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Potential assessment of an increased exchange of core information for remanufacturing in automotive reverse supply chains

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Abstract

An increasing awareness of sustainability and scarcity of resources requires to enhance a product's lifetime. Within the context of a circular economy, remanufacturing therefore can be applied. Used products (so-called 'cores') are returned to at least their original performance. An efficient planning and management of reverse supply chains (RSC) is a prerequisite for successful remanufacturing. Besides the required material flow from the customer via service centers, collection stations, and core brokers to the remanufacturing plants, the reverse flow of core information is essential. The multi-tier exchange of core information potentially facilitates reducing existent uncertainties in RSC, i.e. regarding timing, quantity, and quality of returned products. Yet, current approaches neither consider the multi-tier information flow nor the differentiation of core information for different downstream tasks in detail. Specifically, information flow in the automotive RSC remains to be researched in detail. Therefore, the potential of an increased exchange of core information for remanufacturing in RSC is explored in this paper. A literature review and expert interviews with the stakeholders in the automotive RSC are conducted to assess the status quo of information exchange. Based on this, relevant core-specific information, and their impact on increasing the efficiency of different downstream planning processes are identified. To quantify the potential of an increased information exchange, both a model for the categorical use of information and a receptor model are developed. It can be concluded that an increase in the exchange of information in remanufacturing goes along with a multitude of facilitations, e.g. regarding logistics optimization, material requirement planning and stochastic routing of cores. Moreover, due to the prioritization of core information, a sequence model for core information retrieval can be derived.

Keywords: remanufacturing; reverse supply chain; information exchange, automotive aftermarket; simulation

1. Introduction

A growing society with increasing consumption is confronting a scarcity of resources. To extend a product's lifetime and reuse its components at the highest possible value, so-called remanufacturing can be considered as a circular economy option [1]. Remanufacturing can be seen as an "industrial process whereby products referred as cores are restored to useful life" [2]. Thereby several process steps, such as inspection, disassembly, cleaning, part replacement as well as refurbishment, reassembly, and testing are carried out to ensure that the product meets a like-new standard.

For a product to go through this process, an efficient reverse logistics (RL) between the different participating actors is essential. RL can be defined as "the process of planning, implementing, and controlling backward flows of raw materials, in-process inventory, packaging and finished goods, from a manufacturing, distribution or use point, to a point of recovery or point of proper disposal" [3]. As an extension of this definition, the backward flow of information related to the cores can be added [4].

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In the context of the automotive aftermarket (AA) in general, but specifically in this work, the reverse supply chain (RSC) can be understood as follows: Customers bring their broken vehicles to a workshop, where the defect component is removed and replaced. The removed components, i.e. the cores, are handed over to either collection stations or core brokers, i.e. external companies acting between supply and demand [5]. Remanufacturers then procure the cores from the latter before they are transported to the remanufacturing plant. After the cores have been remanufactured, they are sold to customers through the remanufacturer's distribution channels in a further life cycle [6].

While the described flow of materials is already intensively addressed in research, the exchange of core-related information in RL remains largely unexplored in the sector of the AA. Therefore, the aim of this paper is to (1) explore the current situation in reverse logistics in the AA regarding information exchange between the participating actors; and (2) identify relevant core-specific information and its benefits for the actors involved in reverse logistics.

To achieve this aim, the paper is structured as follows. First, a review and assessment of the research relevant to this topic is provided. This is followed by the development of a methodology for filling the research gap and answering the proposed objectives. The resulting findings are then presented and evaluated, before this paper is concluded with a summary and an outlook on further research.

2. Related Work

Information about the quality of cores is studied by Zikopoulos & Tagaras [7] who consider its impact on the profitability of remanufacturing activities. They choose two collection stations and one remanufacturing plant as actors and consider the optimal quantities to be sourced from the collection stations. It becomes clear that the quality of sorting has a significant influence on profitability.

Based on this approach, Zikopoulos & Tagaras [8] consider the point at which sorting should be conducted. To this end, they compare quick sorting using technical aids at the collection stations with no prior sorting at the remanufacturing plant. As a result, sorting at the collection station before the cost and time intensive dismantling step, is recommended to save the incurring costs.

The impact of a core's quality is further discussed by Barquet, Rozenfeld & Forcellini [9], among others. They underline the central role of information transfer for handling uncertainties when coping with returned cores and point out that the information, however, reaches the remanufacturers only at a late stage. Information is also considered relevant to avoid transport routes and initial steps of the remanufacturing process in case of unsuitable cores. To be able to cope with the uncertainties, they highlight relevant aspects of information that should ideally be addressed in collaboration with other actors in the RSC.

The benefits of an increased efficiency and a higher customer satisfaction resulting from an information flow between actors of the supply chain is addressed by Kurilova-Palisaitiene, Lindkvist & Sundin [10]. As an outcome of their work, the recording of information on the core quality emerges. By visualizing the flow of information, they identify information losses to subsequent stakeholders and feedback bottlenecks.

In the approach of Chunfa, Jingfeng & Jianjian [11] information that is to be captured by an information acquisition system, is presented based on four information categories. They emphasize the importance of information determination to counteract uncertainties and thus, contribute significantly to the efficiency of remanufacturing.

A case study by Li et al. [12] illustrates relevant information in the field of electrical and electronic equipment on the basis of LCD TVs. For the creation of a bilateral, secure, and efficient flow of information, product identification is considered the most important in this sector.

Moving toward the AA, in the work of Kurilova-Palisaitiene & Sundin [13] data from a German engine manufacturer is collected. The authors investigate reasons for uncertainties in material and information flows and try to find lean-inspired internal solutions. Therefore, the current situation of the information flow is considered, which is generally characterized as interrupted and inaccessible, both internally and between the participating actors. According to the authors, the remanufacturing process can be sustainably improved through accessible information on product characteristics, maintenance history and the condition of incoming cores.

Kurilova-Palisaitiene, Sundin & Poksinska [14] define the problems that arise for remanufacturers because of incomplete, incorrect, or missing information transfer from upstream actors. Difficulties in inventory management, the coordination of the production or distribution are mentioned in the context of potential impacts. Therefore, a total of seven lean methods are proposed to counteract the ten predefined problems of remanufacturing.

None of the presented work involves all actors of the AA. Instead, they only consider the remanufacturers or the collection stations, but do not mention core brokers or workshops in specific.

The current situation of the information exchange between the participating actors as well as core-specific information and the resulting use is only obtained from the remanufacturers' point of view (see Table 1).

3. Research Methodology

As can be seen from the assessment of the existing literature, none of the two research goals is fully addressed yet. To tackle the deficits identified in section 2, expert interviews are conducted to determine relevant core-specific information and its benefits for individual participants in the RSC.

Relevant insights to achieve the research objectives can be found among all actors of the RSC flow derived in Chapter 1.

Table 1. Summary of the analysed related work

Literature	Actors of the reverse supply chain	Current situation of the information exchange	Use for actors of the reverse supply chain	Core-specific information
Zikopoulos & Tagaras (2007)	◑	○	◔	◑
Zikopoulos & Tagaras (2008)	◑	○	◔	◑
Baquet, Rozenfeld & Forcellini (2013)	◔	◔	◔	◔
Kurilova-Palisaitiene, Lindkvist & Sundin (2015)	◔	◕	◑	◑
Chunfa, Jingfeng & Jianjian (2010)	◔	◔	◑	◑
Li et al. (2012)	◔	○	◕	◑
Kurilova-Palisaitiene & Sundin (2015)	◔	◕	◔	○
Kurilova-Palisaitiene, Sundin & Poksinska (2018)	◔	◑	◔	◔

● fully realised ◕ largely realised ◑ partially realised ◔ marginally realised ○ not realised

They come from different areas of the industrial environment that guarantee a practical perspective. The underlying business models, which provide incentives for the return of cores, vary over the actors as well as the expected availability and value of information. By the interviewees in this work, either a core-surcharge-model basing on financial incentives on remanufactured products or a direct-purchase model for cores has been considered.

The interviews were divided into three groups according to the respective field of the interviewed expert corresponding to the respective stage in the RSC. Following the division into remanufacturers, collection stations together with core brokers, and workshops, guiding questions were formulated. These were derived from the research domains as well as the interview results from the previous stages beginning with the interviews with the remanufacturers and going further upstream the RSC.

A total number of eleven interviews (4 remanufacturers, 2 collection stations, 1 core broker, 4 workshops of which two are independent and two are brand-related) were conducted. For the workshops, preference was given to those familiar with the remanufacturing process.

After conducting an interview, the recording was content-semantically transcripted and evaluated regarding core-specific information deemed relevant [15]. These interim evaluations used for the guiding questions in the further interviews were completed by a full content analysis after all data had been collected.

Within this analysis, the interviews were subdivided by assigning individual text segments to content groups. This enables identifying overlaps or contradictions, especially within the individual interview stages, in more detail to be able to assess the validity of the results.

4. Results

4.1 Current situation in reverse logistics in the automotive aftermarket regarding information exchange

In the case of the remanufacturers, nowadays little to no information is provided by the prevailing actors in advance. Only rough quantities and product groups are known in all four cases. Thus, more detailed information is desired. Most interviewees mention a prevailing lack of information that complicates and severely limits early planning as well as forecasting, thus resulting in the need to perform on-site information development, e.g., by functionality tests.

For the second interview group, the collection stations and core brokers, the situation is similar. Today, no information is passed on in advance from the workshops, so that they only receive information by determining it themselves.

The workshops, on the contrary, do not need most of the desired information from the other subsequent actors for their processes, which is the reason why only little information about the cores is currently being recorded. In addition to the one-sided view of the flow of information from the workshops to the remanufacturers, the opposite direction is also addressed in the interviews. In this regard, remanufacturers do not provide any information on how the remanufacturing process works in detail for the cores, so that no feedback flow exists. Consequently, the usefulness and profitability of remanufacturing processes are questioned by the workshops. In addition, easier access to the aftermarket product range is seen as helpful.

It can be concluded that, in general, the benefits for all subsequent actors can be maximized, the closer to the last usage phase of the core the information is collected.

4.2 Identified relevant core-specific information

A total of eleven different core attributes are deemed relevant to the participating interviewees. From these, the information on the product number being used for identification purposes as well as the core's mileage, the error codes, and the age to determine how to further proceed with the core are considered the most relevant. Additionally, it is helpful to know the overall core quality in advance. Thereby, characteristics like completeness, damage or corrosion can lead to cores being sorted out at an early stage so that they do not have to pass the entire RSC. Likewise, the core quality includes originality, whether or not the core is a previously remanufactured product, as for some products these cannot be remanufactured a second time.

The core attributes are completed by the less mentioned information on the core classification (e.g., volume, weight), the core's origin, executed inspections of the vehicle during its lifecycle, and the quantity of arriving cores. Especially for the collection stations exact arrival dates of a load as well as its correct marking to allocate the deliveries are needed.

4.3 Use of core-specific information

The usefulness of information can be assigned to the categories of *logistics, planning activities, process steps, product development* as well as *statistics*. The first three are further subdivided (see Table 2).

The information can be classified together with the frequency, which represents how often a connection is seen between a core-related information and a category in the

Table 2. Categorical use and expected advantages of core-related information

		Product number	Mileage	Error codes	Age	Overall quality	Product classification	Origin	Inspections	Quantity	Date of arrival	Correct marking
Logistics	Route optimization			●●	●●●	●●●●		●●				
	Logistics capacity planning					●	●			●		
Planning activities	Production program planning	●●●								●	●	
	Employee capacity planning									●●	●●	
	Material requirements planning – spare parts	●	●●	●	●							
	Lead-time estimation	●	●●	●●●	●	●●				●		
Process steps	Stochastic routing		●●	●●●	●	●						
	Sorting/inspection step	●●		●●●	●	●●●		●				
	Incentive payment process				●●							●
Product development			●									
Statistics			●						●			

interviews with the remanufacturers, collection stations, and core brokers.

Route optimization as a subcategory of *logistics* can be affected by the earlier exclusion of cores due to reasons of excessive age, qualitative defects, or needed spare parts that can no longer be procured. In this way, routes can be optimized, and the cores can be transported as quickly as possible to the next station intended. This connection is often drawn in the interviews. Capacity planning for transport is considered less often and includes the characteristics of a core that can affect transportation, such as weight or special wrapping.

As a *planning activity*, production program planning includes the order which batches are processed and when. To do so, the exact product number can help to calculate the batch sizes accordingly and prefer the cores with a higher demand. The estimation of the required employee capacity can be made more precise by the quantity and the arrival date of the cores in the collection stations and the remanufacturing plants. With the knowledge about installed and possibly defective components that result from the combination of the age and the product number as well as significant error codes, the planning activities of the remanufacturers regarding the need for spare parts can be facilitated. As a last subcategory of planning activities, lead-time estimation is mentioned. From information such as age, qualitative deficiencies, or error codes it can be derived how to proceed with the core. Consequently, the processing steps to remanufacture a core can be planned.

Closely related to lead-time estimation is stochastic routing, which captures the *process steps* needed for reprocessing. As a result of this interdependence, overlaps occur between these two subcategories regarding the connected information and their frequency. Almost half of the information is associated with a benefit in the sorting or inspection step in the interviews. The general observation is that any information that can be communicated at the earliest possible stage facilitates subsequent steps or in some cases even disables them. The incentive payment process is only affected by the correct marking, thus being able to identify the recipient of the payment more efficiently.

The two categories of *product development* and *statistics* are less positively susceptible to core-specific information. Thereby, the link between executed inspections or the mileage and statistical evaluations is seen concerning data gathering for future product developments or predictive maintenance.

4.4 Development of a receptor model for analyzing the effect on material requirements planning and route optimization

To further illustrate and differentiate the effects of the identified core-specific information on material requirements planning (MRP) and route optimization (RO), an exemplary receptor model for these two tasks is developed (see Table 3). It represents an industrial analogy of the biological receptor, which is understood as a sensor that serves as the organism's receiving and recording device for specific signals [16, 17]. In literature, six receptors are defined, namely *product*, *quantity*, *time*, *costs*, *quality*, and *technology* [18]. These channels are only sensitive to certain stimuli and thus, cause-effect relationships of core-specific information influencing remanufacturing-related areas can be displayed [17].

Since the introduced receptors are formulated in general terms regarding production, they are reformulated to the respective field of observation. Thus, five receptors are transferred to the area of MRP to demonstrate interdependencies. To this end, the receptors *product, time,* and *quantity* are specified by the type of the required spare part, the ordering interval of the spare parts, as well as the order quantity. The number of pseudo-remanufactured products that are needed in addition to the remanufactured parts to cover the demand is a combination of the two receptors *quantity* and *quality*, where the second refers to the difference in production input between new, pseudo-remanufactured parts and remanufactured parts from cores. The technological progress of a product within several product generations is considered, which is derived from the receptor *technology*.

In the field of RO, the effect of information is analyzed within the framework of the receptors *cost*, *product*, *time*, and *quantity.* The *costs* are represented by the variable transport costs that are incurred during collection from the workshops and delivery to the remanufacturing plants. The receptor *product* is reflected by the urgent demand for a certain product to prevent shortages and thus, delays in production. The receptor *time* represents the basis for both transport time as well as collection intervals, and the truck capacity is derived from the *quantity* of trucks needed to transport the cores.

The receptor model can be read from left to right and from top to bottom. Crosses without brackets indicate a direct effect on an area and crosses in brackets an indirect effect. A complete exchange of information between the actors and known demand regarding product scope and quantity is assumed.

As a further assumption, the product classification can be determined from the product number. To be able to delimit the influence on the areas by the product number for identification or for product classification purposes, the product number is shown as indirect and in brackets for the second purpose.

Exemplarily, for the first columns of each considered area, as well as the line of the information on origin, the effects via the individual receptors are explained.

Using the information of installed components in a core, the need for specific types of wearing parts can be estimated. This can be achieved with the product number together with the originality giving information about the manufacturer and identifying the core and thus the incorporated components. Additional spare part information, such as age, error codes, mileage, and quality indicate which components may be defective or obsolete and therefore need to be replaced and ordered accordingly.

The costs of RO can be minimized by the information on the origin and consequently the pick-up location to plan optimal routes. Both the nature of the cores, determined by the product classification, and special handling due to the core's quality may require special loading equipment and storage during collection and transport. Their use entails additional variable costs during transport and extra time if these measures cannot be planned. The quality of the cores should be considered as a possible cost factor that only occurs in special cases.

From the origin of a core, weather-related influences such as snow or extreme heat can also lead to damage or particularly severe wear of individual components. Thus, this information joins those that indicate which spare parts are needed. From this

Table 3. Visualization of the receptor model

	Material requirements planning					Route optimization				
	… working via the receptor …									
The information about the …	Spare part type	Spare part order interval	Spare part quantity	Pseudo-remanufactured products quantity	Technological progress of a product	Transport costs	Urgent demand for a product	Pick-up interval	Transportation time	Truck capacity
Product number	×			×	×	(×)	×	(×)	(×)	(×)
Mileage	×			×			(×)			
Error codes	×			×			(×)			
Age	×			×	×		(×)			
Overall quality	×			×		(×)	(×)			
Originality	×			×	×		(×)			
Product classification						×		×	×	×
Origin	×			×		×	×	×	×	×
Quantity		×	×	×		×		×	×	×
Date of arrival		×								

aspect, the origin also influences MRP via the quantity of pseudo-remanufactured products required. The number of cores and their recoverable components can be used to determine the quantity of remanufactured products that can be produced and the difference to the quantity demanded.

In addition to the effect described above regarding transport costs, origin also influences RO via urgent demand for end products. Routes can be adapted to reach a specific point as quickly and efficiently as possible. The receptor of the pick-up interval is influenced by the possibility to connect pick-up places so that uniform pick-up intervals can be introduced and thus, a regulated process can be created for all involved actors. The transportation time is influenced by the origin through the distance from the collection point to the sorting station and from there to the remanufacturing plant. Regarding the trucks to be utilized, the origin can be used to weigh up whether the use of many smaller trucks on smaller routes or trucks with more loading space on larger routes, which however might have to accept detours, is more ecologically and economically effective.

4.5 Suggested sequence for information retrieval

As revealed in the interviews, cores can be excluded from remanufacturing at an early stage based on six pieces of information. These include the product number, age, error codes, mileage, originality, and quality. Ideally, each of these six pieces of information should be checked as early as possible so that the suitability of a core for remanufacturing can be estimated. Figure 1 presents a possible sequence for such a procedure in the AA.

The product label contains three of the six information and, according to the workshops, can be recorded with relatively little effort. Thus, this information carrier should be checked at the beginning of the process. Within this bundle, the originality is placed first to achieve the manufacturer's information as well as the fact on whether a core has already been remanufactured as in most cases these cannot be remanufactured a second time. If it is an original part, the product number and age are determined. Through the unique identification of a part, further information can be verified. Thus, the age of a core for which remanufacturing can take place is checked. Incompatibility of the design level of older cores and the difficulty to procure components are thereby decisive for an exclusion.

The test protocol, which is used in the workshops as an initial diagnosis, provides information on the error codes and the mileage. The error codes are particularly important as the occurrence of certain faults can lead to early exclusion. If there are no excluding error messages, the test is passed and the mileage that must not exceed a certain value can be checked.

The last step is to check the quality in terms of completeness, damage, and degree of corrosion. This information is listed last because it is a matter of judgement and therefore not as clear as the previous information. With the help of pictures and/or detailed descriptions, the cores can be subjected to a quality check and those with excessive corrosion, which are damaged or incomplete can be sorted out.

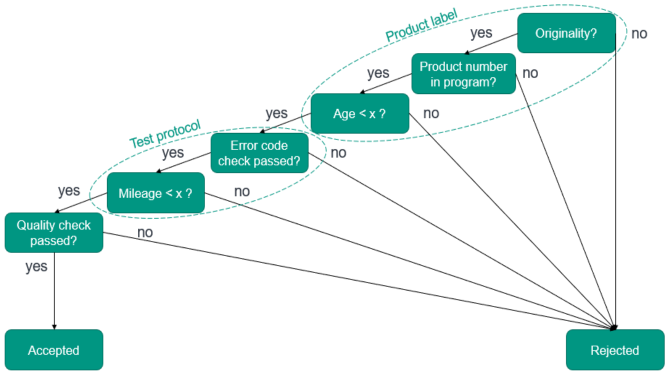

Figure 1. Proposed sequence for information retrieval

5. Conclusion and Outlook

With the help of the interviews and the results obtained from these, the defined aims can be achieved, and the potential of an increased information exchange of core information is derived.

The current situation is characterized by little to no information exchange in RL in the AA. All respondents consider this to be a major problem, causing inefficiency in many areas, and at the same time great potential for improvement. Meanwhile, the recording and forwarding of information is not considered desirable by the workshops themselves. At this point it is necessary to act to achieve a long-term and valuable information exchange.

As already indicated in the literature, it is made clear in the interviews, that information can be used to achieve a wide range of uses. At the collection stations a reduced sorting effort and especially logistical optimization can result. Cores can therefore, and through earlier exclusion, be transported in a targeted manner along pre-planned routes, which can save time and money as well as CO_2 emissions. On the remanufacturing side, arising uncertainties regarding MRP or production program planning can be counteracted due to precise identification, composition, and damages of cores.

In general, the benefit of information can be enhanced by combining it with other information and so, the added value can increase with the number of different pieces of information.

Within the scope of following investigations, the number of interviews must be expanded to cover a wider range of perspectives and experiences. In addition, the impact of the presented information on other areas can be explored.

Furthermore, it is important to relate and validate the theoretical results of this work in practice. For this purpose, selected cooperation partners from the area of workshops can record and forward the information mentioned here within a field experiment, so that the effects for the collection stations and remanufacturers can be better estimated. Besides, the resulting workload and costs in the workshops must also be weighed up and compared with the benefits caused by information exchange. On this basis, a suitable incentive system can also be created to encourage the workshops to integrate information gathering into their daily work processes.

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