It is common that remanufacturers' ways to acquire cores vary between different types of core suppliers, but even the acquisitions within the same type may differ:

- Direct-order: in this situation, the supplier who also is the customer gives an order for the remanufacturing of a used product. The supplier/customer sends the core to the remanufacturer, which, after being remanufactured, is sent back to the supplier/customer. Within the scope of this research, there is a tendency that this type of acquisition is common when remanufacturing relatively complex products such as engines and more likely towards end users. In addition, it is common that the customer/supplier is responsible for the transportation to the remanufacturer.
- Reman-contract: this type of transaction is somewhat similar to direct-order since the supplier, which also is the customer, gives an order for remanufacturing. Also, the ownership of the core and the remanufactured product remains at the customer. However, this type is guided by a contract and spans over a longer time, with closer collaboration between remanufacturer and customer/suppler and also involves greater quantities. While direct-order is common towards end users, reman-contracts are more commonly used in collaborations with original equipment manufacturers (OEMs).

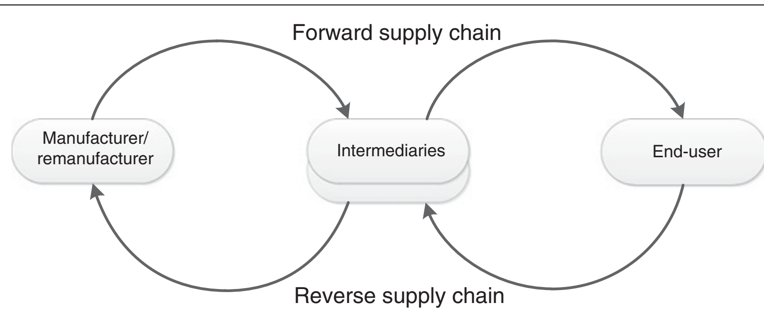

Figure 1 Schematic view of forward and reverse supply chains.

- Deposit-based: this means that when the customer buys a remanufactured product, the customer is obligated to return a similar used product. This type of transaction is frequent within automotive remanufacturing and in particular concerning components that are cheap and often exchanged at services (e.g. brake calipers).
- Credit-based: the customer receives credits for returning a core, which can be used as a discount when buying a remanufactured product. The supplier is also a customer in this case.
- Buy-back: the remanufacturer buys the core. One could say that the characteristic of this type of acquisition is the lack of relationship since neither the supplier nor the buyer has any further obligations after the transaction is made. It is common that remanufacturers buy cores from core brokers or scrap yards but could possibly be end users as well. The supplier is, in this case, seldom the customer.

Types of core suppliers

This section describes the different core supplier types that have been identified within this research. It is a somewhat simplified picture given since a classification is necessary in order to get a uniform view. It is noteworthy to observe that the reverse supply chains depicted are sources of used automotive components (cores), not virgin spare parts, etc. In a sense, end users normally supply all cores, but in this report, the categorisation and the type of supplier derive from the supplier closest down in the supply chain. The identified core suppliers are end users, scrap yards, core brokers, OEMs and independent aftermarket distributors (IAMDs).

Reverse supply chains in the CAN REMAN project

This paper presents a qualitative study of six SMEs, of which their primary, if not solely, business segments are the remanufacturing of, or trading with, automotive mechatronic devices. Four of the companies studied are German remanufacturers (companies A to D). The remaining two are Swedish (companies E and F), where the latter is a core broker and hence not conducting any remanufacturing but is still an important factor in the reverse supply chain. An overview of the participating companies can be seen in Table 1. In a parallel CAN REMAN research study on inter-organisational relationships, companies A to E are studied further with the same notation [20,21].

The following sections present reverse logistics challenges identified and verified during interviews within the CAN REMAN project. An overview of the challenges experienced by the interviewed companies can be seen in Table 2. An empty space in the table means that the company does not consider the specific subject as a challenge or that it has chosen not to answer.

Controlling quantity of cores

Company A is sometimes forced to buy larger quantities than needed by its customers since core suppliers require minimum order quantities. Strong competition among core acquisition for new article numbers forces company B to buy cores without having a concrete demand. Company D experiences difficulties acquiring a sufficient amount of cores for its fast-moving product variants. Although the lack of control regarding quality is considered a challenge, both Swedish companies (E and F) accept it as a part of their business.

Table 1 General characteristics of the participating companies

Company	A	B	C	D	E	F
Products	Automotive, marine, heavy-duty and industrial engines and parts	Alternators, starters and marine and heavy-duty engines	Engines, gearboxes and differential gears	Car engines and diesel injection parts	Brake calipers, DPFs, hydraulic servo pumps, water pumps, EGR valves	Wide range of automotive parts
Company size (employees)	Medium (100)	Small (24)	Medium (80)	Medium (80)	Medium (50 + 110)	Small (6)
Annual turnover (million €)	14	1.6	4	12 to 13	7	0.8
Number of variants	650 cylinder heads, hundreds of engines	2,500 internal variants	Hundreds of variants per product	200 variants of engines, uncountable variants of diesel injectors	2,800 variants of brake calipers, 3,000 in total	10,000 to 20,000
Core suppliers	End users, IAMDs, OEMs, scrap yards, core brokers	End users, IAMDs, OEMs, core brokers	IAMDs, OEMs, end users	OEMs, scrap yards, core brokers, end users	OEMs, core brokers, scrap yards, IAMDs	Scrap yards, core brokers, IAMDs
Relation to OEM	Independent, contracted	Independent, contracted	Independent, contracted	Contracted, independent	Contracted, independent	Independent

Table 2 Overview of reverse logistics challenges identified within CAN REMAN

	Controlling quantity of cores	Controlling quality of cores	Controlling timing of cores	Balancing supply and demand	Additional challenges	Expected CAN bus challenges
Company A	X					
Company B	X	X	X	X	X	X
Company C		X	X			
Company D	X				X	X
Company E	X	X	X	X	X	X
Company F	X	X	X	X	X	X

Controlling quality of cores

According to company E, the challenge of controlling the quality of the returned cores differs between types of products. It claims to have total control of the quality of the returned brake calipers. There are two reasons for that. Firstly, brake calipers have a simple design and are made out of a robust material but also contain few parts, which make units worn beyond their remanufacturability infrequent. Secondly, because of their design, it is easy to visually determine whether a unit is remanufacturable or not. Regarding servo pumps, the situation is different since one cannot determine a core's condition without disassembling it. Internal parts may be broken beyond remanufacturing, and it is not feasible to have every single core opened before they arrive at the facility.

Another quality-related challenge concerns the handling of the cores. Company E estimates that 60% to 70% of the initially sound diesel particulate filters (DPFs) from one of its core suppliers are being damaged when dismounted from the cars or when transported to company E's remanufacturing facility. The damages are assumed to be caused by the mechanics at the OEM dealers as well as by the companies responsible for the transportation of the cores - they do not recognize the value of the cores and thereby handle them in an incautious way. This is especially critical for DPFs since reckless handling and transportation can lead to damage not visible to the naked eye, hence first noticed in the remanufacturing process. The effects are increasing scrap rates and that cores originally suited for remanufacturing can no longer be remanufactured. This issue is also being referred to as a challenge by company B.

Company C uses check sheets that private customers and car dealerships/repair shops must fill out in advance to avoid receiving non-remanufacturable cores and cores too costly to remanufacture. This improves quality control, but does not eliminate the need for quality inspections at arrival.

Company F considers the lack of control of the cores' quality as a challenge, but in contrast to the remanufacturers, 90% of the cores are visually inspected before they are bought, making the degree of control higher in this case.

Controlling timing of cores

The lack of control regarding the timing of the returned cores is considered a challenge by companies E and F, but only if there is a lack of the specific core in the market. Company B controls the timing of deliveries for all supplier types except for private customers, who are harder to control. Company C lacks control of the core deliveries from OEMs, but the use of check sheets (see previous section) for private customers and car dealerships/repair shops facilitates influence over the timing of the incoming cores from those suppliers in a positive way.

Balancing supply and demand

Companies E and F experience a lack of control regarding balancing supply and demand, but their situation differs from each other. Company E usually gets a 12-month time horizon on the estimated demand from the contracted OEMs, which are core suppliers/customers that company E is contracted to perform remanufacturing for. From these forecasts, additional cores are bought if needed from other suppliers, e.g. scrap yards and core brokers. Statistics from previous years are also kept, thereby helping to distinguish trends in demand. The prerequisites are similar for company B. Company F has much shorter time horizons, usually only a week or a month ahead.

A different aspect on the issue of balancing supply and demand is how company F buys certain cores without having a concrete demand but believes it will rise in the future. The motive is twofold; cores that are bought prior to the actual demand are cheap, hence displaying large profit margins if later sold. In addition, buying predemand cores prevents or diminishes competition within core acquisition. However, the speculating comes with a price tag. Apart from the obvious cost associated with storing cores until demand arises, there is an imminent risk that the anticipated demand never occurs, thus making the acquired cores less worth. This situation especially concerns CAN bus mechatronic devices that have yet to be remanufactured.

Additional challenges within the collection phase

A challenge identified by company E concerns the identification and sorting of cores at its suppliers, which, in this case, are OEM retailers. The deliveries often contain unwanted parts and mechatronic devices (e.g. turbochargers and dashboards). This is believed to be caused by a lack of routines at the retailer where the personnel, even though having specified which parts were to be sent for remanufacturing, do not put the right parts in the right core bins. The effect on company E is that warehouse space is allocated, both to store the unsorted goods as well as to store the unwanted goods before being transported away for scrapping. It is also time-consuming to perform the sorting. However, this identification issue is not considered as severe and can sometimes even provide useful information about new part numbers currently not in the remanufacturing program.

A challenge acknowledged by company F is the decreasing number of scrap yards, which are core suppliers to company F. One plausible explanation for the decrease is that insurance companies certify fewer scrap yards now than before. The consequence for company F is twofold. Firstly, fewer suppliers result in less competition among those remaining and hence higher core prices. Secondly, but not less important, the fewer larger suppliers remaining tend to focus their business on scrapping cars rather than dealing with cores.

The second challenge affecting company F is the recently increasing scrap prices, which follow the prices of raw materials, which, in this case, are metals. When scrap prices are high, scrap yards would rather sell the dismantled cars as scrap than sell the individual mechatronic devices to core brokers or remanufacturers.

A further challenge for company F is the competition from low-labour cost countries. When there are brand-new spare parts available at a cost close to, or even cheaper, than a remanufactured part, the demand for remanufactured parts decreases. This is also acknowledged by companies B and E.

In addition, company F has experienced actions from OEMs where they have tried to hinder competition from core brokers and remanufacturers, either by dumping prices of new parts or by clean-sweeping the market from cores. Similar actions have been taken against company D, where OEMs refuse to sell spare parts needed to perform remanufacturing of their products. Company B experiences that OEMs delay technical information (e.g. test parameters) about the products on purpose, which, due to the effort, put into reverse engineering results in higher remanufacturing costs, which is further elaborated on in [8].

Expected reverse logistics challenges of CAN bus mechatronic devices

A concern for companies B, D, E and F is the handling of cores containing CAN bus mechatronic devices. Three perspectives on this matter have been brought up during the interviews. These are the following:

- *Disassembly*: it is important that OEM retailers and scrap yards have routines for how to remove parts without damaging them.
- *Storage*: cores containing electronics are sensitive to moisture; hence, it is important that CAN bus cores are stored in dry and preferably warm environments.
- *Transportation*: there is a concern that cores not being handled and stored properly during transportation will be damaged on their way to the remanufacturer or core broker.

A challenge company F will be facing, and is currently facing to a certain extent, is the large gap between the sales price of the remanufactured product and the cost of the core. For example, a remanufacturer buys a used ECU for $3 to $5 from the core broker which is then sold remanufactured for up to $500. For a core broker to sell a core for $3 to $5, it has to be bought for $1 to make profit, which is scrap price. This is claimed to be caused by the lack of competition among remanufacturers of automotive electronics.

During the interview with company F, it was mentioned that dealing with electronic mechatronic devices will further complicate the supply versus demand challenge since an entirely mechanical device will surely fail during a car's life, while the fail pattern of an electronic device is much more stochastic - it might even last the vehicle's entire lifetime.

In addition to the findings of this paper, another paper by Freiberger et al. [8] outlines challenges, possible solutions and technological progress for the reverse engineering process of CAN bus mechatronic devices. That paper includes the reverse engineering process demonstrated on an electro-hydraulic power steering, which is a CAN bus mechatronic device used in a Volkswagen Polo [8].

Discussions

The business model that the remanufacturing company uses might have an effect on the remanufacturing system and especially the core acquisition. For example, Sundin and Bras [22] stated that functional sale reduces the uncertainty regarding returns by giving the remanufacturing company better knowledge of the timing and quantity of the return. This is also acknowledged by Thierry et al. [10] who stated that quantity and timing of the returns are easy to predict at the end of a leasing or rental contract even though the quality still can be uncertain. It is easier to have rental programs for OEMs to perform remanufacturing than for those independent remanufacturers included in this study. However, the independent remanufacturers could move towards being contracted by the OEMs in order to benefit from a functional sales (e.g. rental) business model.

How close collaboration the remanufacturing company has with the retailers and distributors also affects the possibility for a remanufacturing company to coordinate the collection of returned products [18,19]. Different relationships and the effect they have on the situation for the remanufacturing company were deeply discussed by Östlin et al. [18] and Lind et al. [20,21]. A type of relationship that also was discussed by Guide [11] and Östlin et al. [16] is when the remanufacturing company remanufactures used products (cores) that the customer sends to them. Then the challenge with balancing supply and demand does not exist, though this might add additional challenges to the production planning.

Conclusions

This paper addresses reverse logistics challenges experienced by six SMEs in the automotive remanufacturing industry. Indeed, these companies, five remanufacturers and one core broker, face challenges traditional manufacturing companies do not have to deal with. The challenges previously identified by researchers, e.g. Lundmark et al. [13], which are faced by remanufacturers in general, were also confirmed as challenges by the interviewed companies remanufacturing automotive mechatronic devices. For instance, a reflection of the uncertainties regarding the demand and the difficulties in securing core supply was given by company F, which keeps a stock of cores despite not yet having a concrete demand for remanufacturing.

Additional challenges varying in significance and frequency were identified during the interviews. One concerns the reckless handling of the cores, both during disassembly and during transport to the remanufacturer. A possible solution that seems simple to implement, at least theoretically, is to inform mechanics as well as the responsible logistics company how to handle and package cores. This issue was also discussed during the interviews, now concerning future challenges when remanufacturing CAN bus mechatronic devices. The majority of the interviewed companies believe that careful dismantling, storage and transportation of cores containing electronics will be of high importance.

This paper, along with a previous literature review by Lundmark et al. [13] and the work on inter-organisational relationships by Lind et al. [20,21], builds a foundation for the future work to design, verify and implement reverse supply chains that diminish the impact of the challenges identified in this paper and hence better suit CAN bus mechatronic device remanufacturers. In addition, remanufacturing needs to deal with more process-oriented challenges such as testing and diagnosing as described for the CAN REMAN project in Freiberger et al. [8] in order to boost and facilitate CAN bus mechatronic device remanufacturing even more.

Methods

The empirical data have been collected through semi-structured [23], face-to-face interviews ranging between 2 and 3 h and were conducted by native-speaking interviewees from both Germany and Sweden. The interviews were held at the companies' sites in late 2009 and late 2010.

Abbreviations

CAN: Controller Area Network; DPF: diesel particulate filter; ECU: electronic control unit; OEM: original equipment manufacturer; SME: small and medium-sized enterprise.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

Both authors have collaborated in writing the manuscripts of this paper. ES planned and designed the interviews together with the Ph.D. students who conducted the interviews. ES conducted the pilot interview. OD summarized the Ph.D. students' interview data and made the first draft of the manuscript. Both authors read and approved the final manuscript.

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