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## Towards facilitating circular product life-cycle information flow via remanufacturing

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### Abstract

In order to achieve a sustainable development, circular economy approaches and circular material flows are explored in industry. However, circular information flows remain essentially unestablished. The aim of this paper is to: 1) explore categories and types of product life-cycle information available for remanufacturing; 2) identify constraints for efficient product life-cycle information flow via remanufacturing; and 3) propose initiatives to facilitate product life-cycle information flow via remanufacturing.

Data was collected through workshops and interviews at five remanufacturing companies. An accumulated Sankey diagram illustrates product life-cycle information flow, losses and bottleneck. Based on the analysis, possible initiatives to facilitate efficient product life-cycle information flow via remanufacturing are presented.

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*Keywords:* Remanufacturing; Product life-cycle stakeholder; Feedback; Feed forward; Sankey diagram

### 1. Introduction

While achieving sustainable development via circular economy, resource efficient production system and closed-loop supply chain are challenged [1-6]. In order to develop circular economy, circular material flows have been explored [7-10]. However, circular information flows remain essentially unestablished [7 and 11].

Circular product life-cycle (CPLC) information originates from various CPLC stakeholders in the product life-cycle: *Product Development*, *Manufacturing*, *Use/Service*, and *End-of-life* (see Fig. 1). This information is collected in the form of tacit knowledge, practical experience, customer feedback, paper manuals, software, hardware, pictures and advanced specifications [11, 12].

Major CPLC stakeholders often fail to share available product data with the stakeholders in the end-of-life phase, e.g. between Original Equipment Manufacturers (OEMs) and competing independent remanufacturers. As a matter of fact, remanufacturers insist on product life-cycle information sharing across the product life-cycle stakeholders [12].

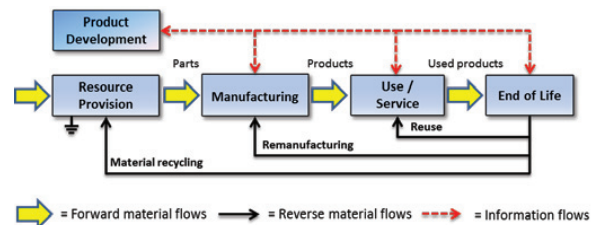


Fig. 1: Product life-cycle (adopted from [11]).

Ideally efficient CPLC information flow would benefit all product life-cycle stakeholders. The main benefit of product information is greater customer satisfaction through improved product performance and level of service. The increase in product knowledge at each CPLC stakeholder would contribute towards a more efficient circular economy. Consequently, a circular economy would stimulate product circulation and multiple product use, implying transparent and accessible product life-cycle information flow across a system of shared values [13].

1.1. Aim

The aim of this paper is to:

1. explore categories and types of product life-cycle information owned or received by remanufacturing;
2. identify constraints for efficient product life-cycle information flow via remanufacturing; and
3. propose initiatives to facilitate product life-cycle information flow via remanufacturing.

1.2. Research approach and data collection methods

In order to fulfill the aims of this paper Material and Information Flow Analysis (MiniMifa) workshops and semistructured interviews were performed at five remanufacturing companies [11, 12, 14]. In three of the companies, the interviewees worked in the product development, manufacturing, service and remanufacturing departments (see Table 1). In parallel, MiniMifa workshops were performed at three of the companies. The objective of the interviews and workshops was to identify the product life-cycle information owned or received by remanufacturers. The focus was to identify the remanufacturers' contribution to information generation, which could be provided as feedback to the other CPLC stakeholders.

Table 1. Case company characteristics and data collection methods.

Characteristics	Case A	Case B	Case C	Case D	Case E
Company size	Large	Large	Large	Large	Small
Sector	Machines	Machines	Furniture	Automotive	IT
Product complexity	Medium	High	Low	High	High
Remanufacturing experience	10 years	10 years	20 years	20 years	10 years
Remanufacturing business compared to manufacturing	Medium	Minor	Minor	Medium	Major
Remanufacturing status	Contracted	OEM	OEM	Contracted	Independant
Data collection method	Interviews	Interviews and MiniMifa workshop	Interviews	MiniMifa workshop	MiniMifa workshop

2. Circular product life-cycle information

In this section the circular product life-cycle information, identified from the stakeholders at the case companies, is explored and categorized (see Table 2).

2.1 Product Development

During product development the product's properties are determined. Customer data is essential to product designers [15]. However, preferably the product should be designed considering all product life-cycle phases, including manufacturing, use/service and end-of-life [16]. Efficient remanufacturing requires a product design that facilitates disassembly and upgrading, if needed [17]. However, few products are designed for remanufacturing [18].

2.2 Manufacturing

Product development and manufacturing is often carried out within the same company. Additionally, manufacturing staff are often involved, to varying degrees, in the product development projects. Design for manufacturing ideas can be encouraged as some design issues are hard to predict. Feedback from manufacturing personnel tends to be on concrete and detailed level of the product design features [19].

2.3 Use/service

Service can be maintenance, replacement of parts, upgrading and instructions on how to best use the product in order to prolong the use phase [20]. Service also means interacting with the users, enabling information feedback [21]. Design for service should be carried out in order to more easily obtain increased revenue and environmental benefits [20]. In order to facilitate forecasting of when a product is in need of service, modern ways of monitoring products from a distance could be efficient. Thus, condition monitoring is one way of capturing product use data and feeding it back to product development [22].

2.4 End-of-life via remanufacturing

Remanufacturing is one of the most effective ways of managing a product's end-of-life [23, 24]. According to several comparative studies on environmental research, remanufacturing is more environmentally sound than new manufacturing and material recycling [25]. By bringing used products back to useful life, remanufacturing puts the product life-cycle into a sustainable loop [26]. Remanufacturing is an industrial process and often consists of several steps, e.g. inspection, cleaning, disassembly, testing, reprocessing and reassembly [27]. However, today remanufacturers depend more on established product life-cycle stakeholders, like manufacturing [26]. Moreover, insufficient information flow within the product life-cycle, multiple networks that interface poorly with one another and miscommunication all hinder closing the product life-cycle loop via remanufacturing [24, 26, 28].

There are three different kinds of remanufacturers, OEMs that remanufacture, contracted remanufacturers and independent remanufacturers [21]. OEMs that remanufacture are in control of the both product development and product recovery, while a contracted remanufacturer receives some information from the OEM and could provide the OEM with feedback, whereas an independent remanufacturer is a competitor and often treated as such [29].

3. Analysis of the product life-cycle information flows

3.1 Categories and types of product life-cycle information

The analysis of product life-cycle information flow derives from the data collected at case companies and presented in Table 2. The categories and types of product life-cycle information are classified in the first two columns. Additionally, the level of product life-cycle information accessibility, format, description, stakeholders' status as O

Table 2: Categories and types of product life-cycle information with its Owners (O) and Receivers (R) found in the industrial cases.

Category of product life-cycle information	Type of product life-cycle information	Accessibility (secret, sensitive data - limited access; public, available data - open access)	Information format (digital, paper, oral)	Description of product life-cycle information	Stakeholders						Case
					Product development	Manufacturing/Original part supplier	Use	Service	Remanufacturing	Second Use	
Product design specifications	PD project meetings	limited access	digital/paper	The preparation/ meeting before initiation of product design	O	R		R			A, B, C
	Drawings	limited access	digital/paper	The detailed drawing of the product design	O	R		R	R		A, B, C
	Assembly instructions	limited access	digital/paper	Design for assembly	O	O					A, B, C
	Disassembly instructions	limited access	digital/paper	Design for disassembly	O			R			C
	3D models	limited access	digital	Digital product prototype	O	R					B
	BOM (bill of material)	limited access	digital/paper	The classified and chronological list of components and materials required for product	O	R		R	R		A, B, C
Manufacturing specifications	Manufacturing instructions	limited access	digital/paper	Stepwise instruction		O			R		B
	Process specifications	limited access	digital/paper	Description of the product assembly, quality standards		O			R		D
	Manufacturing specifications	limited access	digital/paper	Description of the production requirements and available processes	R	O					A, B, C
Service specifications	Repair manuals	open access	paper	Description of the service requirements and available processes	O			O	R		A, B
	Training material	open access	paper	Instruction on how to repair				O	R		B
	Physical training	limited access	oral	Description of recommended training				O	R		A; B
	Technical support	limited access	oral	Instruction or advice via phone				O	R		B
	Spare part catalogue	open access	paper	A list of spare parts with specifications				O	R		A, B, C
Original product quality assurance	Condition monitoring	limited access	digital	Momentary or continuous monitoring of the product or its parts				O	R		A
	Quality monitoring	open access	digital	A short visit at the customer site to monitor the condition of the product before it has been collected for remanufacturing		R	R	O	R		B
	Service report	limited access	digital/oral	Description of the service carried out	R			O	R		A, B, C
	User feedback	limited access	digital/oral	Opinions from users	R		O	R			A, B, C
Core quality assurance	Bill of lading	open access	digital/paper	A detailed list of a shipment of goods in the form of a receipt given by the carrier to the person consigning the goods			O		R		B
	Picture	open access	digital	A picture of the collected core for quality inspection					O		B, D
	Documentation of core quality	open access	paper	A quality assurance of the received core for the previous customer for refund/compensation/reward after take-back			R		O		B, D, E
	Classification of cores	limited access	paper	An internal document to define the remanufacturability of the core					O		B, D, E
	Defect measurement	limited access	digital	Core quality defect measurements to define the remanufacturability					O		D
Remanufactured product quality assurance	Self-control of processed core quality	limited access	oral	A simple quality control by observing the defects and smelling					O		D
	Final quality assurance	open access	paper/oral	Final control of remanufactured products after all processes are performed					O		B
	Feedback	open access	oral	Perception of product functions after remanufacturing					R	O	E
	Remanufacturing knowledge	limited access	oral	Experience about the remanufactured product and operations		R			O		B

(owner) or R (receiver) and case origin are aligned to each specific type of product life-cycle information.

### 3.2 Constraints of the product life-cycle information flow via remanufacturing

Analysis of the product life-cycle information flow showed a lack of initiative to interact with remanufacturing for

information exchange and sharing. Few attempts to close the product life-cycle into a sustainable loop via remanufacturing were challenged by the restrictions in the exchange of sensitive business information, the deficit of knowledge sharing platforms and the absence of data transferring channels between stakeholders. This is closely related to the undeveloped system of shared values, where every life-cycle stakeholder focuses on information mainly relevant to their own activities [13].

Information uncertainty reflects a weak collaboration between remanufacturing and other product life-cycle stakeholders. Information deficit due to the fear of competition with remanufacturing diminishes the remanufacturer’s capability to close the information loop and respond to customers’ requirements. To summarize, the following constraints to the product life-cycle information flow via remanufacturing were discovered at the case companies:

- Little awareness of the need for circular information
- Underdeveloped system of shared values
- Information uncertainty and inflexibility
- Information deficit due to fear of competition
- Limited knowledge about information created at remanufacturing
- Few motives to use and share information with remanufacturer

Figure 2 depicts an accumulated Sankey diagram of product information flow, losses and bottleneck in a CPLC system. As can be seen in the Sankey diagram, five information sources on product life-cycle information are available to remanufacturing:

- Product Development
- Manufacturing
- Use
- Service
- Second Use

The thickness of the Sankey diagram's information flow lines depends on the amount of various information types created and owned by the product life-cycle stakeholder. For example, Product Development owns six types of product life-cycle data, while only four are successfully transferred forward to Manufacturing, and three of them to Service and only two finally reach Remanufacturing (Sankey diagram is

an illustration of the product life-cycle information flow and therefore some deviations from Table 2 may occur).

Accumulated information utilized by the corresponding product life-cycle stakeholder is framed in a box along the information flow. As long as the colored line passes through the stakeholders’ box, the stakeholders of this phase receive and use the collected information in their processes. Information that is not fed forward or pulled by *Remanufacturing* is depicted as an arrow that goes up or down from the main flow. The thickness of this line is also correlated to the number of different information types lost during information transfer between stakeholders.

Two major **information waste** could be distinguished during the analysis of the Sankey diagram:

**Feed forward information losses** – losses of information during feeding forward. This corresponds to the amount of lost information on the way towards *Remanufacturing*.

**Feedback information bottleneck** – unutilized information, feedback from *Remanufacturing*, to close the loop (see Fig. 2). This second issue covers the amount of product information created by remanufacturers which is not used by the other product life-cycle stakeholders.

As can be seen in Figure 2, **information losses** occurs at a majority of product life-cycle stakeholders, e.g. *Product Development* and *Manufacturing*; even *Service* product information is transferred with a loss. Product information flow speed and frequency tend to be correlated to the distance to the product information owners from *Remanufacturing*. The losses of product information that never reach *Remanufacturing* could be seen as one of the reasons for overworking, as remanufacturers have to recreate and rework while establishing product knowledge. In other words, the prevention of information losses along the product life-cycle would enable *Remanufacturing* to employ this information, rather than develop their own same or similar information.

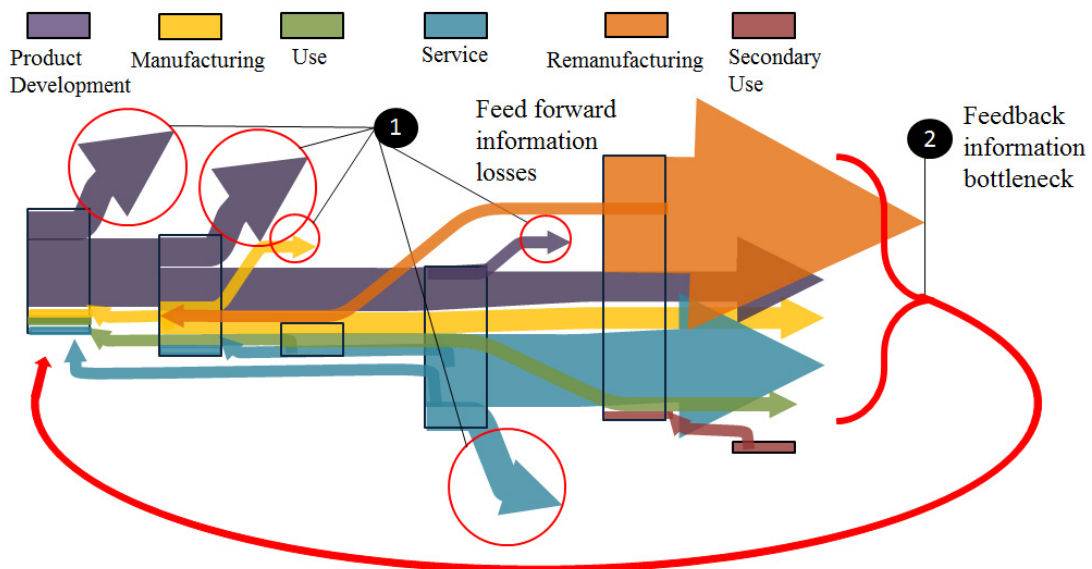


Fig. 2: Sankey diagram of product life-cycle information flow and waste between the product life-cycle stakeholders.

However, the question of the importance of different types of available product life-cycle information to remanufacturing is not covered in this study.

As observed in the performed study, disrupted, uneven, chaotic and inaccessible information between *Remanufacturing* and product life-cycle stakeholders is a big challenge for the majority of remanufacturers [12]. In case B, the *Remanufacturing* department receives drawings and data on about half of the products available. Further, they have access to the service manuals as well as technical support, both in-house and via phone. The *Remanufacturing* technicians and the *Service* technicians also receive regular training on new product models [11].

The analysis of product life-cycle data flow at case D and E showed that there is no information feed forward, which means that the remanufacturers must search for a possible source of information [12]. In case C the sales of remanufactured products were seen as a side business and the products should not be marketed. Thus, *Remanufacturing* was kept out from the information flow. Case D reveals that in the beginning of remanufacturing activities, none of the product life-cycle stakeholders shared their information due to a fear of competition after disclaiming secret product information. However, it has been agreed on in case A that after many years of cooperation with the *Manufacturers* the information is more easily collected. It was also discovered that the *Remanufacturers* establish their own product knowledge, which in many cases overlap, compliment and even overcome the available product information.

The product information in the last two categories of Table 2 was mainly created by remanufacturers, and hardly used by any of the other product life-cycle stakeholders. In some cases, remanufacturers' information was fed back to the *Manufacturer* (case B) and *Users* (cases B, D, E). However, no attempt to pull or to push remanufacturing product information to *Product Development* was observed in any of the case companies. The majority of the case companies had no channels of interaction with remanufacturers, and therefore was unaware of the data available. *Remanufacturers* create a comprehensive set of valuable data which almost never leaves the remanufacturing. This can be seen as an **information bottleneck**. In their turn, remanufacturers are willing to share information in return for open and easy access to the other stakeholders' information.

To sum up, the information that reaches remanufacturing differs from case to case, as shown in Table 2. However, as seen in the Sankey diagram information losses occur prior to the remanufacturing stage. Thus, being at the end of product life-cycle, remanufacturing does not receive the accumulated amount of product information created along the life-cycle. Information produced at the remanufacturers is largely unutilized by the other stakeholders in the product life-cycle and can be seen as information bottleneck. There are either no obvious receivers of the information, or there is no established channel to provide that information through.

### 3.3 Initiative to develop efficient product information flow via remanufacturing

Possible initiatives that should lead to an efficient circular product information flow via remanufacturing are briefly presented here. One way to solve the **feed forward** and **feedback information waste** is to establish standard information exchange channels or networks. This could facilitate quick information feedback as well as frequent data exchange opportunities. The common knowledge exchange platform would stimulate sharing the information ownership in the product life-cycle, leading to a system of shared values.

## 4. Conclusions

The contribution of this paper is the categorization of the product life-cycle information owners and receivers as well as the visual representation of the constraints in the product life-cycle information flow, named as information losses and bottleneck. In line with the aim of this paper the following three outcomes were discerned.

1. The available product life-cycle information types are classified into six categories:

- Product design specifications
- Manufacturing specifications
- Service specifications
- Original product quality assurance
- Core quality assurance
- Remanufactured product quality assurance

Each of the mentioned categories hosts between three and six different types of product life-cycle information. This information is comprised of, for example: digital product drawings, 3D models, the original product manufacturing and assembly instructions, repair manuals, technical support, condition monitoring, and classification of cores, remanufacturing knowledge as well as customers' and second users' feedback.

2. The following constraints of the CPLC information flow via remanufacturing were identified at the case companies:

- Little awareness of a need for circular information flow
- Undeveloped system of shared values
- Information uncertainly and inflexibility
- Information deficit due to fear of competition
- Limited knowledge on information created at remanufacturing
- Few motives to use and share information with remanufacturer

Furthermore, the analysis of the Sankey diagram discovered two major kinds of **information waste** that prevent efficient CPLC information flow via remanufacturing:

- Feed forward information losses**
- Feedback information bottleneck**

Dealing with the feed forward and feedback information waste is one of the effective ways to facilitate CPLC information flow via remanufacturing.

3. The possible initiatives that lead to an efficient circular product information flow via remanufacturing are proposed:

Develop standardized data sharing channels  
 Establish accessible knowledge exchange platforms  
 Increase the data exchange speed through tied collaboration with stakeholders  
 Expand the data ownership in the system of shared values.

#### 4. Future research

This study is an attempt to focus on the CPLC information flow from the remanufacturing perspective. Complimentary studies on CPLC information flow could contribute to the validation and verification of Table 2. Therefore, additional measures and practices to facilitate product information flow via remanufacturing could be investigated. Moreover, increasing the incentives for sharing information along the product life-cycle would contribute to the development of the system of shared values. The industrial implication of the information waste is an object of the future research. Finally, the value and importance of information contra the amount of information and number of information sources could be studied.

In addition, the following questions were derived from this study: What information is valuable for the remanufacturers? How, and how frequently, should this information reach the remanufacturers? What information from remanufacturing would add value to the rest of the product life-cycle stakeholders?

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