ResCoM

collaborative software platform

D4.1: Report containing matrices of factors defining mutual relationships and their criticality

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Abstract	This document describes the essential factors underlying the ResCoM requirements and analyzes the interaction and criticality of these factors with the design structure matrix method.
Key Words	Design Structure Matrix (DSM), closed-loop product system, multiple lifecycle products.

1. Introduction

The objective of deliverable 4.1 is to identify the critical factors for modeling closed-loop product systems specific to the four case studies of ResCoM. Based on the findings in earlier deliverables and research and industrial practices, this document creates lists of essential factors and analyzes the criticality / ranking and interaction of these factors.

This document starts with outlining the steps towards a closed-loop business model in the ResCoM perspective for each case study company, followed by a discussion on the major issues when moving towards this business model. Based on these major issues (that are identified in work package 2) this document analyzes the underlying factors of these major issues and assesses the relationships and criticality of these factors, taking into account the relevant business model and environment of the specific case study company. As discussed in D2.3 a stepwise approach is followed to identify the critical factors. Factors are identified based on literature and interviews with the four case study companies. All findings are combined and a design structure matrix (DSM) is used to assess the interdependency and ranking of the factors. This deliverable lists the factors needed to model closed-loop product systems specific to the four case studies. The combination of factors will describe a system perspective fulfilling the ResCoM requirements.

The identification of critical factors is complex, due to the nature of the creative design process. In the design process, problem-solving can be characterized as the co-evolution of the problem and solution space (Dorst and Cross, 2001). For instance, the business case will inform the design brief, whereas on the other hand a new design can enable the realization of a new business solution. Likewise, an existing supply chain infrastructure will influence closed-loop design options, while a new solution can enable an 'end-of-life' scenario that was not technically or economically feasible with the existing design. Within the ResCoM perspective, different routes can be pursued: for example new designs can enable specific closed-loop systems or design can have a subordinate role within a pre-defined business model.

1.1. Method

Based on the ResCoM requirements and major issues of each case study that need to be addressed when moving towards a closed-loop product system, identified in D2.3, this document analyzes the underlying factors of these major issues and assesses the relationships and criticality of these factors.

To identify the essential factors, the following steps are taken:

1. Building on the how-to procedure for implementing a closed-loop product system at the four OEMs as described in chapter 2 of D2.3, this deliverable starts with describing the steps the four case study companies can take to implement the ResCoM model. The steps for each OEM to make the transition from a linear to a closed-loop product system as envisaged in ResCoM in a timely manner are discussed.
2. For each step, the major issues are described, building on research and industrial practices as well as knowledge gathered during the company visits and interviews. Where possible, the issues are justified with company data, for example with impact on costs or CO_2.
3. A literature review on specific issues for each company to identify factors that might be relevant when modeling closed-loop systems[1] is performed.

[1] The performance (economic and environmental) of closed-loop product systems is modelled in D4.2. Critical factors that are relevant for this model are identified in D4.1.

Assessing the relationship between the essential factors in the ResCoM model:

4. Process maps of essential factors are drawn where possible to show the relationships between the factors. Each relationship is also described in the text and based on academic literature.
5. Based on these findings the initial ResCoM model that is applicable for the OEM is described and the essential factors for this ResCoM model are listed in a table.
6. The essential factors for the ResCoM model are analyzed for their one-to-one relationship with the method design structure matrix (DSM). This is further explained below. These factors are analyzed on mutual relationship in the closed-loop product system and the criticality of the factors will be identified. This deliverable describes four ResCoM models and their critical factors.
7. The document ends with a short discussion on how these factors can be modeled and validated (i.e. outlook to D4.2 and D4.3 in combination with WP6).

The goal of ResCoM is to design a closed-loop system that is cost-effective, resource-efficient and more sustainable than the current linear manufacturing system. In order to design this closed-loop system, a detailed calculation of the economic and environmental impacts is needed. This is planned over the course of the next two years. An iterative process will be used in designing closed-loop product systems and calculating the impact of it. In this deliverable, an initial idea of how a ResCoM closed-loop system might look like is discussed, based on early findings in this research project and assumptions underlying the initial ResCoM idea. To remind the reader, the main assumptions made at the start of the ResCoM project can be found in appendix 2.

It is important to note that the analysis in D4.1 is based on the stepwise procedure and issues for the specific case study companies, as outlined in the DoW. However, the described ResCoM model will be applicable to a wider set of companies with the same characteristics. Identifying these characteristics is part of D2.4.

Design structure matrix (DSM)
DSM[2] is used as method in areas like product design, manufacturing, building construction, etc. (Browning, 2001). It gives a matrix representation of a complex system or project (Pektas and Pultar, 2006). Although developed and mostly used for studying interdependencies between product development activities, it can be used to find relationships among elements in many different systems and several variants of the method are developed to suit the specific problem (see table below). With DSM, dependencies within one domain are analyzed, meaning that the same elements are written on the row and column headings and therefore resulting per definition in a square matrix. In this way the one-on-one relationships between all essential factors can be identified.

[2] Also called dependency structure matrix, dependency source matrix, dependency map, interaction matrix, incidence matrix, precedence matrix, etc. (Browning, 2001).

<table>
<tr><th colspan="2">DSM type</th><th>Representation</th><th>Applications</th><th>Integration analysis via</th></tr>
<tr><td rowspan="2">Static</td><td>Component-based or architecture DSM</td><td>Components in a product architecture and their relationships</td><td>System architecting, engineering, design, etc.</td><td rowspan="2">Clustering</td></tr>
<tr><td>Team-based or organization DSM</td><td>Individuals, groups, or teams in an organization and their relationships</td><td>Organizational design, interface management, application of appropriate integrative mechanisms</td></tr>
<tr><td rowspan="2">Time-based</td><td>Activity-based or schedule DSM</td><td>Activities in a process and their inputs and outputs</td><td>Project scheduling, activity sequencing, cycle time reduction, risk reduction, etc.</td><td rowspan="2">Sequencing</td></tr>
<tr><td>Parameter-based DSM</td><td>Parameters to determine a design and their relationships</td><td>Low-level process sequencing and integration</td></tr>
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Table 1: Design Structure Matrix types (adapted from Browning, 2001).

As the goal of this deliverable is to find the interaction between the factors in a closed-loop product system in order to be able to model the closed-loop product systems, this deliverable applies a component-based DSM. The clustering step allows finding mutually exclusive or minimal interacting subset of factors (Yu et al., 2007). Because the criticality of the factors has to be identified, a numerical DSM is applied (Sosa et al., 2007).

DSM method consists of three steps (Browning, 2001):

1) Decomposing the system into elements (step 1 to 3 in this deliverable)
2) Understanding and documenting the interactions between the elements (step 4)
3) Analyzing the potential (re)integration of elements via clustering (step 6)

Findings (e.g. the essential factors) are integrated in a matrix. Relationships are indicated in the matrix, with inputs on an element's row and outputs in the column (Danilovic and Browning, 2007). More specifically, each entry d_{ij} in the matrix represents the degree (e.g. criticality) of dependency between node *i* and node *j* which are both elements or variables in a complex system (Sharman and Yassine, 2004). The collaborative rating of the essential factors will result in an identification of the critical factors and the relationship between the factors. The criticality of the dependencies will be captured with a three point scale: 1) Low, 2) Medium, and 3) High. Relationships that have an average value higher than 2 are considered to be critical and are discussed at the end of each chapter.

2. Baby strollers

It is expected that the high prices of strollers are withholding potential customers from buying one, despite that they would like to have a good quality stroller for their newborn baby. Mont et al. (2006) argue therefore that both remanufactured strollers and a leasing scheme can provide these potential customers with a high quality "as-new" (i.e. new or remanufactured) stroller for the period they need it.

Different steps are discussed in D2.3 that can facilitate the transition of a linear to a closed-loop product system. First, Bugaboo can look into selling used strollers on the second-hand market and identify suitable business models for their second-life high-end stroller. A strategy for the returned strollers is needed before leasing can be implemented at large scale. Second, Bugaboo can plan a lease concept for new strollers. Third, Bugaboo can explore how to remanufacture the returned strollers. Finally, leasing with both new and remanufactured strollers can be investigated, i.e. multiple lifecycle strollers. These four options are discussed below.

2.1. Second-hand strollers

Baby strollers have a high recovery value at their end-of-use due to the discrepancies between the long durability and the short actual use time, normally between 6 and 12 months by the first customer[3] (Mont et al., 2006). This led to a relatively large second-hand market, even though baby strollers are considered to be an emotional product where customers put high value on safety and quality. The second-hand market is estimated to represent a significant part of the market (between 17 and 75%). The table below gives an overview of the size of second-hand market for baby strollers.

Percentage	Country	Year	Source
83% of baby carrier purchases were new. 17% is second-hand or borrowed.	US	2009	Mintel, 2010, cited in Compass Diversified Holdings, 2012
22.54% of parents bought most recent baby buggy second-hand. 6.83% from auction site, 8.92% from family member or friend.	UK	2010	Halifax, 2010
Second-hand prams represents 65-75% of total sales.	Sweden	2006	Mont et al., 2006
70% of lightweight strollers are bought new.	US	2010	Mintel, 2011, cited in Bruins et al., 2011

Table 2: Estimations of second-hand baby strollers market.

Even though the Bugaboo stroller is not the most durable stroller available, the Bugaboo strollers have a high value at their end-of-use period and can be easily sold on the second-hand market (Clarke, 2014).

2.1.1. Market for second-hand strollers

From online forums[4] where consumers discuss reasons to buy a certain stroller, it can be concluded that the high resell value influences the consumer decisions to buy a Bugaboo stroller. High resale value increases the consumers' willingness-to-pay for new products (Waldman, 2003; Oraiopoulos et al., 2012). Waldman (2003) reviewed studies that analyze the effect of second-hand markets on the price and value of new products and found that a producer with market power benefits from reducing the quality of used products such that new products can be sold to high-

[3] In the case of Bugaboo strollers, the average usage period is estimated between 20 and 30 months, as it includes both the carrycot and stroller(seat) functionality.

[4] Online forums like Mumsnet and Bubhub are used to analyze reasons to buy a Bugaboo stroller.

valuation consumers. A general strategy to achieve this is reducing the (physical) durability of the product or the (emotional) durability by frequently changing product styles. Introducing new styles deteriorates the value of products over time and has an impact on both the price of new (increased due to reduced substitution between used and new strollers) and second-hand strollers (reduced). The assumption is made here that two types of consumers are existing; high-valuation (those who buy high-end new products) and low-valuation consumers (those willing to buy second-hand).

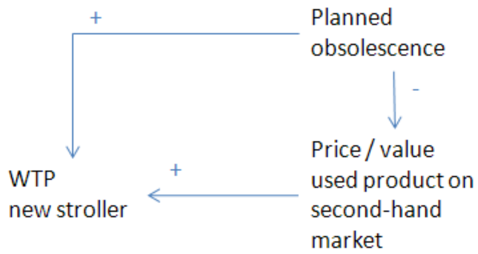


Figure 1: Effect of second-hand market and obsolescence on willingness-to-pay for new strollers (based on Waldman, 2003).

Bugaboo does not plan design obsolescence, but introduces new models / designs to either respond to changing legislation and service complaints or to compete with new models of competitor strollers. On average, Bugaboo updates the stroller every three years, which is around the same time of one usage cycle. Consequently, the strollers on the second-hand market are "old" models and consumers can distinguish between these second-hand and new strollers.

Cannibalization occurs when the purchase of a second-hand product displaces the sale of the new product (Atasu et al., 2010). Depending on the consumer type, a consumer is willing to switch to a second-hand stroller for a given price discount. However, not all consumers will consider second-hand strollers as potential alternative. According to the discussion on online forums, worries about the quality and cleanness of the stroller withhold them from buying a second-hand stroller. High safety concerns of expecting parents is another reason for not buying second-hand (Mintel, 2011, cited in Bruins et al., 2011). It is likely that those consumers buying a new Bugaboo stroller are not interested in a second-hand stroller and cannibalization is therefore limited. More research is needed into the different consumer types and the underlying reasons of buying or not buying a second-hand stroller.

2.2. Leasing[5] of new strollers

Waldman (2003) argues that leasing can be used as strategy to reduce the availability of used goods and therefore to retain high sales prices for new products. As discussed above, high availability of second-hand products that can substitute the new products lowers the monopolist's new unit price. This substitution effect can be reduced by differentiating the new from the second-hand products.

[5] Functional sales, production service systems, servicizing, installed base management are used as synonyms for leasing. In this document, leasing is used to describe situations where the product is leased to the consumer (ownership remains with retailer / manufacturer) and maintenance and repair services are bundled with the product for a fixed period of time or usage.

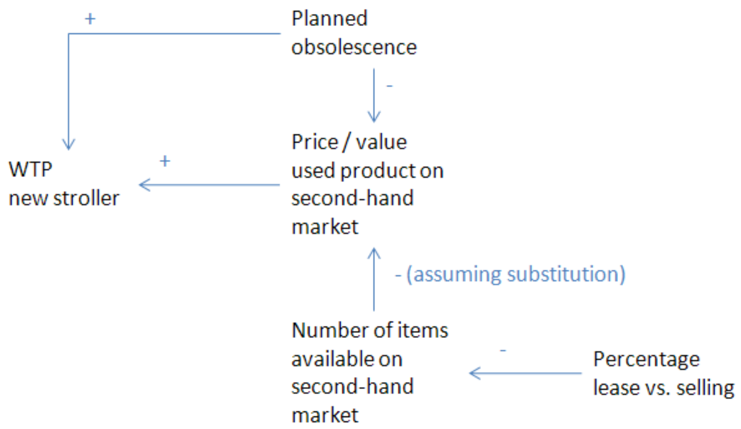


Figure 2: Effect of leasing durable products for a producer with market power (based on Waldman, 2003).

Catulli et al. (2013) studied the consumer perceptions of access based models for baby strollers with focus groups and interviews in the United Kingdom. Leasing of high-end strollers can provide a social accepted image. For that reason, they argue that the strollers should look brand new and it must not be possible to distinguish between new bought strollers and leased ones. Leasing also makes it easier for consumers to switch from a pram to a stroller and dispose of the pram (i.e. by returning), which is especially beneficial to those consumers with limited space. Others argue that they will get attached to the pram and would like to have the opportunity to buy the pram at the end of the lease contract. Catulli et al. found that a lease concept gives access to premium brands like Bugaboo that would otherwise be too expensive to buy (monthly fees can be paid with the additional child benefit). However, lease concepts that expand the market base for Bugaboo must be carefully assessed as it might deteriorate their brand value built on exclusivity.

Other benefits to consumers can be created when Bugaboo designs a stroller for the purpose of leasing, for instance by offering features unique to leasing, make the stroller more durable, design custom fabrics, easy to maintain, etc. This will improve the business case for leasing.

The benefits of leasing (control over second-hand market, increased customer base) must be carefully assessed against the potential disadvantages (brand value, additional costs). Revenues of leasing strollers comes from leasing fees, selling strollers after its leasing time, interest (due to deposits) and indirect revenues from selling complementary products (Mont et al., 2006). While the leasing scheme may provide higher revenues per stroller, the cash flow is changed. Profits are made towards the end of the stroller lifetime, which creates negative cash flow at the beginning. Capital is needed to finance the first years of the leasing system (Mont et al., 2006). This might create a major barrier for companies to implement leasing.

Retailers might also raise arguments against leasing when they will earn less per leased stroller compared to traditional selling. This can be partly compensated if the leasing scheme attracts customers that are currently buying on the second-hand market (Mont et al., 2006). Another strategy would be to bypass the retailers and lease strollers directly to the end-consumers. However, also in that case, conflicts with retailers might arise.

2.2.1. Reverse logistics in a leasing system

The current reverse logistics of Bugaboo (to repair strollers) is outsourced to service centers. The flow of goods is shown in the figure below.

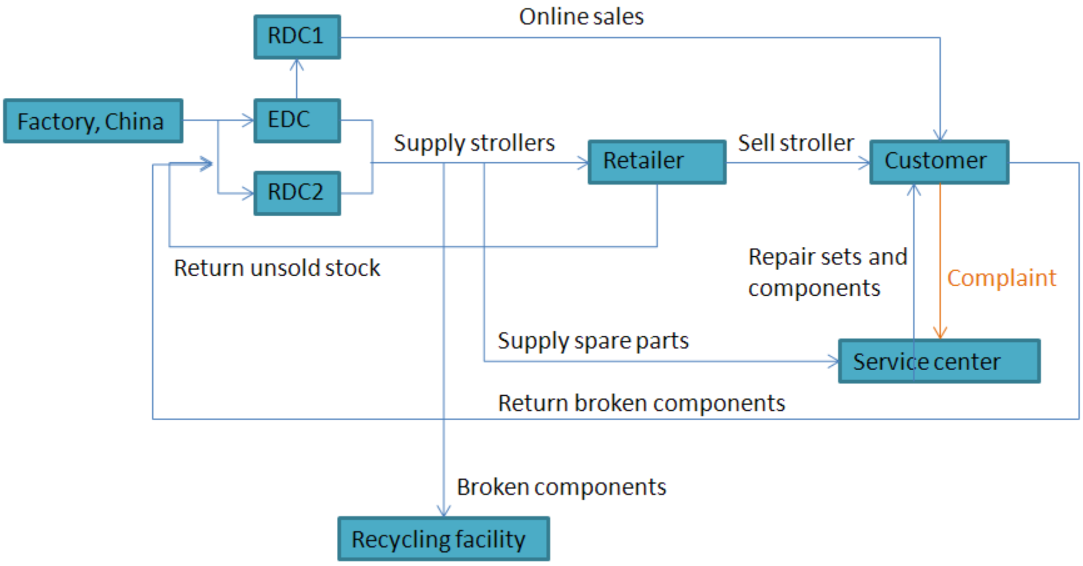


Figure 3: Current supply chain of Bugaboo. Note: some service centers are operated by retailers and they do in some cases replace broken components and return them to Bugaboo instead of the customer.

When a company decides to implement a lease system, products will be returned at the end of the lease contract. The reverse logistics network, that collects used products from the customers and transports them to the recovery facility, is crucial as the efficiency and effectiveness of the reverse logistics network can have a significant impact on the economic and environmental performance of the closed-loop system (Aras et al., 2010).

A strategic question in the reverse logistics network is the reverse channel structure. OEMs can collect the used products directly from the customer or can outsource the collection to a third-party. In some cases, collection by retailers is more suitable due to the proximity of the retailer to the end-customer. The profitability of the different channels is investigated by Savaskan et al. (2004), Savaskan and Van Wassenhove (2006) and Atasu et al. (2013). The optimal strategy depends on factors as the investment costs to achieve a certain collection rate, reverse logistics costs, quantity collected, and the payment to the retailer. In a lease system, consumers are required to return the products[6] and acquisition costs are mainly transportation costs.

A second question is the location of the collection centers and recovery facility. The optimal reverse logistics network and potential integration with the forward network is researched in several studies. In cases where the forward network is already specified, as is the case in Bugaboo, the optimal reverse network can be determined with factors as return rate, transportation costs, and fixed and variable costs of the locations (Fleischmann et al., 2001). Simultaneously optimization of the forward and reverse logistics network becomes more important when the return ratio increases (Verter and Aras, 2008 cited in Aras et al., 2010).

Although leasing gives a high degree of control on returns, not all products are immediately returned at the end of the contract; some consumers might want to extent the lease period or wait

[6] However, this does not mean that all consumers will return the product when requested.

with returning the product (Östlin et al., 2008). A flexible leasing period, where the consumer decides how long they want to lease the stroller, is also possible. Also the quality of the returned products is uncertain and the impact of quality on the reusability (e.g. yield rate) and therefore profitability should be taken into account when designing a closed-loop system.

2.2.2. IT / Technology

Leasing of strollers has also implications for the IT systems. As discussed in D2.3, a lease system would require functions as product traceability, configuration management and a failure recording and analysis system. This section explores the underlying factors of these functionalities.

Product traceability requires a definition of the multiple lifecycles of a product design on several levels; product, modular, component and material level. Both the method to identify an individual product, for example with serial number or Radio Frequency Identification (RFID), and the level on which the product should be traced (i.e. product, module, component, material) should be specified. The product (and components) will be traced during lease and information on usage and maintenance can be used for deciding the optimal recovery strategy. During the use phase, the maintenance activities can be traced. A schema of maintenance activities, in the form of a predefined maintenance plan or triggered by failure reports, is needed. Also a maintenance and repair knowledge repository, including activities, methods, processes, resources (like materials, spare parts, energy, facilities, etc.) and relevant stakeholders for performing the maintenance, will be necessary to conduct maintenance in an efficient way. Capturing the failures with a failure recording and analysis system will give essential data on usage of the strollers. Decisions are therefore needed on how failures should be reported and how to analyze the failure results.

Besides maintenance, information regarding the lease contract should also be captured. Feedback on the usage and condition of the product in the lease contract will be captured. If a leasing period of two years is defined for a baby stroller, then a system is needed that could record the start date and end date of leasing and send a reminder message to call back the product at the right time[7]. Alternatively, the leasing periods are flexible and the user can decide when to end the lease contract. At the end of the lease contract, products are returned and recovered. Different value recovery operations will have to be defined in the IT system, including a schema of value recovery options, to make decision on the best strategy. The value creation of the recovery activities, the processes, resources, distribution channels, partners, suppliers and customers need to be specified. A value recovery knowledge repository can be useful. Further, information regarding product acquisition times, quality and quantities will be necessary to define the recovery strategy.

Besides product traceability, product configuration management will be useful in the remanufacturing process. The configuration management system consists of three factors. The first piece of information is the product bill of materials (BOM) that includes the engineering BOM, manufacturing BOM, maintenance BOM, etc. Second, the definitions of configuration management activities over the complete multiple lifecycles are defined. Third, the compatibility of components is described. This includes the compatibility among different products (e.g. components that can be used both in the stroller Donkey and Buffalo), and compatibility among different versions of a product (e.g. component of version 2 can replace a component of version 1).

An essential IT functionality in the ResCoM project is the collaborative platform. Decisions need to be made on what IT tools will be used for analysis and decision making in product design,

[7] Note that the assumption in the ResCoM project is made that products are recalled at predetermined times. Further calculations will show whether this assumption is beneficial in terms of economic and environmental impact.

business model and supply chain, how these IT tools will be used and what inputs are needed for doing the analysis, and what outputs can be made available. Furthermore, the relationship between the requirements in the four ResCoM pillars (business model, product design, supply chain and technology) has to be traced. Data on the hierarchy and interrelations among the requirements and the requirements verification can be essential.

The IT functionalities discussed above will help the company in monitoring and managing the lease system and will therefore have a supportive role in the closed-loop product system. Consequently, besides the cost of the IT system and the related tasks to capture, process and use the data, the aspects mentioned above have no direct impact on the economic or environmental performance of the closed-loop system.

2.3. Remanufactured strollers

Although the second-hand market represents a significant share of the total market, there are no professional refurbished or remanufactured strollers on the market. Once a reverse supply chain is in place and strollers are returned to the manufacturer, Bugaboo could remanufacture[8] the used strollers before putting them back on the market. The necessary remanufacturing steps will influence the profitability and environmental impact of remanufacturing. Besides that, professional remanufactured strollers are differently perceived by consumers than used strollers and influence the consumer market. Both issues are discussed below.

2.3.1. Product design

In closed-loop product systems, a different mixture of product life extension, remanufacturing and closed-loop recycling scenario's (over time) is to be considered, depending on economic, environmental, and legislative factors. Such factors are often uncertain at the time of product design (Bras, 2010). It is assumed at this stage that the design team – for each of the four cases- has the freedom to develop new solutions that enable a closed-loop product system (for instance the freedom to develop a platform based design or to apply different materials for specific parts). When more input is available on the design freedom within the design teams, as well as the anticipated business cases and circular chain infrastructure, the list of factors will be more specific. Knowing the processes that are involved throughout the product lifecycle and the critical technical and economic factors in these processes is considered critical for successful product design (Bras, 2010). Research on product design from a business perspective, for example whether a company should apply design for remanufacturing, is still very limited (Souza, 2013). The effect of product design on consumer preferences, selling price and demand is often unknown (Kwak and Kim, 2013). Souza (2013) advises to use flexible and comprehensive choice models, such as discrete choice, to capture the trade-offs along multiple design dimensions.

The Bugaboo strollers typically last longer than they are needed in the 'stroller-life' of a child (see also section 2.1). The value of second-hand Bugaboos is high because of this durability, but also due to the availability of spare parts, the ability to replace fabric parts that have a lower emotional and visual durability than the frame, and the aesthetic design of the frame that has stood the test of time.

Degree of reprocessing, ease of material recovery, degree of recycling, ease of inspection
The existing products already have the potential to be used multiple lifecycles, but how users value the not completely new products (e.g. second-hand or remanufactured strollers) is part of the Bugaboo study. Catulli et al. (2013) found in a focus group study that the majority of the participants were not willing to lease refurbished strollers due to safety and hygiene risks. This

[8] It is likely that remanufacturing is the most feasible option for Bugaboo to produce multiple lifecycle strollers due to the high consumer requirements on safety and cleanliness (see section 2.1.1 and 2.3.2). This does not mean that recycling is excluded.

perception of ‘usedness’ is determined by the underlying factors associated with for instance (economic) durability (see also section 2.3.2). However, when considering a new product design, reprocessing is a key route to tackle the ‘usedness’ of vital components. Reprocessing, i.e. the ability to bring used components back into specification, is therefore considered as key design factor[9]. For Bugaboo, a dominant specification will be the visual appearance of parts. If used parts cannot be up to specification, the number of lifecycles will be limited. Mont et al. (2006) studied remanufacturing for a high-end baby strollers manufacturer in Sweden[10]. Based on the wear and tear information that was available to the design team, they found that the chassis and wheels need to be changed two times in four years[11], while all textile parts, including interior lining, wind stopper, hood, side pockets and mattresses need to be changed after each user. Washing of textile could be an option, depending on the location and volumes of the remanufacturing. The ability to test if components meet their requirements, vital for the warranty of strollers, is also a key issue. The fraction of parts that need replacement influences the environmental impact and decreases the economic viability.

In the current design, not all parts can be recycled due to difficulties in material recovery (severability of materials), and degree of recycling. The related design factors will be of key importance for closing the loop, and will affect the economic and environmental performance.

2.3.2. Market for remanufactured strollers

Remanufactured strollers will compete with new and second-hand strollers in the already highly competitive market. Several studies analyze the willingness-to-pay for remanufactured products compared to new products and found that remanufactured products have a lower purchase price than new products, even if the two products have the same quality and warranty (Guide and Li, 2010). The optimal selling price depends on many factors and can include brand equity, perceived product quality, negative consumer perceptions / disgust towards remanufactured products, whether the product is remanufactured by the original OEM and / or by a third party, the seller reputation, and the perceived risk by the consumers (Abbey et al., 2014; Agrawal et al., 2012a; Subramanian and Subramanyam, 2012; Wang et al., 2013). The effect of these factors depends on the product type and the above studies mainly focus on technological consumer products. In a focus group discussion on remanufactured Bugaboo strollers in the UK, the importance of quality and safety aspects were stressed. While high-end brands help assuring the proper quality of the remanufactured strollers, information on quality control and the treatment of wear and tear, accidents, and hygiene are essential to convince parents to buy a remanufactured stroller. When interviewed on the acceptance of leased strollers, expectant women and mothers of young children indicated that they want to know the product history, for instance how many people have used it and how old the stroller is (Catulli et al., 2013).

The willingness-to-pay (WTP) of consumers to purchase remanufactured or second-hand products (research in previously mentioned articles) assume that consumers are willing to buy the products. Jakowczyk et al. (forthcoming) found in their research that the market size and interest in remanufactured or second-hand electronic products depends positively on the interest in new products, the price of the new products and negatively on the product weight. Other factors might exist and future research is needed. Ovchinnikov (2011) also argues that not all consumers are willing to buy remanufactured products (even if discounted significantly) and perceived quality

[9] Reprocessing is part of remanufacturing and is the specific step where components are processed to return them to a certain specification (based on Sundin, 2004 and Hatcher et al., 2011). For example, in the Bugaboo case, this could include removing scratches from the frame. Other steps in remanufacturing are inspection, cleaning, disassembly, storage, reassembly, and testing.

[10] Due to changes in top management, the planned leasing pilot was not implemented.

[11] Mont et al. (2006) assumed 8 users which uses the stroller for 6 months each.

might be more important. For Bugaboo, these findings indicate that among the product attributes, *perceived* quality of the stroller is vital in developing a new design and business proposition.

Like the case for second-hand products, the presence of remanufactured products influences the WTP for new counterpart products. Agrawal et al (2012a) found for example that introducing remanufactured printers or MP3 players by the original OEM reduces the WTP for new products due to a lower perceived quality of the new product by consumers. However, they also found that remanufacturing by a third party increases the consumer quality perception for the new product. Bugaboo could consider to remanufacture the product under a different company to capture this positive effect on brand value, and this needs to be carefully examined.

Cannibalization can be perceived as threat when remanufacturing strollers. As discussed earlier, there are several consumer types that value new, compared to remanufactured and second-hand products, differently. Atasu et al. (2010) argue that the effect of cannibalization is most often relatively limited for high-end consumer goods as consumers who buy remanufactured goods are otherwise likely to buy low-end products. This heterogeneity of the market must be included in WTP studies. Note that this assumes substantial lower prices for remanufactured products. Charging lower prices for remanufactured products may decrease cannibalization of the high-end product and can at the same time attract lower-end customers (Ovchinnikov, 2011). Cannibalization and optimal price points for new and remanufactured products must therefore be considered together to determine the best strategy for Bugaboo. Cannibalization is not per definition a negative concept and depends on the price points and the remanufacturing and production costs.

2.4. Leasing remanufactured strollers

Pricing decisions in a leasing system is more complex than in traditional sales where it only involves price. Robotis et al. (2012) determine in a monopolistic setting the profit formulation of a leasing contract, where remanufactured and new products are perfect substitutes. The optimal leasing fee and leasing duration depends on the remanufacturing savings, the product's lifecycle, and capacity constraints. In the case of Bugaboo, the pricing of the multiple lifecycle lease concept might be even more complex; consumers classify, most likely, the remanufactured products as "outdated" compared to new products[12]. In that situation, remanufactured strollers would be valued lower and pricing decisions made by the company should include the different consumer segments (and their WTP) and the overall effect remanufacturing has on brand value. Alternatively, strollers could be designed for long emotional durability, eliminating unnecessary product changes, making it difficult to distinguish between new and multiple lifecycle strollers. Ma and Kim (2014) developed a continuous preference trend mining algorithm to determine which product design maximizes the profit over multiple product lifecycles, and taking into account several lease cycles and, when the product becomes technologically obsolescent, the disposal or recycling costs. The algorithm gives access to consumer preferences information about which parts of the product need to be of the latest technology and for which parts older generations can be used. However, they did not include possible product upgrades that could extend the product lifecycle. Obviously, the product design strategy would also have wider implications on the business strategy of Bugaboo.

2.5. ResCoM closed-loop system for multiple lifecycles

In ResCoM a service based model will be developed that allows the OEM to design and market products for multiple lifecycles (see also appendix 2). For Bugaboo, the initial model would be a lease system for both new and remanufactured strollers. In such lease system, the stroller will be used for a flexible period of time (minimal 6 months) after which the stroller is returned by the

[12] On average the Bugaboo stroller is updated and improved once in the three years, around the same time as one use cycle. This can limit the possibilities for Bugaboo to implement a multiple lifecycle leasing program, if not properly addressed in the product design.

customer (customer decides when to end the lease). The OEM collects the used strollers, remanufactures the stroller and leases them again until the stroller can no longer be brought back to the specification (i.e. quality is too low for another lifetime). Then, the parts will be recycled. Customers in the lease program do not know whether they get a new or remanufacturing stroller (obviously they are informed that remanufactured parts can be included in the product). The impacts this has on sustainability is discussed below, followed by a summary of the essential factors for this initial model identified in the analysis above.

2.5.1. Sustainability

LCA studies of strollers are rare. Only one study was found (Ang and Yifan, 2012). This study confirms the findings of the initial LCA for Bugaboo (see D3.1), that materials production is the dominant life cycle phase in the case of a stroller. The materials with the greatest impact in the Donkey stroller are aluminum (used for the frame) and glass-fiber reinforced nylon (used for the hinges). The sustainability recommendation for the Bugaboo stroller is rather straightforward: reuse the frame and hinges in order to prolong their useful life. This will decrease the relative impact of these materials (see D3.1).

Sustainability-related factors in transition to closed-loop model
With the introduction of the Bugaboo flex-plan (i.e. lease) pilot, the reuse of frame and hinges will be tested. An interesting question is whether the reverse logistics (with local, distributed and often rather inefficient modes of transport) will have a large impact on the overall lifecycle footprint of a remanufactured stroller. Mont et al. (2006) argue that the additional transportation in the leasing program can negate all the environmental benefits of product reuse (remanufacture) and recycling. Also Agrawal et al. (2012b) argue that leasing is not always environmentally superior, even if all products are reused and designed for long physical durability. To assess the environmental implications of leasing compared to selling strollers, a detailed assessment is needed.

Impact of reverse logistics
The Bugaboo pilot will give us insight in the impact of reverse logistics on the total lifecycle impact of a stroller. As the stroller does not consume electricity or water in the course of its life, the resource impact resulting from cars and vans driving around to service the strollers may be considerable. This will need to be explored in more detail.

2.5.2. Critical factors

Assuming that Bugaboo would implement a lease system that includes new and remanufactured strollers next to the sales of new strollers, the factors that must be considered are listed in the tables below. The requirements listed below are taken from D2.3. Note that some factors are relevant for several ResCoM pillars and requirements. In that case, the factor is only shown once.

Business requirements	Factors for multiple lifecycle closed-loop of high-end strollers	Includes
Value proposition	Product attributes; quality, safety, hygiene	Durability / length of functional life
Value creation and delivery	-	-
Value capture	Profit	Cost of logistics (transportation and warehouses / depots) Cost of leasing (additional resources, IT, incentives to retailers interest charge, etc.) Remanufacturing costs Production costs new strollers Revenue of leasing (fees, duration or length of use phase, indirect revenues of selling complementary products, etc.) Selling price after leasing time / disposal costs
Market for multiple lifecycle product:	Demand (for new and multiple lifecycle strollers)	Consumer segments Market size or interest in remanufactured products Cannibalization of new product sales

	WTP / optimal price points of selling new versus leasing new and remanufactured	Perceived product quality Negative consumer perception / disgust, Seller reputation / remanufacturer, Consumer resell value second-hand stroller Brand value Product lifecycle (design obsolescence)
Product acquisition to close the loop	Return rate	Quantity collected / stock of returned strollers
	Quality of returns	-
Sustainability	Environmental impact	Environmental impact of production Environmental impact of transportation (distribution and reverse logistics)

Table 3: Essential business model factors for modeling closed-loop product system.

Product design requirements	Factors for multiple lifecycle closed-loop of high-end strollers	Includes
Product attachment and trust	-	-
Reliability and Durability	-	-
Conformity to legislation	-	-
Modular product architecture (requirements 1-4):	-	-
1- Ease of maintenance and repair	Ease of inspection	-
2- Standardization and compatibility	Modularity of components	Material variety and compatibility / number of modules Percentage of product parts remanufactured
3- Upgradability and adaptability	Product upgradability	Number of upgrades between customers (use of additional material in remanufacturing process)
	Degree of reprocessing (in how far components can be returned to specifications)	-
4- Dis- and reassembly	Ease of disassembly	Number of disassembly required / ease of cleaning
Recycling and bio-cycling	Ease of material recovery	-
	Material recyclability / percentage of materials or parts recycled	-

Eco-performance	- (included in sustainability)	-

Table 4: Essential product design factors for modeling closed-loop product system.

Supply chain requirements	Factors for multiple lifecycle closed-loop of high-end strollers	Includes
Customer integration	- (incentives included in business model)	-
Coordination of (modularized) production flow in an integrated supply chain	-	-
Warehousing and inventory control	-	-
Operational value recovery (manufacturing level)	Yield rate / ratio of usable parts	Stock of “as new” strollers

Table 5: Essential supply chain factors for modeling closed-loop product system.

Information technology requirements	Factors for multiple lifecycle closed-loop of high-end strollers
PLM	-
System integration	-
Models for MLPs	-
Product identification and traceability	-
Data processing	-
Access control	-

Table 6: Essential IT factors for modeling closed-loop product system.

As discussed in chapter 1, the mutual relationship of the factors in the closed-loop product system and the criticality of the factors are determined with the DSM method. The one-on-one relationships between the essential factors are rated by the consortium partners. The output of the combined rating is shown in the matrix below. Relationships that are rated on average higher than 2 are indicated as crucial for the performance of the envisaged ResCoM closed-loop system and are shown in red in the matrix below.

DSM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Profit		0.57	1.00	0.43	0.57	0.43	0.86	0.57	1.00	0.43	0.57	0.29	0.43	0.71	0.29
WTP / optimal price points of selling new versus leasing new and remanufactured	2.71		1.00	0.71	0.57	2.29	0.14	0.29	0.57	0.43	0.14	0.00	0.14	0.14	0.14
Product attributes; quality, safety, hygiene	1.57	3.00		0.57	2.00	1.86	0.71	1.29	1.29	1.57	1.43	0.57	1.43	1.43	0.86
Return rate	2.00	0.43	0.86		1.00	0.86	0.86	0.71	2.14	0.71	0.57	0.57	1.00	1.29	0.43
Quality of returns	1.86	0.86	0.57	0.57		0.57	0.71	0.71	1.57	1.86	0.43	0.86	0.43	2.57	0.43
Demand (for new and multiple lifecycle strollers)	2.14	1.57	1.43	1.14	0.71		0.57	1.00	0.43	0.57	0.57	0.14	0.00	0.14	0.29
Modularity of components	1.43	0.43	0.86	0.71	0.57	0.57		2.71	1.57	1.29	2.00	1.71	1.14	2.00	1.29
Product upgradability	1.43	1.86	1.57	1.29	0.86	1.43	1.14		1.43	1.29	1.14	0.57	0.86	1.57	0.71
Environmental impact	1.00	1.00	0.86	0.71	0.71	0.86	0.86	0.86		0.86	0.71	0.29	1.00	0.86	0.86
Degree of reprocessing	1.86	1.14	1.43	0.57	0.57	0.71	0.57	1.00	2.00		0.86	0.57	0.57	2.00	0.57
Ease of disassembly	1.71	0.29	0.71	0.43	0.57	0.71	0.86	1.71	1.14	1.43		1.71	0.86	2.00	1.57
Ease of inspection	1.00	0.29	0.57	0.29	1.00	0.29	0.43	0.71	0.71	0.86	0.71		0.43	1.29	0.57
Material recyclability / Percentage of materials or parts recycled	1.43	0.71	0.43	0.71	0.14	0.71	0.43	0.29	2.43	0.29	0.43	0.14		0.43	0.71
Yield rate / ratio of usable parts	2.29	0.43	0.43	1.00	1.00	0.86	0.71	0.86	2.57	0.71	0.71	0.57	0.57		0.57
Ease of material recovery	1.29	0.14	0.29	0.14	0.29	0.14	0.57	0.57	2.00	0.57	0.57	0.29	2.43	0.71	

Table 7: DSM rating for the closed-loop system for Bugaboo.

Due to the high interdependencies of the essential factors in the closed-loop system, it is not possible to identify mutually exclusive subset of factors. The combined rating identified 11 relationships as critical. The highest score can be found between product attributes and WTP. Attributes, like the quality, safety and hygiene of a stroller determine the price or leasing fee consumers are willing to pay. If customers perceive remanufactured strollers appearance, quality and hygiene the same as a new one, their WTP will increase. The WTP of consumers, which greatly decides demand, is strongly related to the opportunity to generate profit. Yield rate has a crucial impact on profit and environmental impact; a high ratio of usable parts could bring more profit in terms of saving resources (materials, energy, labor and facilities costs). The yield rate depends on the quality of returns. The higher the quality of returned products the more reusable parts and therefore the higher the degree and effectiveness of remanufacturing. A high return rate of strollers means high potential to get reusable and valuable resources which will benefit the environment, on the other hand, one should consider how to optimize the reverse supply chain to reduce environmental impact during the transportation phase (overall effect needs to be calculated). Material recyclability can have a crucial effect on environmental impact as several important materials currently used cannot be recycled. Ease of material recovery is therefore needed as only materials that can be recovered will be recycled. Finally, product modularity is identified as having a crucial relation to product upgradability. Modules allow future changes to be implemented in existing products because of standard interfaces.

These crucial factors and the initial model for Bugaboo will be used as input for D4.2 that will calculate the economic and environmental performance of this closed-loop system. This is further explained in chapter 6.

3. Washing machines

Possible business plans for a closed-loop product system for the professional washing machine will be analyzed as first step to answer the strategic question whether or not Gorenje should move to a closed-loop system (i.e. whether it is profitable and more sustainable than linear manufacturing). Gorenje is not the first white good producer that is looking into service-based business models. Electrolux trialed pay-per-wash in Sweden in the early 2000s. Currently, washing machines are leased or rented via many third-parties to small companies and consumers. Pay-per-use is offered by Bundles in the Netherlands, and refurbished professional washing machines are offered by ISE in the United Kingdom.

ResCoM has as goal to reduce costs and environmental impact by combining end-of-life strategies with new business models. More concrete, one option could be to combine remanufacturing with a service-based model. As outlined in D2.3, requirements for developing a closed-loop product system and therefore key issues in preparing this business plan are the market for returned professional washing machines including the customers' requirements on such multiple lifecycle product, product design, and the profitability and sustainability of remanufacturing as recovery option. These issues are discussed below, followed by a description of the initial ResCoM model for Gorenje.

3.1. Market for second-life professional washing machines

Reconditioned or refurbished washing machines are sold by many small retailers, often at significant lower prices their new counterparts. These washing machines have generally a lower quality and warranty than new products, which justifies the lower price. Remanufactured washing machines, however, can provide "as new" quality.

As indicated above, the WTP of consumers for remanufactured products depends on factors as perceived quality and risk, consumer perception of remanufactured products, price of the new product, the seller reputation, and the remanufacturer. The WTP of consumers for remanufactured products depends on the consumer segment. It is argued that consumers belonging to a green segment might value remanufactured products equal to new products. The size of such green consumer segment is therefore positively related with the price a company can ask for their remanufactured products (Atasu et al., 2008). This green consumer segment is small but growing in the past years (Kirchoff et al., 2011; Sabharwal and Garg, 2013). However, whether these environmentally conscious consumers are willing to pay for green products is still an open question; there is a discrepancy between survey findings about consumer buying intentions and actual purchase decisions made at point of sale (Michaud and Llerena, 2011).

Michaud and Llerena (2011) performed an auction study (third price sealed bid) to analyze the effect of WTP of consumers for remanufactured single use cameras. They find that consumers value remanufactured products less, unless they are aware of the environmental benefits of the remanufactured products. However, they also found that consumers are not willing to pay more for green remanufactured products. Interestingly, providing information that the remanufactured product is environmentally better, decreased the WTP of consumers for the conventional (e.g. new) product. The proportion of remanufactured components or the remanufacturer (the OEM or independent firm) has no significant effect on the WTP. Watson (2008) also concluded from a literature review that environmental concerns play only a minor role in the consumers' decision to buy remanufactured, repaired, or reused goods, while price is the most important factor. Further research is needed to draw conclusions on the WTP for washing machines.

In the case of Gorenje, remanufacturing is considered a potential recovery option for professional washing machines. The remanufactured washing machines can be sold in the future to small companies and / or individual consumers. Besides that, Gorenje is looking into how these washing machines can be leased. The interaction between these different channels, via the second-hand market, influences the optimal prices in each channel. Tilson et al. (2009) studied the manufacturer pricing decisions in the case of a monopolist that sells durable products to individual consumers and leases durable products to both corporate and individual consumers. Products returned from the lease contract are sold on the second-hand market. Among the results, they conclude that when used and new products are close substitutes, the transaction costs associated with reselling the used products make leasing to individual consumers unprofitable. Pricing decisions that include new and remanufactured products for both corporate and individual consumers on leasing and selling basis are not yet researched.

3.2. Product design

The Asko professional line of washing machines is a long-lasting product that could be leased rather than sold and redesigned to increase modularity and usability of parts across generations. The materials used are already recyclable and the factory recycles waste from production. A remanufacturing production line has yet to be established to execute the case.

Sundin et al. (2009) conducted a case study on product design for service models for a washing machine of Electrolux. Design for maintenance and remanufacturing are considered and the authors discuss that for remanufacturing, design-for-disassembly should take “fitness for reuse” into account, ensuring that parts are not damaged during separation. Krikke et al. (2003) developed a quantitative model for decision making of a product design (including modularity, reparability, and recyclability) and the logistics network structure and applied it to a refrigerator case. Decisions were analyzed on costs, energy use and residual waste. They found that especially product design can influence energy and waste, while the logistics network design has more impact on costs.

Product upgradability, modularity of components, and ease of disassembly

On Gorenje washing machines, most parts are used from generation to generation. Main differences between generations concern the user interface, visual outside parts, and software. Parts such as the motor, drum and frame change less frequently. As a consequence, remanufacturing of used washing machines may resemble upgrading existing machines with a new interface and exterior. For the economic viability, it is thus essential that upgrades are cost-effective and value adding. Upgrades should be planned with the launch of the platform, and with the available upgrades, the reusable portion of the product should serve the market for as long as possible. It requires Gorenje to enhance the modularity and in particular interface standardization. The modules have to be easy to disassemble if the replacement and updating of modules is to be cost effective. Non-reusable parts will create environmental impact in every use cycle; their subsequent disassembly or recycling compatibility has to be optimized to minimize environmental impact.

3.3. Profitability

Gorenje has an advanced IT system that captures the after-sales services, including the repairs and replacements made at the individual customer level. This allows Gorenje to analyze what parts or components of the professional washing machine should be replaced when selling or leasing the second-lifetime product on the market. An initial investigation shows that the electronics component likely needs to be replaced between customers. Also some data on the average use time of the professional washing machine can be extracted from their IT systems.

Based on the direct production cost that exists of 13-17% labor and 83-87% on material and parts costs, it is likely that remanufacturing can save money. The reverse supply chain costs can however be substantial in heavy products like washing machines. The costs will be heavily influenced by the location of the recovery facility and tradeoffs between a recovery facility close to the market base but in high labor cost countries must be carefully assessed against lower labor costs but higher transportation costs.

Besides costs, the revenue stream is also changed when providing washing machines to users based on a service contract. As discussed in chapter 2, the capital needed to finance the first years of the leasing scheme can be a major barrier for the company.

3.4. Sustainability

Washing machines are part of the Ecodesign Directive and have been thoroughly scrutinized by the European Commission. The preparatory studies done by the EC have shown that washing machines (in this case household washing machines) have the most significant environmental effect in the use phase, through **water and electricity consumption** (EU, 2010). The European Environment Bureau calculated that the use phase accounts for 72 – 74% of the total environmental impact (Garcia, 2013).

Sustainability-related factors in transition to closed-loop model

The environmental impact of washing machines is assessed by several researchers. While recovering washing machines can save raw material, the energy efficiency of washing machines is improved over time and recovering an older washing machine model might therefore offset material conservation with higher energy usage during the use phase (Devoldere et al., 2009). O'Connell et al. (2013) analyzed the life-cycle impacts of reuse versus recycling of washing machines, taking into account the average electricity impacts in Ireland during the use phase. They found that the preferred end-of-life strategy depends on the energy label, the intensity of usage, and period of ownership / usage.

From a lifecycle perspective it is always an issue whether a greater environmental benefit is achieved through extending the lifetime of the product (through repair), or replacing it with a more resource efficient model.

"Best environmental option"		New replacement energy rating		
		A	A+	A++
Old machine energy rating	C	Repair	Replace	Replace
	A	Repair	Repair	Replace

Table 8: Replacement recommendations (WRAP, 2010)

A study by WRAP concluded: "Based on our assessment, until there is a significant step-change in the energy performance of washing machines available to the market, WRAP recommends that machines are designed for easy repair and to ensure that repaired or refurbished machines continue to operate for a long time" (WRAP, 2010). In the case of closed-loop product systems, it is important that the environmental impacts are measured as objectively as possible (Bloemhof-Ruwaard et al., 2004). Due to the circular nature of products and components in the closed-loop system, it is even more difficult to determine the system boundaries than in a linear product LCA.

Repair or replace?

Developments in resource consumption of washing machines (water and electricity) are critical factors – if radical technological improvements for resource efficiency are introduced, this is a strong case for early replacement. If not, design for easy repair and / or modular design should have priority. We assume this is also applicable to professional washing machines. Professional washing machines are less susceptible to inefficient use than household washing machines (related to load and filling rate), making repair / modularity even more important from a sustainability point of view. This assumption will be verified in D3.1.

3.5. ResCoM closed-loop system for multiple lifecycles

Once the above described issues are researched, a sustainable and profitable closed-loop product system can be designed. Based on early findings and assumptions in the ResCoM project (see appendix 20, it can be anticipated that the new system will include the take back of products to a recovery facility, where products are cleaned, repaired, and upgraded to fit the requirements of multiple lifecycle customers. The flow of goods and information in such system is simplified shown in the figure below.

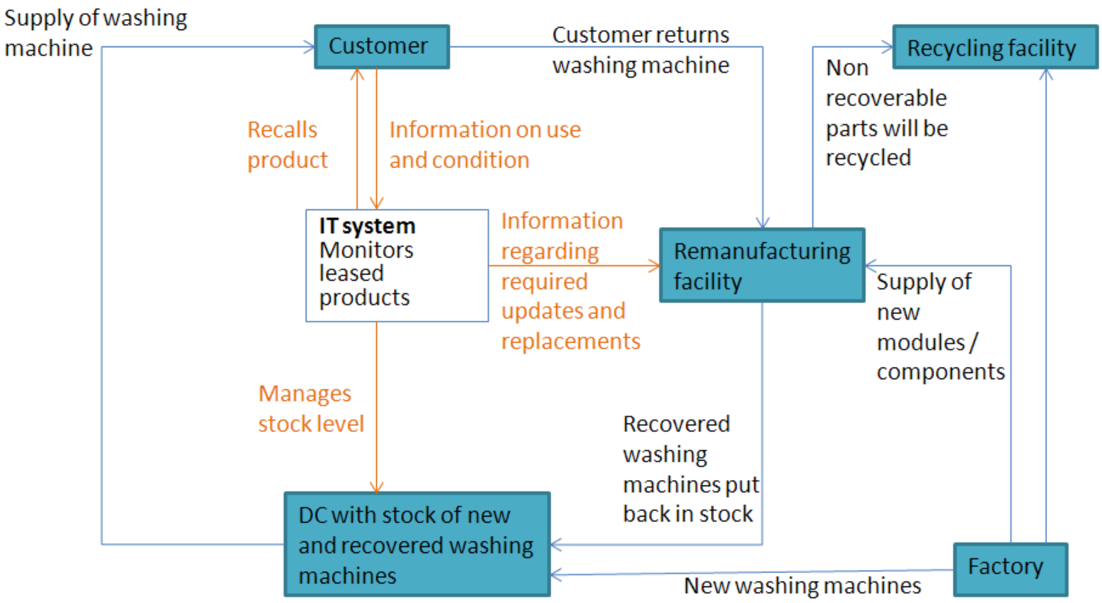


Figure 4: Flow of products and information in a ResCoM closed-loop product system for professional washing machine of Gorenje.

Similar factors for the IT system as defined in section 2.2.2 are identified for Gorenje. Due to the different nature of product, washing machines provide more possibilities regarding data collection. A monitoring system is possible that can count the number of washing cycles and can provide this information remotely to the OEM, a system already sold by Bundles (see D3.2). Gorenje could use this information to define leasing durations. An IT system will then be needed that can record the washing times and recall the product after a predefined amount of washes. However, due to privacy concerns of customers, such system might be difficult to implement and further research will be needed.

The reverse logistics network for returning washing machines in the lease system must be designed. Collection centers close to the customer might be preferred. Due to the nature of the product, a pick-up strategy would be logical. Consequently the reverse logistics cost depends on the collection rate, density of used products, cost of operating a collection center, transportation costs, and capacity of trucks (Aras et al., 2010). From the collection centers, transportation to a remanufacturing facility and from the remanufacturing facility to the depots and warehouses should also be included in the calculation and compared with the current system where washing machines are collected for recycling.

3.5.1. Critical factors

The factors that are essential to model the economic and environmental impact of the initial closed-loop system where both new and remanufactured products are leased as multiple lifecycle washing machines are listed below. It is assumed that customers are aware that remanufactured parts might be included in the product.

Business requirements	Factors for multiple lifecycle closed-loop of professional washing machines	Includes
Value proposition	Product attributes; quality, sustainability	Durability / length of functional life
Value creation and delivery	-	-
Value capture	Profit	Cost of logistics (transportation and warehouses, depots and collection centers) Cost of leasing (additional resources, IT, incentives to retailers interest charge, etc.) Remanufacturing costs Production costs new washing machines Revenue of leasing (fees, duration or length of use phase, indirect revenues of selling complementary products, etc.) Selling price after leasing time
Market for multiple lifecycle product:	Demand (for new and multiple lifecycle washing machines)	Consumer segments Market size or interest in remanufactured products Cannibalization of new product sales
	WTP / optimal price points of selling versus leasing, new versus remanufactured	Negative consumer perception / disgust Perceived risk Seller reputation / remanufacturer
Product acquisition to close the loop	Collection rate / return rate	Quantity collected / stock of returned washing machines
	Quality of returns	-
Sustainability	Environmental impact	Water consumption during use Electricity consumption during use / energy label Period of ownership / usage Energy efficiency improvements in washing machines Environmental impact of production Environmental impact of transportation (distribution and reverse logistics)

Table 9: Essential business model factors for modeling closed-loop product system.

Product design requirements	Factors for multiple lifecycle closed-loop of professional washing machines	Includes
Product attachment and trust	-	-
Reliability and Durability	-	-
Conformity to legislation	-	-
Modular product architecture (requirements 1-4):	-	-
1- Ease of maintenance and repair	-	-
2- Standardization and compatibility	Modularity of components	Ratio of modular and non-modular components Module reusability / ratio of standard parts or modules / material variety and compatibility
3- Upgradability and adaptability	Product upgradability (use of additional material in remanufacturing process)	Number of functions that can be upgraded / number of upgrades between customers Backward compatibility of new accessories
4- Dis- and reassembly	Ease of disassembly	Number of disassembly required / steps to get to key components / ease of disassembly Number of components recovered through disassembly
Recycling and bio-cycling	-	-
Eco-performance	- (included in sustainability)	-

Table 10: Essential product design factors for modeling closed-loop product system.

Supply chain requirements	Factors for multiple lifecycle closed-loop of professional washing machines	Includes
Customer integration	- (incentives included in business model)	-
Coordination of (modularized) production flow in an integrated supply chain	-	-
Warehousing and inventory control	-	-
Operational value recovery (manufacturing level)	Yield rate / ratio of usable parts	Stock of "as new" washing machines
	Ratio of product reuse / remanufacturing / recycling (recovery policy)	-

Table 11: Essential supply chain factors for modeling closed-loop product system.

Information technology requirements	Factors for multiple lifecycle closed-loop of professional washing machines
PLM	-
System integration	-
Models for MLPs	-
Product identification and traceability	-
Data processing	-
Access control	-

Table 12: Essential IT factors for modeling closed-loop product system.

The combined rating resulted in the identification of the critical relationships between factors in a closed-loop product system for Gorenje (shown in red). The interaction of the factors in the envisaged closed-loop system explained above are shown in the matrix below.

DSM	1	2	3	4	5	6	7	8	9	10	11	12
Product attributes; quality, sustainability		1.71	2.86	1.86	1.29	0.71	2.00	0.71	1.29	1.57	1.29	1.00
Profit	1.00		0.71	0.71	0.43	0.57	0.71	1.00	0.86	0.57	0.86	0.71
WTP / optimal price points of selling versus leasing, new versus remanufactured	1.00	2.86		2.43	0.00	0.71	0.71	0.14	0.57	0.43	0.86	0.00
Demand (for new and multiple lifecycle washing machines)	1.43	2.14	1.71		0.14	1.29	0.86	0.43	0.57	1.14	0.57	0.57
Yield rate / ratio of usable parts	1.00	2.43	0.14	0.43		0.71	0.57	1.00	2.14	1.14	2.14	0.57
Collection rate / return rate	0.71	1.86	0.57	1.00	0.86		1.00	0.86	1.86	0.71	2.14	0.57
Quality of returns	1.00	1.86	0.57	0.57	1.86	0.57		0.57	1.43	0.71	1.43	0.43
Modularity of components	1.14	2.00	0.43	0.71	1.57	0.86	0.71		1.43	2.71	1.57	2.14
Ratio of product reuse / remanufacturing / recycling (recovery policy)	0.86	2.00	0.57	0.43	1.14	0.71	0.71	0.86		0.86	2.57	0.86
Product upgradability	1.71	1.14	1.57	1.14	1.00	0.86	0.57	1.00	2.14		1.43	0.57
Environmental impact	1.29	1.00	1.14	0.86	0.86	0.71	0.71	0.86	0.86	0.86		0.86
Ease of disassembly	0.71	1.71	0.14	0.43	1.43	0.29	0.57	0.86	1.57	1.71	1.29	

Table 13: DSM matrix for closed-loop system for Gorenje.

Product attributes, like the quality and sustainability of the washing machine, are key for customers' WTP. The WTP has an important impact on demand and profit. The more customers are willing to pay for a remanufactured or new product, the more potential the company has to earn profit (larger profit margins). Demand is necessary for generating profit. Yield rates have a significant impact on profit. A high ratio of usable parts could bring more profit by saving resources (materials, energy, labor and facilities costs) and is necessary to maintain profitability, due to high costs for transporting washing machines. Yield rates also have a crucial impact on environmental impact. Environmental impact of remanufactured washing machines mainly depends, according to the DSM rating, on the yield rate, collection / return rate of washing machines, and the ratio of product reuse / remanufacturing and recycling. More returns will result in more reuse of parts and materials and in more transportation which will impact the environment footprint of the washing machine. Product upgradeability, the use of additional material in the remanufacturing process to customize the product to the customer's requirements, means that parts that are still functional will be replaced with updated parts regardless of their reusability. This will have a negative effect on the environmental sustainability of remanufacturing. Modularity of components allow future changes to be implemented in existing products because of standard interfaces and makes it therefore possible to upgrade components when necessary, resulting in a critical relationship with product upgradability. Finally, modularity of components has a crucial effect on ease of disassembly. Modular design considers the design of the interfaces which will facilitate both assembly and disassembly of a washing machine with a complex assembly structure.

4. TVs

As discussed in deliverable 2.3, the first step for Loewe to move towards a closed-loop product system is to organize the after-sales service in such way that information can be collected that will be essential for setting up a return system and for recovering the returned TVs. Especially information around the usage patterns and the lifetime of the different parts will be useful when evaluating which closed-loop product system option is the most cost-effective, resource-efficient and sustainable. In a second step, this information can help in designing TVs with a high level of modularity, such that relevant components can be easily reused. Due to the high innovation pace, which means that every six months a new TV is designed, and the long use phase (on average 8 to 12 years), there is no overlap between the new and remanufactured product life cycle. The remanufactured TVs must be either upgraded to new generations or a market for these old generations TVs must be found. Remanufacturing is therefore unlikely (see also D2.3 and D3.2). It is more likely that modules and components can be used as spare part for the after-sales market. Spare parts cannibalization will help Loewe in building a closed-loop product system. In the long term, Loewe can then move towards a closed-loop product system where used parts and components are used in the production of TVs. In order to determine what the best recovery strategy would be for Loewe, the current costs of the after-sales service should be analyzed and the environmental impacts of the recovery strategies assessed.

4.1. After-sales services and spare parts management

This section presents first the current after-sales process of Loewe, followed by a high-level analysis of the system. In the second part, essential data and changes in the after-sales process are discussed that facilitate the transition towards a closed-loop product system.

4.1.1. The after-sales process

The after-sales service of Loewe is outsourced to retailers who provide service to customers within the 3 years warranty period in Germany. During this “dealer warranty” policy, the retailers replace faulty components with new ones. The retailers are required to send the faulty components to Loewe in order to get the full price of the dealer warranty. After the warranty period, TVs can be repaired in the production facility or new TVs can be offered at lower prices. This policy depends on the product line. Due to legal restrictions and economic reasons, there are no components returned to Loewe outside the German market.

After a customer complaint, the retailer sends a service technician to the customer or asks to bring the TV to the showroom. The technician performs the troubleshooting and repairing, i.e. exchange of the faulty component. Both the retailer and Loewe have an inventory of spare parts. The flow of spare parts is shown in the figure below.

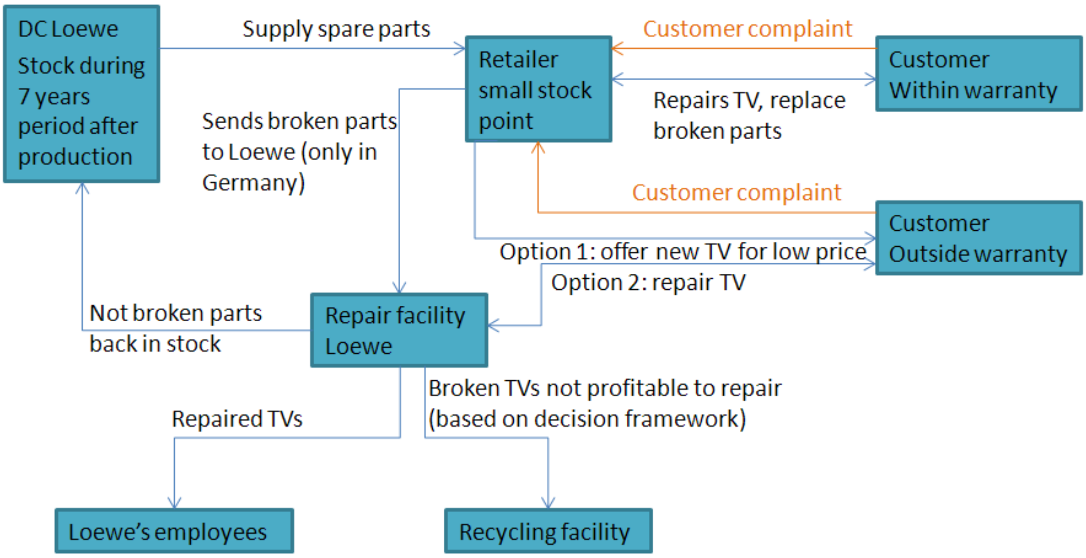


Figure 5: Flow of spare parts in after-sales service of Loewe.

As outlined in D2.1 and D2.3, the high innovation pace in the consumer electronics industry and the high customer service cause high costs for Loewe as they have to keep stock of all parts for several years. When Samsung decides to stop the production of a certain display type, Loewe is forced to place a Last Time Buy (LTB) order. A LTB-order is the final order a company can place to fulfill all future demand for that particular component / spare part. In order to obtain high service levels, companies often order larger quantities which results in high obsolescence levels at the end of the service period (Behfard et al., 2013).

4.1.2. Using after-sales data for spare parts planning

Due to the high obsolescence risk and the associated costs, companies should invest in making use of all available information that can help forecasting spare parts demand (Dekker et al., 2013). The forecasts should take into account the lead time (both the manufacturing and transport lead time to get the product to the consumer), the costs including stock-out costs, inventory holding costs, and obsolescence costs, and the product lifecycle phase. In many industries information is not shared between the supply chain partners and it might be difficult for a manufacturer to estimate the set of products to which it provides after-sales service, i.e. the installed base. Having data on the installed base which is fed into the forecasting procedure improves the accuracy of the prediction compared to forecasts based on historic demand, but the benefits greatly depend on the situation (Dekker et al., 2013). Jalil et al. (2011) studied the economic benefits of using installed base data in the planning of spare parts at IBM, a company with multiple stock locations. They compared the situation where the customer location is unknown with the situation using detailed information on customers geographical location and found that the benefits are significant especially for low demand rates (as is often the case with spare parts). Quality errors in the installed base data, however, can negate these benefits and it is important to understand the data. A detailed analysis is therefore needed in order to determine whether or not Loewe should invest in collecting after-sales data.

One possibility to gather information on the installed base and usage patterns of the TVs is by installing electronic systems. As discussed in D2.3, electronic systems that collect usage data facilitate not only maintenance and repair on individual level, but combined also provide Loewe with crucial information to design TVs for maintenance and reparability and for spare parts planning. In the long-term, this information could be used to analyze the suitability of reusing components and TVs in order to close the loop further. The benefits of such IT system will be calculated in detail in D4.2 and D4.3.

4.2. Reuse of components

Instead of using new spare parts, Loewe could reuse the returned components after repair. Besides the environmental benefit, reusing parts can significantly reduce the initial stock and therefore reduce the after-sales costs (Teunter and Fortuin, 1999). Using repaired items as spare parts is widely studied in the literature. This section discusses first briefly the literature on spare parts inventory management that considers LTB and repairable returns, followed by the integration of usable end-of-use returns. Other options are possible as alternative for using new components as spare parts, for example to supply consumers with new products, to buy second-hand parts on the free market, to provide a compatible part, or to change the system in such way that the part is not needed. However, as the focus here is on closed-loop product systems, only systems that reuse used components are presented.

4.2.1. Spare parts inventory management with LTB and repaired failed parts

A major issue is the decision whether returned items are repaired immediately upon arrival (push) or on demand (pull) (Krikke and van der Laan, 2011). When repair costs are negligible, all returned items can be repaired and restocked immediately, using a push policy (Teunter and Fortuin, 1999). Behfard et al. (2013) consider the pull situation where a company makes repair decisions (based on the base stock repair policy) to fulfill expected demand in the next time period during and after the LTB-call for a specific single part. They assume that the costs of having items returned to the company is considerable less than the repair costs and items are therefore always directly returned to the company after failure. Spengler and Schröter (2003) look how parts reuse can contribute to spare parts management after the LTB order. With a system dynamics model they determine a strategic planning tool for component recovery.

4.2.2. Spare parts inventory management with LTB, repaired failed parts, and phase-out returns

Phase-out returns are products that are abandoned and returned by customers because they prefer a newer generation but can still be used for spare parts for products at other customers (Krikke and van der Laan, 2011). Krikke and van der Laan (2011) assesses the LTB and repair and disposal policy of returns in a model where failed products and phase-out returns are used to cover the demand for spare parts in the decreasing installed base over time. They assume an infinite repair capacity but a limited repair yield in both return streams and the quantity and timing of the phase-out returns are deterministic and known. They found that in general the pull policy leads to lower costs. Pourakbar et al. (2014) determines the optimal repair policy after the LTB and found that the optimal repair policy depends on factors as level of serviceable inventory, holding costs, disposal costs and repair yield.

Based on the literature findings described above, the essential factors for reusing components in the after-sales process and their relationships are shown below.

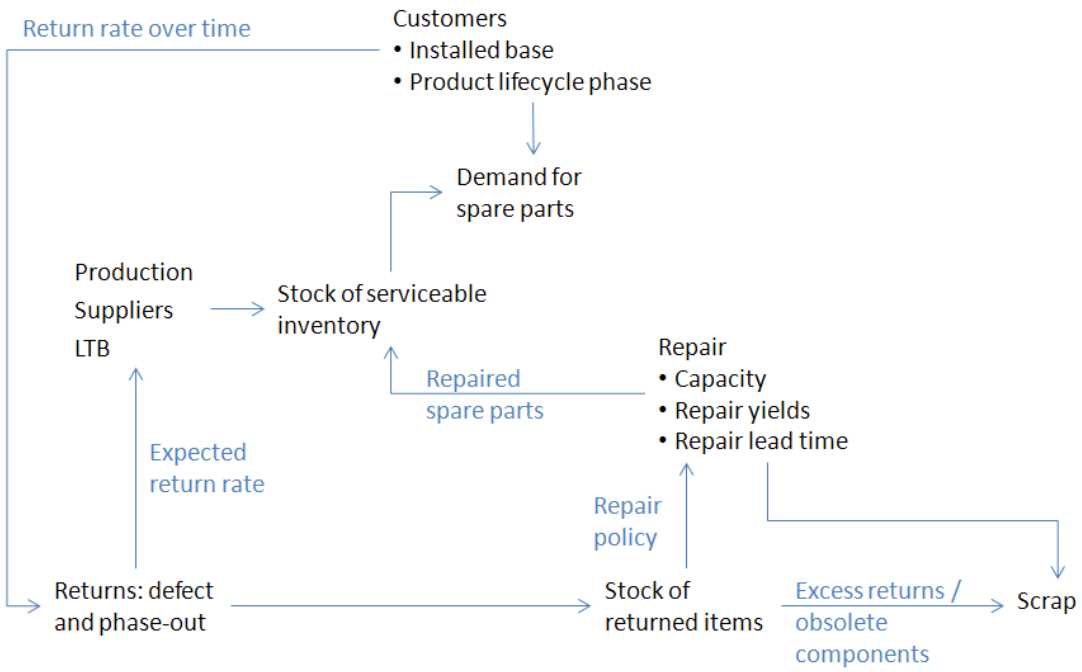


Figure 6: Essential factors in spare parts management with repair of returns.

4.2.3. Product modularity

The Loewe TV sets are long lasting, and are prone to be replaced because of advances in technology well before their useful life (as the primary television set in the home) is over. Advancing panel technology is also the main driver of new product development, which severely limits the possibility to remanufacture used products and to provide spare parts for products in use. When components can be used across multiple product generations, returns can be used for spare parts and the percentage of recoverable parts will increase. Modular product design and standardization is therefore needed for efficient closed-loop systems.

Product platform stability, modularity of components, and degree of recycling

ConnectID is an existing product line and to create circular versions, the design of some parts will change more rapidly than others due to market forces. It is key that the platform is flexible towards especially panel developments, but offers sufficient stability to secure the usability of parts across successive generations. In other words, the product's value retention over multiple lifecycles depends in Loewe's case on the applicability of valuable parts to new and state-of-the-art generations of the product platform. As described by Bras (2010) OEMs that internalize remanufacturing will spend significant time on designing a product architecture that allows for technology upgrades.

Customer service is currently expensive because it requires a stock of components for each product that works with only one or a few product generations. A possible solution that Loewe investigates is a modular system of a smart box and separate screens. This is a good example of reducing the costs of fast-changing components and creating other components with a long-lasting value. To be economically viable, a large portion of the parts that can be recovered from used TV sets has to be valuable for new products. Currently, TVs are recycled through a centralized recycling infrastructure and as a result, only marginal value for Loewe is recovered in the form of financial returns from recycling. For those parts that cannot be used multiple times it is critical that sufficient value is recovered through (dedicated or generic) recycling. If recycling is not viable, these single parts would determine a large share of the environmental impact of the system.

4.3. ResCoM closed-loop system

If Loewe decides to embed the electronic system in the TVs and collect after-sales data, Loewe could use this information to design closed-loop product systems. The environmental and economic impact of the recovery options and new business models are first discussed, followed by the ResCoM critical factors for Loewe.

4.3.1. Sustainability

In the period 2007-2010 the average TV screen size increased by 4.5 inches, and in 2012, 65% of the screens sold measured between 40” and 60”. On-mode power has however impressively decreased with 55% between 2008 and 2012 – despite the average increase in screen size. In 2008 the average TV sold in the EU reached an on-mode power of 156 W, by 2012 the average was 70 W (Michel et al., 2013). This is mainly due to the introduction of flat panel LED TVs.

With these radical energy efficiency gains (on a power per screen area basis), the environmental impact of the **production phase** of televisions becomes more and more important. A study by Bakker et al. (2012) shows that the production and use phases of the Philips Econova LED TV have comparable impacts. With increasingly bigger screens and increasingly energy efficient electronics, the materials production phase will have a much greater relative importance (Hischier et al., 2014).

Sustainability-related factors in transition to closed-loop model

The general tendency for the production phase to become more important leads to the recommendation to extend the lifetime of the TV through design for easy repair and upgrading (for instance through modular design). This is in line with the transition to a closed-loop model. The environmental impact of extending product life, for example with product modularity, must be carefully assessed as this might have wider implications. Wider implications and effects of the new closed-loop product system must be included in the LCA analysis. For example, Agrawal and Ulku (2013) argue that product modularity might accelerate obsolescence and can, for that reason, have a detrimental effect on the environmental performance.

Introduction of TV repair and upgrade

The current screen innovation cycle is pushing Loewe to introduce new TV models every 6 months. This is a serious barrier for the introduction of TVs designed for easy repair and upgrade.

4.3.2. Profitability

As discussed in D2.2, several solutions exist that can help in creating sustainable and profitable business models for multiple lifecycle products, including service based models and product recovery options. This section explores in more detail the consequences of several business models for Loewe in terms of profitability.

Due to the high innovation pace in the home entertainment industry and the long use phase of the TVs (which means that the end-of-use TVs are 16 to 24 generations old) the reuse of TVs is unlikely. Even if there is a market for these old generation TVs, the WTP for such TV will be substantially lower and hence limit the profitability of remanufacturing. Component reuse, like parts cannibalization, is more suitable (Östlin et al., 2009). Product standardization will positively impact the reusability of the components.

Leasing can be profitable when the disposal costs are substantially lower for the company than for the consumer (Agrawal et al., 2012b). Due to the limited reuse possibility, this is most likely not the case. The revenue generated over the lease period should be carefully assessed against the costs of leasing; including transportation costs, incentives to retailers, interest charge, cost for the IT system and cost for initiating the leasing program. An earlier trial of leasing TVs in the Netherlands showed further that substantially high margins are needed to cover losses due to consumer carelessness and theft. Leasing seems to be therefore not the optimal choice for Loewe at this point in time.

4.3.3. Critical factors

The factors that are essential to model the economic and environmental impact for a closed-loop system for Loewe are listed in the table below. In the initial ResCoM model, returned TVs (repaired failed parts and phase-out returns) are used for spare parts[13]. Modular product design and standardization (in combination with design for repair, etc.) is applied to increase the usability of old / used components and modules.

Business requirements	Factors for ResCoM closed-loop system for Loewe	Includes
Value proposition	Warranty policy / customer service policy	-
Value creation and delivery	Innovation speed of components	-
Value capture	Profit	Costs of logistics (transportation and warehouse / depots) After-sales costs (inventory holding costs, out of stock costs, obsolescence / disposal costs, Last-Time Buy) Costs of electronic system Repair costs
Market for multiple lifecycle product:	Spare parts demand	Installed base
Product acquisition to close the loop	Return rate	Stock of returned items Lead time
Sustainability	Environmental impact	Environmental impact of production Lifetime of components (duration of use) Electricity consumption during use

Table 14: Essential business model factors for modeling closed-loop product system.

Product design requirements	Factors for ResCoM closed-loop system for Loewe	Includes
Product attachment and trust	-	-
Reliability and Durability	- (included in spare parts demand)	-
Conformity to legislation	-	-
Modular product architecture (requirements 1-4):	-	-
1- Ease of maintenance and repair	-	-

[13] In the long run, these parts can be used in the production process of "new" TVs. Another analysis of essential factors will be needed to capture the relationships in such system.

2- **Standardization and compatibility**	Product platform stability	Usability of parts across successive generations and parallel product lines
	Product modularity	Ratio of modular components
3. **Upgradability and adaptability**	-	-
4. **Dis- and reassembly**	-	-
Recycling and bio-cycling	Degree of recycling	-
	Ease of material recovery	Severability of materials
Eco-performance	- (included in sustainability)	-

Table 15: Essential product design factors for modeling closed-loop product system.

Supply chain requirements	Factors for ResCoM closed-loop system for Loewe	Includes
Customer integration	-	-
Coordination of (modularized) production flow in an integrated supply chain	-	-
Warehousing and inventory control	-	-
Operational value recovery (manufacturing level)	Yield rate / ratio of usable parts	Inventory of serviceable inventory Product lifecycle phase
	Ratio of product reuse	Number of obsolescence products or parts
	Capacity / lead time	-

Table 16: Essential supply chain factors for modeling closed-loop product system.

Information technology requirements	Factors for ResCoM closed-loop system for Loewe
PLM	-
System integration	-
Models for MLPs	-
Product identification and traceability	Accuracy of demand prediction
Data processing	-
Access control	-

Table 17: Essential IT factors for modeling closed-loop product system.

The combined rating is shown in the matrix below. The critical relationships are shown in red.

DSM	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Spare parts demand		1.00	1.57	1.00	1.00	1.71	0.43	0.71	0.71	1.43	0.57	0.43	0.86	1.29
Warranty policy / customer service policy	2.29		1.57	0.86	0.43	1.71	0.43	0.71	0.71	0.86	0.57	0.29	0.71	0.57
Profit	0.57	0.57		0.86	0.71	0.57	0.57	0.57	0.71	0.57	0.29	0.43	0.71	0.57
Environmental impact	0.57	0.71	1.29		0.71	0.86	0.86	0.29	0.43	0.71	1.14	1.29	0.43	0.43
Innovation speed of components	1.86	0.71	1.86	0.71		0.57	1.00	1.71	1.29	1.43	0.57	0.57	1.14	1.00
Return rate	1.00	1.29	1.29	1.86	0.71		1.29	0.71	0.71	2.00	0.86	0.29	1.29	1.57
Yield rate / ratio of usable parts	1.00	0.86	2.14	2.14	0.43	0.71		0.57	0.86	2.29	1.14	0.71	0.86	0.71
Product platform stability	1.71	1.43	1.14	1.00	1.29	1.00	1.43		1.00	1.86	0.29	0.43	1.14	1.14
Product modularity	1.14	0.86	1.43	1.57	2.14	0.86	2.00	0.57		1.86	1.29	1.43	1.57	0.71
Ratio of product reuse	1.14	1.14	2.14	2.71	1.14	0.71	1.29	0.86	1.00		0.86	0.57	0.71	0.71
Degree of recycling	0.00	0.43	1.29	2.29	0.43	0.43	0.86	0.29	0.57	0.57		0.86	0.43	0.29
Ease of material recovery	0.14	0.14	1.71	1.71	0.57	0.43	0.71	0.29	0.71	1.00	2.29		0.57	0.14
Capacity / Lead time	1.14	0.43	1.71	0.57	1.29	0.71	1.00	0.57	1.14	1.14	0.57	0.43		0.57
Accuracy of demand prediction	0.71	1.00	2.14	0.71	1.00	0.57	0.43	0.57	0.43	0.29	0.14	0.57	1.00	

Table 18: DSM rating for closed-loop system for Loewe.

The most critical relationship identified in the Loewe case is the impact of the ratio of product reuse on the environmental impact. A higher ratio of product reuse could save more resources (materials, energy, labor, etc.) and can reduce the environmental impact of TVs per usage cycle (impacts from transportation will however have a negative effect and further calculations need to be made to estimate the direction of the environmental effect). High yield rate is identified as critical for product reuse; higher yield rate will most likely lead to more products reused. Products that cannot be reused have to be scrapped, leading to higher environmental impacts per usage. Both yield rate and ratio of product reuse have a critical effect on profit. Assuming production of new spare parts is more expensive than the repair of used parts, profit can be generated when reusing parts. The accuracy of demand prediction can have a significant impact on profit.

The combined rating also identified the relationship between degree of recycling and environmental impact as critical as several important materials are currently applied in the short-cycle component (monitor) that cannot be recycled cost-effectively. Degree of recycling depends on the ease of material recovery; the easier the separation and recovery process the more likely the recycled share will increase. Product modularity is an enabler to cope with product innovation speed, modularity of components allows use of modules across generations and parallel product lines. The last critical relationship is identified between warranty policy and spare parts demand. As discussed before, these factors will be included in the calculations in D4.2.

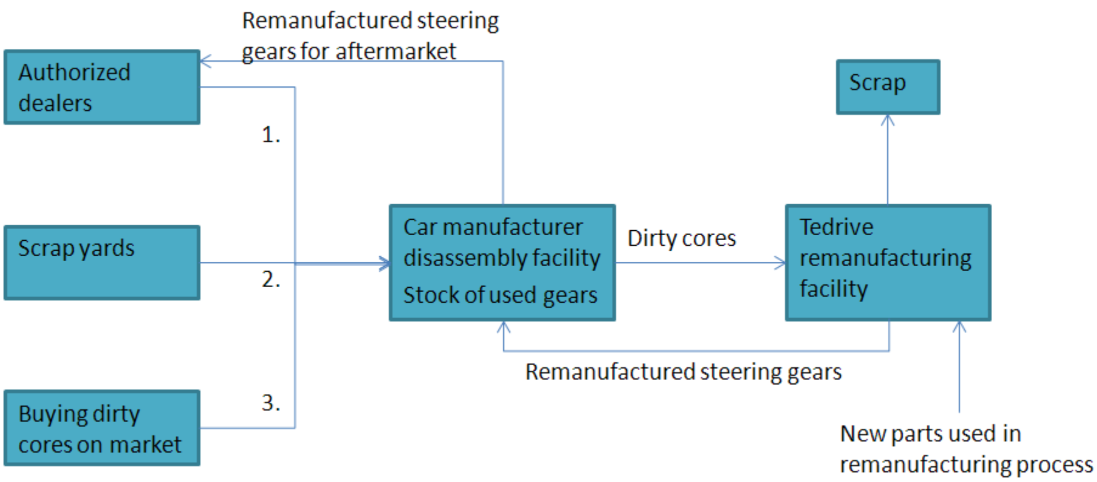
5. Steering gears

For implementing a ResCoM system, the question for tedrive is *how can the remanufacturing business be expanded?* Expanding the remanufacturing business will increase the percentage of steering gears remanufactured and will therefore facilitate the transition from a linear product system to a fully closed product system. As discussed in D2.3, the main issue of tedrive is to design the business model and supply chain in a better way[14]. Product design is a less pressing issue; design for remanufacturing in the form of design for disassembly is already implemented.

Several possibilities can be looked at. The most obvious one is to look at how the intake of used steering gears and the sales of remanufactured ones can be expanded via the currently utilized channels. Second, the remanufacturing of hydraulic steering gears sourced and sold on the free market can be explored. These options will increase the number of steering gears remanufactured, and are therefore contributing to a circular economy.

5.1. Expand current remanufacturing business

As discussed in D2.1 and D2.3, tedrive gets used steering gears from the car manufacturers and sells them back to the car manufacturer who sells them on the after-sales market as spare parts. This is shown in the figure below.



1. Authorized dealers are required to send the replaced components to the car manufacturers.
2. Scrap yards that dismantle the cars and send parts to the original equipment manufacturer. Not all scrap yards dismantle the cars.
3. In order to meet EU directive, car manufacturers are obligated to buy back dirty cores on free market.

Figure 7: Current supply chain of remanufactured steering gears.

At the moment about half of the cores tedrive receives are damaged and will be scrapped, this while better packaging of the dirty cores can dramatically reduce the scrap rate. Earlier discussions with the suppliers of the dirty cores did not result in changes in the process. Because employees in the car dismantling factory work with components weighing more than 10 kg a piece, putting dirty cores in individual packaging, which means additional handling, is not preferred.

[14] The main issue is defined as the problem that currently withholds currently the largest percentage of steering gears from being recovered and therefore the problem that prevents a fully efficient closed-loop product system as envisaged within ResCoM.

However, this might change when the right incentive is provided, for example with sharing the benefits of the reduced scrap rate with the car manufacturer.

The costs to disassemble and to test the steering gear to see whether the steering gear can be used for a second lifetime are significant. With a current scrap rate of 50% significant improvements can be made. Reducing this scrap rate is especially beneficial towards the end of the after-sales service period; when the current supply is not sufficient to fulfill demand for remanufactured steering gears.

5.2. Remanufacture steering gears for the free market

Tedrive can increase the intake of dirty cores by sourcing used steering gears on the free market (D2.3). This requires new channels for sourcing and selling the remanufactured steering gears. Both issues are discussed below.

5.2.1. Sourcing used steering gears on the free market

Active product acquisition management can influence the quantity, quality and timing of the returns (Guide et al., 2003). A first step will be to classify the different return options on product quality and to analyze the associated costs of the product acquisition. In a waste-stream system discarded products are returned to the OEMs (normally due to legislation), while a market-driven system gives incentives to users to return the products (Guide and Van Wassenhove, 2001). In the second system, producers are able to control the quality of the returned cores.

Obviously the product acquisition costs will have an influence on the profitability of the remanufacturing business (Guide et al., 2003). The costs of acquiring the cores on the free market should therefore be considered in relationship with the price and associated demand of the remanufactured steering gears. This will be further discussed below.

5.2.2. Remarketing of remanufactured steering gears

New channels to sell the remanufactured steering gears can be directly to the end-consumer via the internet, selling directly to repair shops, or selling them to car manufacturers. While different channels might increase sales, disintermediation of supply chain partners can lead to conflicts and the benefits of this strategy should be carefully assessed against the disadvantages.

The remanufactured steering gears market is highly competitive, and price is the main decision factor for consumers (Anonym, 2010). Wang et al. (2013) identified the underlying reasons for lower purchase intention, compared to new, for remanufactured automobile spare parts in China. They find that the purchase intention can be predicted by purchase attitude (individual's evaluation of behavior), perceived behavioral control (whether the individual feels that the behavior is under their control), product knowledge, and subjective norm (whether the individual thinks that the behavior is accepted by important people in their life). Product knowledge has a negative effect on purchase intention. Attitude can be predicted by perceived benefit, product knowledge, and perceived risk. Perceived risk is in turn predicted by financial risk (cost of repair and purchase of other part due to shorter remaining life), performance risk (malfunctioning), physical risk (safety), time risk (time and effort lost in repairs), resource risk (harm caused by dishonest remanufacturers), social risk (loss of status in social group), and product knowledge. Perceived risk has an indirect effect on purchase intention via attitude.

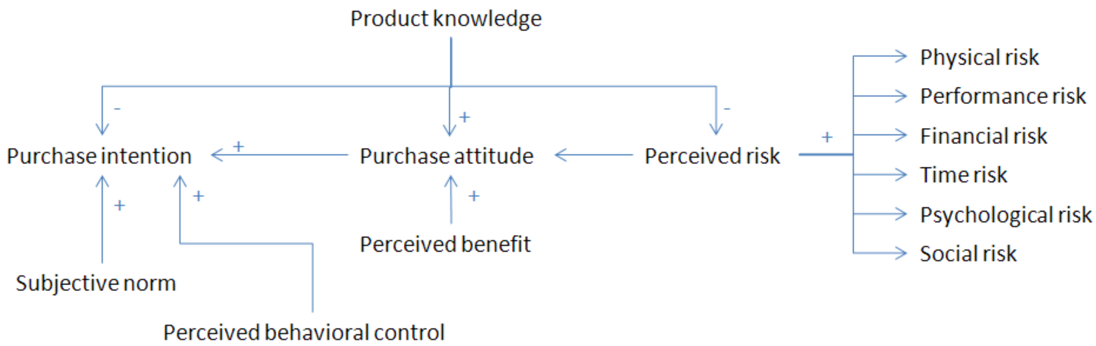


Figure 8: Underlying factors purchase intention of remanufactured automobile spare parts in China (Wang et al., 2013).

With expanding sales to other channels, the cannibalization effect of remanufacturing also changes. While remanufactured steering gears are now sold at the same location as new steering gears, remanufactured steering gears sold on the internet compete mainly with second-hand and third parties remanufactured steering gears. The effect of sales to lower-end customers via internet on the sales of new steering gears should be analyzed further to be able to calculate whether such strategy will be profitable.

5.2.3. Profitability

Buying and selling steering gears on the free market impacts profitability. The price tedrive has to pay for the used steering gears will increase; while they get the gears now for free, a steering gear on the free market costs around 150 to 200 Euro. Remarketing costs will also increase as they have to find new channels and actively sell the remanufactured steering gears. On the other side, remanufacturing costs can be decreased (both due to higher product quality and due to economies of scale) and steering gears can be potentially sold at higher prices due to disintermediation of supply chain partners, especially when the remanufactured steering gears are sold directly to the end-user via e-commerce. However, due to the different competition the optimal price for remanufactured steering gears in these channels might be different.

Kwak and Kim (2013) developed a profit optimization model for remanufacturing where product design, target market, and product acquisition decisions are made simultaneously.

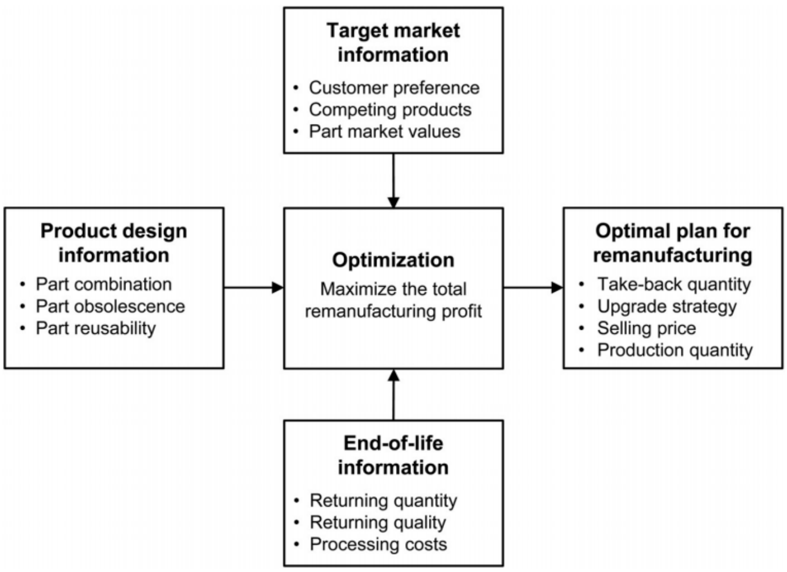


Figure 9: Integrated model for market positioning of a remanufactured product (Kwak and Kim, 2013).

Kwak and Kim compared the situation where a company receives returns without paying any financial incentives (i.e. the waste stream system) with the situation where the remanufacturer buys back used products to manage quantity and quality (i.e. market-driven system). They found that even though the product acquisition costs increase, the savings achieved in remanufacturing due to higher quality of the returned product can result to higher profit and market share. Moreover, they showed that early consideration of product design, consumer product specifications and selling points can help in maximizing profit from remanufacturing, although it might be difficult to predict this accurately when designing the product.

5.2.4. Product design

The scale of remanufacturing is limited by the availability of cores and the limitation to only apply remanufactured products as service parts. The product platform is very stable and used for many different clients and their even more diverse range of vehicles. The current product is easy to be recycled, but scaling up the remanufacturing operation could capture significantly more value for tedrive.

Ease of disassembly, ease of inspection, component durability

The tedrive case is centered around scale. Circular products are sold as new, but tedrive would have to be very sure about the quality of the reused parts, which may have hidden defects that new parts cannot have. Consequently, quality inspection of incoming core parts as well as outgoing remanufactured products is a critical factor that can be affected by design. Designing parts to highlight any defects, as tedrive currently does with fluorescent fluid that highlights surface flaws on the rods, would facilitate quality inspection. When expanding the remanufacturing business as described in 5.2, cores will be remanufactured that have functioned beyond the warranty period. Consequently, component durability, considering functional robustness and potential lifetimes, is a vital factor for determining the value that is recovered through remanufacture. Tedrive already renders considerable attention to disassembly of their products, for reasons concerning remanufacture and tested product inspection. In the balance of costs for disassembly and value recovered through remanufacture lies the economic viability of the scale-up. The environmental impact in a circular system for tedrive comes from the recycling of materials in parts that cannot serve another use life. The materials currently used make recycling possible, so the component durability remains as the key driver of environmental impact.

5.2.5. IT / Technology

At the moment, tedrive has only access to the information saved on the barcode of the product when the product returns to tedrive. While this gives information on the production year of the steering gear, the mileage driven with the steering gear is unknown. To implement a system where steering gears are recalled after a certain mileage, a system is needed that can check the distance driven. However, the benefits of predefined mileage recalls need to outweigh the costs of such system and wider implications on the business model of tedrive have to be investigated.

5.3. ResCoM closed-loop system for multiple lifecycles

In the initial ResCoM model, steering gears are remanufactured for multiple lifecycles until quality of the steering gears no longer allows reuse of the components, after which they are recycled. Remanufacturing can be expanded by acquiring used steering gears (with better quality) from the free market and sell them on the free market.

5.3.1. Sustainability

No LCAs of steering systems were found in the literature. However, given that tedrive's steering systems consist mainly of stainless steel with some hydraulics, it can be expected that the main impact will be in the materials production phase. Additionally, we expect to see impacts from the transportation (both distribution and reverse logistics) of the steering systems. As stainless steel can be recycled well, end-of-life impacts will be relatively low.

Sustainability-related factors in transition to closed-loop model
Given the emphasis on the production phase, reusing the steering system makes excellent sense from a sustainability perspective. Tedrive is already doing this through their remanufacturing operations. The most critical element in the lifecycle footprint of the steering system is most likely the impact of reverse logistics, combined with the number of steering systems that are scrapped because of bad handling.

Impact of reverse logistics & transport losses
Reverse logistics have an impact because these are usually less efficient than the distribution of new products from factory to outlet. A critical factor therefore is the footprint of tedrive's reverse logistics operations (including losses). More data from tedrive is needed to further validate this statement.

5.3.2. ResCoM model and critical factors

The essential factors for a closed-loop product system with remanufacturing are shown in the table below.

Business requirements	Factors for ResCoM closed-loop system for tedrive	Includes
Value proposition	Sales channels	Conflict with retailers
Value creation and delivery	-	-
Value capture	Profit	Acquisition cost (cost of dirty core) Cost of parts in remanufacturing process Cost of remanufacturing (labor) Cost for remarketing on free market
Market for multiple lifecycle product:	Demand	Consumer segments, Market size / interest in remanufactured products Cannibalization of new product sales
	WTP / optimal price point for selling new and remanufactured steering gears	Perceived behavioral control, Product knowledge, Subjective norm, Perceived benefit, Perceived risk including financial, performance, physical, time, resource, and social risks
Product acquisition to close the loop	Supply / return rate	Number of units of returned product with certain quality level Number of units available for take back with certain quality level Stock of returned items
Sustainability	Environmental impact	Environmental impact of production

		Environmental impact of transportation (distribution and reverse logistics) Durability / length of use phase

Table 19: Essential business model factors for modeling closed-loop product system.

Product design requirements	Factors for ResCoM closed-loop system for tedrive	Includes
Product attachment and trust	-	-
Reliability and Durability	Component durability	-
Conformity to legislation	-	-
Modular product architecture (requirements 1-4):	-	-
1- Ease of maintenance and repair	-	-
2- Standardization and compatibility	-	-
3- Upgradability and adaptability	-	-
4- Dis- and reassembly	Ease of disassembly	Number of disassembly and inspection steps required Number of components recovered through disassembly
	Ease of inspection	-
Recycling and bio-cycling	-	-
Eco-performance	- (included in sustainability)	-

Table 20: Essential product design factors for modeling closed-loop product system.

Supply chain requirements	Factors for ResCoM closed-loop system for tedrive	Includes
Customer integration	-	-
Coordination of (modularized) production flow in an integrated supply chain	-	-
Warehousing and inventory control	-	-
Operational value recovery (manufacturing level)	Yield rate	Stock of remanufactured steering gears

Table 21: Essential supply chain factors for modeling closed-loop product system.

Information technology requirements	Factors for ResCoM closed-loop system for tedrive
PLM	-
System integration	-
Models for MLPs	-
Product identification and traceability	-

Data processing	-
Access control	-

Table 22: Essential IT factors for modeling closed-loop product system.

The rating of the essential factors is combined and shown in the matrix below. Critical relationships are shown in red.

DSM	1	2	3	4	5	6	7	8	9	10
Sales channels		2.00	2.00	1.57	0.43	0.29	1.43	1.14	0.29	0.29
Profit	0.86		0.57	0.86	0.43	0.43	0.57	1.00	0.29	0.14
Demand	1.57	2.71		1.71	0.14	0.71	1.43	0.71	0.43	0.14
WTP / optimal price for selling new & remanufactured	0.86	2.43	2.43		0.14	0.86	1.14	0.71	0.14	0.14
Yield rate	0.57	2.14	0.43	0.57		0.71	0.57	2.43	0.43	0.43
Component durability	0.29	1.43	1.43	2.29	1.71		1.43	2.00	0.29	0.29
Supply / return rate	1.00	2.00	0.57	0.71	1.86	0.71		2.14	0.43	0.43
Environmental impact	0.71	1.14	0.86	1.14	0.86	0.71	0.57		0.71	0.57
Ease of disassembly	0.29	1.57	0.57	0.14	1.86	0.43	0.71	1.29		1.57
Ease of inspection	0.29	1.14	0.43	0.14	1.29	0.57	0.86	1.00	0.57	

Table 23: DSM rating for closed-loop system for tedrive.

The combined rating identified seven critical relationships. The most critical relationship is the effect of demand on profit, followed by the WTP or price of the steering gears on profit and demand. The more customers are willing to pay for a steering gear, the more demand will be generated for a certain sales price and more profit can be made. According to the DSM output, the WTP of the customers greatly depends on the component durability; the length of time a customer can use the steering gear influences the price customers are willing to pay. Critical relationships between environmental impact and yield rate and supply / return rate are also identified. If more steering gears are returned to tedrive, there will be more potential to get reusable and valuable resources which likely reduces the environmental impact of a steering gear. However, the environmental impact needs to be calculated as the reverse supply chain can reduce the environmental benefit of remanufacturing. A low yield rate can further reduce the environmental impact of remanufacturing and improvements to reduce the current scrap rate will significantly impact the environmental benefits. These relationships will be used as input for D4.2.

6. Conclusions

In D2.3 the major issues and requirements for implementing closed-loop product systems as envisaged by ResCoM are discussed for the four case study companies. This deliverable identified the essential factors underlying the major issues. Based on the economic and environmental impact anticipations of the ResCoM model, the initial ResCoM models (at high level) for each of the case studies are described. Further research (see below) will assess the profitability and sustainability of these models and will use the findings to further create the ResCoM models and find the desired business model, product design, supply chain and IT / Technology system.

This deliverable identified the critical factors for modeling the initial ResCoM models. The one-on-one relationships between the essential factors are shown in the DSM tables and the weights indicate the criticality of the relationships. Due to the nature of the DSM method, only the relationship and the magnitude between the factors can be identified and not the impact of the factors as percentage of the total environmental or economic performance. These calculations will be part of D4.2. The DSM rating of the four ResCoM models showed that the following factors have crucial effects on the performance of the closed-loop product systems.

Critical factors	Baby strollers	Washing machines	TVs	Steering gears
Product attributes	√	√	-	-
WTP or price point	√	√	-	√
Demand (for Loewe spare parts demand)	√	√	√	√
Profit	√	√	√	√
Environmental impact	√	√	√	√
Ratio of product reuse	-	√	√	-
Degree of recycling	-	-	√	-
Return rate	√	√	-	√
Quality of returns	√	-	-	-
Modularity of components	√	√	√	-
Product upgradeability	√	√	-	-
Ease of disassembly	-	√	-	-
Ease of material recovery	√	-	√	-
Material recyclability	√	-	-	-
Yield rate	√	√	√	√
Warranty policy	-	-	√	-
Innovation speed	-	-	√	-
Accuracy of demand prediction	-	-	√	-
Component durability	-	-	-	√

Table 24: Critical factors in the closed-loop systems for each case study company.

Even though only one critical factor is identified in the IT / Technology pillar, the link with materials data and PLM need to be clear when implementing a closed-loop product system. The software platform, that will be developed in the ResCoM project, will gather and use information to give guidelines when implementing a closed-loop product system. In that way, IT systems will have a crucial supportive role in the decision and implementation process.

In the next step (D4.2) the interactions between the critical factors will be modeled and analyzed on economic and environmental performance specific to the case studies. This means that the factors will be parameterized with company specific data. The boundaries of the modeling will be chosen in such a way that all critical factors (and other relevant factors) are part of the model, are in line with the design methodology for multiple lifecycles, and impacts on sustainability and profitability are as much as possible included in the model. The dynamic character of the modeling allows identifying the influence of the interaction among processes, operations, people and policies on the economic and environmental performance of the closed-loop product system that is suggested for each OEM. Due to the iterations that are needed to design a profitable and sustainable closed-loop product system, the insights generated in task 4.2 will further specify how the ResCoM model for each case study will look like. The task will end with a thorough internal validation in line with the method chosen for the modeling.

The profitable and sustainable ResCoM model that is envisaged for each OEM will be further validated in D4.3. The output of D4.2 will be combined with research on innovative business models, product design, and supply chains. Research in these areas will identify important aspects that can make or break the closed-loop product system. The findings will be combined with the findings of D4.2 and the ResCoM model that will be tested at the four case studies through implementation will be specified. The second part of D4.3 will externally validate the ResCoM model. Through implementation of the model at the four OEMs, further insights on the interactions between the ResCoM pillars will be gathered. The ResCoM platform[15] could be used as tool for external validation.

[15] The ResCoM platform is a software platform that is designed to manage closed-loop product systems, building on product lifecycle management and material information management modules. What data that tool can provide and in how far that tool can be used for external validation need to be assessed at later stage, when the platform is further developed (i.e. v2 is released).

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Appendix 1: Comparison with DoW

DoW description	This document
Identify critical factors for modeling closed loop products system specific to case studies	Critical factors for modeling the appropriate ResCoM model specific for the four OEMs are shown in the matrixes. The procedure how these critical factors are found is described in section 'Method'.
This task will identify critical factors for modeling the interactions among design, supply chains, business models and technology in a system perspective fulfilling the ResCoM requirements for closing the loop.	The ResCoM requirements are used as starting point for the analysis. Based on the necessary requirements for closing the loop, major issues for implementing the ResCoM model are identified and the applicable ResCoM model is described. The four ResCoM pillars are used to identify the factors, and the interaction of the 4 ResCoM pillars are assessed.
Using the ResCoM requirements as input from WP 2 and based on research and industrial practices a list of essential factors will be created.	See above.
These factors will be first analyzed for their one to one relationship and assigning criticality using methods such as pair-wise comparison, analytical hierarchical process (AHP) and design structure matrix (DSM). In this process it will take into account ranking methods like AHP and design methods like DSM to identify critical factors for closing the loop, and will chart their interactions.	Design structure matrix (DSM) is applied to analyze the relationship and criticality of the factors.
Report containing matrices of factors defining mutual relationships and their criticality This report will explain, for the case study products, the critical factors, their ranking and their interaction in the perspective of ResCoM requirements for the closed loop systems.	Four ResCoM models and their associated factors are described in this deliverable. For each ResCoM model, the factors are analyzed on mutual relationship and criticality and the findings are presented in the matrices.
It will also elaborate how-to procedures to support the validation tasks in WP4 and implementation tasks in WP5 and 6	A short discussion on the following research steps (as part of WP4, 5 and 6) is given, following the process as outlined in the DoW.

Appendix 2: Assumptions and ideas in ResCoM models

Taken from Asif et al. (2012), DoW, and Rashid et al. (2013).

ResCoM approach:
- At end of each predefined life cycle, products are returned to the original equipment manufacturer (OEM) or to the authorized third party. If a third party remanufactures the product, the remanufactured products are supplied to the OEM.
- Forward and reverse supply chains are integrated in a single business enterprise.
- Same product come back and forth in several occasions; multiple lifecycles.
- Used products are used in the manufacturing forward material flow.
- Remanufactured products are sold in the same way as new products; is not considered as a different product variant, and order and supply is not handled separately.

ResCoM life cycle duration
- Life cycle monitoring devices to monitor the physical / functional condition of critical components integrated in the product to reduce uncertainty in predicting end-of-life.
- When minimum performance level is reached, product is recalled.
- Product is upgraded and components replaced to reach the desired performance level.
- This continues until the product finishes its predetermined number of life cycles[16].
- The idea of multiple product-lifecycle is valid as long as each and every lifecycle is economically feasible and ecologically efficient.

ResCoM product design
- Products are designed for multiple lifecycles.
- Remanufacturing can include replacement of worn or malfunctioning components, standard replacement of certain components, or upgrading in both performance and function.

ResCoM supply chain:
- Quantity and timing of product returns are predictable within a certain confidence interval. All products are returned.
- Uncertainty in quality of returns is minimized; age of product is known and service is managed and controlled by the OEM (or authorized service provider). Functional condition of critical components is monitored, and products are recalled when performance falls below the minimum allowable performance. Almost all returned products can therefore be remanufactured.

ResCoM business model:
- Strong relationship between supply chain partners.
- Customers are part of the business enterprise.
- High level of customer responsibility for ecological sustainability.
- New products have a lower ecology label and therefore less societal prestige, changing customer behavior and market response.
- Returning products is a social responsibility of consumers.
- Not based on ownership, buy back, or sell-buy-sell, but on product service systems.

[16] In ResCoM a product is designed for multiple product lifecycles of predefined length (time or performance) where quality of the product (i.e. fitness for next lifecycle) is designed-in and already known (Rashid et al., 2013).

- Product service systems, like service selling, functional sales, leasing and product service systems must be developed tailored to the product.

Appendix 3: Taxonomy of design factors

	Design factor	Definition & *Examples of underlying design factors*
Product Life extension	**1. Product durability**	Designed lifetime of the product. *Physical durability or product integrity, product reliability, emotional durability, potential lifetime of product.*
	2. Product upgradability	Degree to which the product can be updated to meet changing requirements over time. *Number of functions that can be upgraded, backward compatibility of new accessories.*
	3. Product reparability	Degree to which the product can be restored to a sound or good condition after decay or damage. *% of parts that can be repaired in service centers, % of parts that can be replaced in service centers, possibilities for DIY repair, severability of fasteners.*
	4. Ease of product maintenance	Ability to easily perform inspection and servicing tasks required to maintain functional performance. *Robustness of maintenance design (preventing incorrect maintenance), possibilities for DIY maintenance.*
Component Remanufacture	**5. Component durability**	Designed lifetime of the component. *Functional robustness of components, Visual wear resistance, potential lifetimes per component.*
	6. Platform stability	Degree to which the platform facilitates multiple lifecycles of products. *The planned lifetime of the product platform, usability of parts across successive generations and parallel product lines, market forces.*
	7. Modularity of components	Degree to which functional components can be used across successive generations and parallel product lines. *Ratio of modular and non-modular components, module reusability, interface standardization.*
	8. Degree of reprocessing	Degree to which used components can be processed back into specification. *Material type, Planned use of 'excess' material.*
	9. Ease of disassembly	Ability to disassemble into useful fractions (including reassembly) *Time and cost of (non-destructive) disassembly, steps to get to key components, disassembly tools, components recovered through disassembly.*
	10. Ease of inspection	Ability to inspect if components meet their requirements. *Component self-diagnostics, technology for inspection, product traceability, number of different inspection steps needed.*
Material Recycling	**11. Material durability**	Designed lifetime of the material. *Rate of deterioration of mechanical properties, discoloring, impact resistance.*
	12. Ease of material recovery	Ability to easily break down into mono-material fractions *Time and cost of material recovery, materials recovered through disassembly, severability of materials, material variety and compatibility.*
	13. Degree of recycling	Degree to which compatible material fractions will be processed into a form that can be used in the same or another 'high' value product. *% of materials recovered through generic recycling, through dedicated closed-loop recycling, % of units sold going into generic or dedicated recycling, material recyclability, recycled content, compatibility of coatings, blends and additives.*

	14. Degree of biodegradation	Degree to which materials can be consumed by microorganisms and return to compounds found in nature. *% of materials used as biological nutrients, material bio-compatibility, restoration of natural value and resources.*

Table 25: overview of critical design factors related to modeling closed-loop product systems (Based on Blanchard, 2004; Gutowski et al., 2001; Hatcher et al., 2011; Hucal, 2008; McDonough and Braungart, 2002; Sundin, 2004).