D4.2 Circular supply/value chains implementation report

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List of abbreviations

Abbreviation	*Explanation*
ICT	Information and communication technology
PPW	Pay-Per-Wash
WLP	Warehouse-Location-Problem
WP	Work package

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1. Executive Summary

This deliverable report 4.2 on the implementation of circular supply/value chains considers the reverse supply chain planning processes in the demonstrator phase for the automotive spare parts and the white goods demonstrator.

Regarding the automotive spare parts business model, a cloud-based platform was developed in a previous work package in the ReCiPSS project to increase the transparency in the reverse supply chain. In this report, it was determined at which stage of the reverse supply chain the cloud-based platform is implemented in order to improve the economic and ecological performance of the company.

Considering the white goods demonstrator, a new ‘pay-per-wash’ (PPW) business model was introduced. For the white goods demonstrator, the optimal locations for storing and remanufacturing the used washing machines were determined.

In this context, a new system for improving circular supply/value chains activities is developed for the automotive spare parts demonstrator and the white goods demonstrator respectively. The core idea of the system’s logic is to solve the above-described problem for both business models with the help of an ADD algorithm.

The behaviour of the systems is examined with the help of simulation. Regarding the automotive spare parts demonstrator, the economic and environmental performance of the as-is scenario, which represents the current business model is compared with the to-be scenario. Thereby, the to-be scenario achieves a higher fulfilment regarding the target figures ‘transport cost’ and ‘CO_2-emissions’ than the as-is scenario. The target figure ‘transport cost’ in the to-be scenario could be reduced by 56.6 % compared to the as-is scenario. Also, the CO_2-emissions in the to-be scenario could be improved by 10.6 % in comparison with the as-is scenario.

Regarding the white goods demonstrator, this report highlights the importance of determining the optimal location for storing and remanufacturing used washing machines in the new PPW business model. Thereby, the target figures ‘transport costs’, ‘service time’ and ‘CO_2-emissions’ of the circular supply/value chain were exemplary determined for the Dutch market. By selecting optimal locations for the new business model, transport costs could be reduced up to 24,532.922 €, the service time could be reduced by six hours and up to 22,178.646 kg/t of CO_2-emissions could be saved.

2. Introduction

This deliverable report is a result of the Task 4.3: Defining the infrastructure required by circular value/supply chains that focused on the development of the required infrastructure considering all relevant areas and their interconnections.

The deliverable report 4.2 "Circular supply/value chains implementation report" focuses especially on the reverse supply chains of the two large-scale demonstrators and their implementation in the respective markets. The forward supply chain will also be considered in this report, but no major changes will be made since this part of the circular supply/value chain has been already optimized for the existing linear business models by the two OEMs in the previous work.

Figure 1 shows how Task 4.3 is embedded in work package (WP) 4 "Circular Value/Supply Chains". The task is based on the results of Task 4.2, where different scenarios for the automotive spare parts and white goods demonstrator regarding the circular supply network design and its optimization were simulated.

Furthermore, Figure 1 provides an overview of the relationship between Task 4.3 and other WPs of the ReCiPSS project, which serves as input (WP2 and WP3) and output (WP5, WP6 and WP7). Especially the results from the deliverable report 2.2 "Circular business model development plan and report" from WP 2 "Circular Business Models" were used to consider the effects of the new circular business models on the reverse supply chain. In addition, results from WP3 "Circular Design Methodologies" were also taken into account in this work. Many synergies could be achieved through the intensive exchange with the partners of the ReCiPSS projects in general and using and extending the simulation models developed in deliverable report 4.1 in particular.

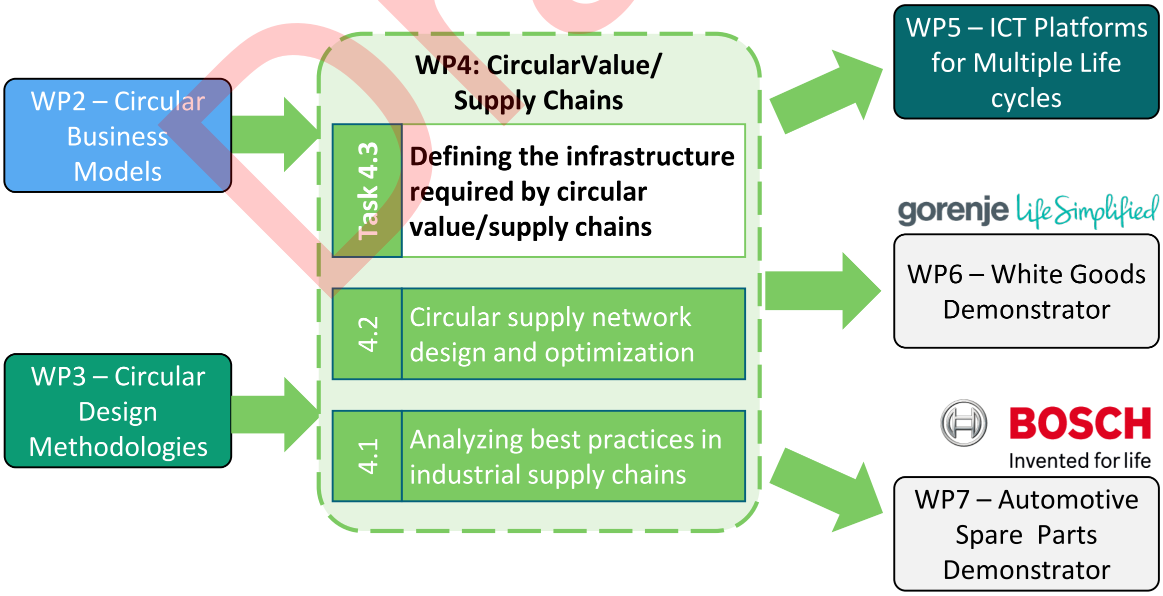

Figure 1: Relationship of Task 4.3 and relevant Work packages

Results of Task 4.3 serve as input for the Automotive Spare Parts Demonstrator (WP 7), the white goods Demonstrator (WP 6) and the information and communication technology (ICT) Platforms of both demonstrators, which are developed in WP 5.

2.1. Document Scope

This report considers the reverse supply chain planning process in the demonstrator phase for the automotive spare parts and the white goods demonstrator. For planning the circular value/supply chain processes, only the existing infrastructure and their facilities of the OEMs and their service providers are taken into consideration. It is neither cost-efficient nor ecologically reasonable to set-up new facilities during the demonstrator phase of the project.

Regarding the automotive spare parts business model, a cloud-based platform was developed in the previous WP 5 to support the reverse supply chain planning processes. Information about the manufacturer, type and condition of the core[1] should be identified as early as possible in the reverse supply chain. By identifying the used parts at an early stage, the transparency in the reverse supply chain increases. Hence, direct core return from the wholesaler to the related remanufacturer and one-time core evaluation is possible instead of repeatedly handling and inspecting cores at different stages of the reverse supply chain.

For this business approach, the goal is to figure out at which stage of the reverse supply chain, it is optimal to introduce the cloud-based platform in order to improve the economic and ecological performance of the company. From an economic point of view, the objective is to minimize the target figures transport costs and transport time. Regarding the ecological goal of the company, the objective is to minimize the CO_2-emissions at the same time.

Considering the white goods demonstrator, a new ‘pay-per-wash’ business model is introduced. Thereby, the customer no more buys a washing machine, but only pays for its use. With the new business model, Gorenje is responsible for installation, deinstallation and repairs at the customer's premises. The used washing machines are remanufactured according to a defined time or usage interval and later reintroduced to the market.

Therefore, the traditional linear white goods business model with only limited reverse logistics processes is transformed into a circular business approach. The increased logistics activities associated with this new approach are therefore considered in this report.

The goal of the circular white goods demonstrator is to figure out the optimal locations for storing and remanufacturing the used washing machines. Thereby, the objectives are to minimize the target figures transport costs, service time (the time between the placement of a customer order and its fulfilment), as well as minimizing the CO_2-emissions caused by transportation.

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[1] For the purposes of this document, the definition of a core as determined by the Automotive Parts Remanufacturers Association (APRA) applies: “A core is a previously sold, worn or non-functional product or part, intended for the remanufacturing process. During reverse logistics, a core is protected, handled and identified for remanufacturing to avoid damage and to preserve its value. A core is not waste or scrap and is not intended to be reused before remanufacturing.”

2.2. Methodology

In order to determine the optimal locations for both business models, two simulation models are developed which are able to validate the results by manipulating, controlling and measuring the input and output variables. In addition, the simulation considers the size of the change and the relative importance of its findings. This means that different scenarios will be displayed in the simulation and the effects on the variables and how they will occur, are observed.

For this task, the simulation allows investigating cause-effect relationships, which cannot be observed in reality at the moment, since the implementation of the business models is still in the planning phase.

For the white goods demonstrator, the simulation is also used as decision support to figure out the effects of implementing the new PPW business model in regards to the above mentioned ecological and economic target figures. Regarding the automotive spare parts demonstrator, the effects on the dynamics in the reverse supply chain through the introduction of a cloud-based platform will be investigated.

However, the precise replication and control of the affected parameters of a situation are hardly possible due to the inherent complexity of reality. Hence, for the simulation model, an idealised form of the real situation is assumed towards scientific progress (McKelvey, p. 5). The simulation models gather sufficient numerical size of quantitative data in order to generalise a conclusion statistically.

2.3. Document Structure

The deliverable report 4.2 “Circular supply chain/value chains implementation report” is structured in six chapters, as shown in Figure 2. Following the executive summary, the scope of the document is demarcated along with the methodology.

In Chapter 3, the problem of finding the optimal location for industrial facilities, which is also known as Warehouse-Location-Problem (WLP) is presented. To solve the WLP, the ADD algorithm is described in the following section.

Chapter 4 commences with the theoretical basics of systems theory. For the simulation, a system model of the reverse supply chain is generated for both demonstrators. The abstract models describe the important subsystems as well as the system’s elements for the development of the systems.

Next, the basics of simulation are explained and from there the simulation method used is derived in Chapter 5. Furthermore, the simulation models for both demonstrators are described. The system behaviour of the as-is and to-be scenario of the automotive spare parts demonstrator is analysed. Regarding the white goods demonstrator, the three different scenarios for the implementation of a PPW business model are exemplarily analysed for the Dutch market. The obtained data from the simulation results are then evaluated in terms of the defined target figures.

Chapter 6 contains a conclusion of this deliverable report and briefly discusses the key findings. In addition, an outlook is provided for further investigations for other WPs within the ReCiPSS project e.g. for Task 9.2 “Developing business cases and upscaling plans”.

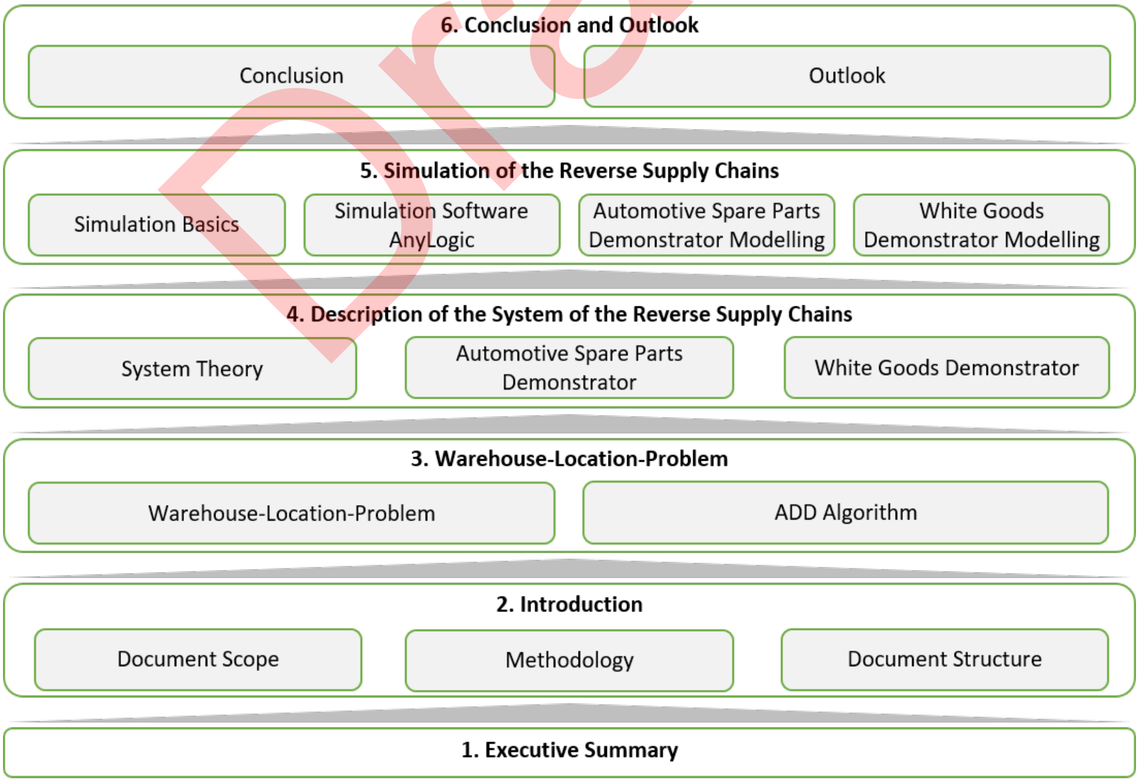

Figure 2: Document structure of the deliverable report

3. Warehouse-Location-Problem

Task 4.3 deals with reverse supply chain planning processes, especially with location planning for the two circular business models. Therefore, in this chapter, the WLP is presented and discussed. Furthermore, the ADD algorithm is presented as a heuristic method for solving WLPs. This algorithm is characterized by the relatively simple possibility to solve problems that aim to minimize the sum of variable transport costs and fixed location costs.

3.1. Warehouse-Location-Problem

Finding the optimal location for industrial facilities has always been of crucial importance and priority from economics/financial viewpoint. Numerous location planning problems are characterized by the fact that costs caused by transport activities have to be considered. In addition, the costs of setting up, for example, production facilities or distribution warehouses play a critical role (especially in medium and long-term planning) (Klose 2001, p. 32; Zanjirani Farahani and Hekmatfar 2009, p. 475; Sonmez 2012, p. 1; Domschke et al. 2018, p. 2).

In the following section, an uncapacitated single-stage WLP is described and the structure of a WLP is illustrated by the bipartite graph shown in Figure 3: In this example, a company supplies n customers per period b_1, …, b_n with a certain quantity. The company aims to reduce its distribution costs by setting up and operating distribution warehouses. Therefore, the company has m potential locations which are suitable for a warehouse. If a warehouse is set up at the potential location i = 1, …, m, fixed costs of warehousing f_i per period are incurred. The transport costs amount to c_{ij} if customer j is fully (i.e. with b_j) supplied by a warehouse set up at location i. The WLP calculates the number of warehouses to be planned and the potential set up location. Thereby, the objective is to minimize the sum of fixed warehousing costs and transport costs while fully satisfying customer demand.

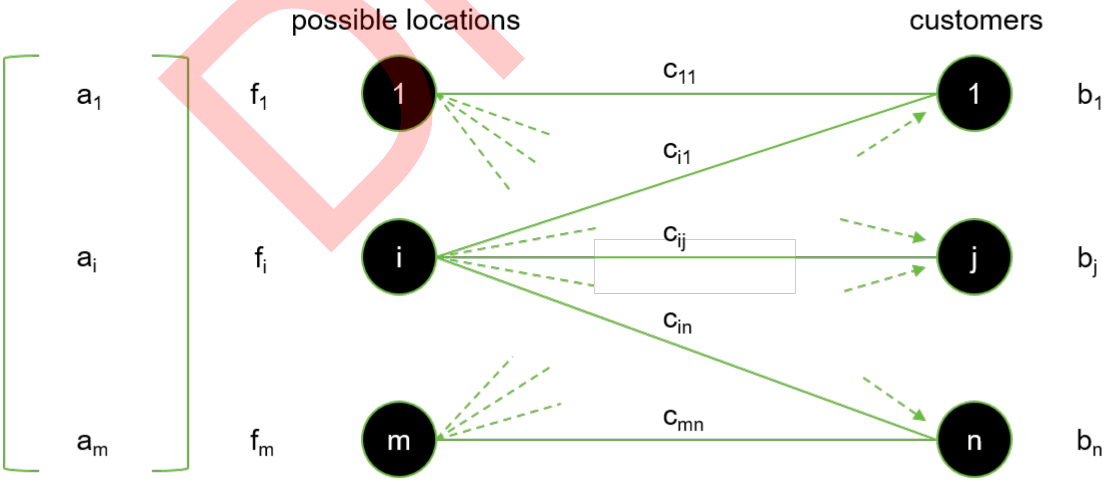

Figure 3: Structure of the single-stage WLP based on (Domschke et al. 2018)

The uncapacitated single-stage WLP can be formulated mathematically according to Domschke et al. (2018, pp. 5–6) as follows:

$$\mathbf{min}\, F(x,y) = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij} + \sum_{i=1}^{m} f_i y_i \tag{1}$$

Subject to

$$x_{ij} \leq y_i \; with \; i = 1, \dots, m \; and \; j = 1, \dots, n \tag{2}$$

$$\sum_{i=1}^{m} x_{ij} = 1 \; with \; j = 1, \dots, n \tag{3}$$

$$y_i \in \{0,1\} \; with \; i = 1, \dots, m \tag{4}$$

$$x_{ij} \geq 0 \tag{5}$$

The variables have the following meaning:

$$0 \leq x_{ij} \leq 1, if \; j = b_j \times x_{ij} \tag{6}$$

$$y_i = \begin{cases} 1 \; set \; up \; warehouse \; at \; potential \; location \; i \\ \qquad 0 \; else \end{cases} \tag{7}$$

The constraints of Eq. 2 ensure that a customer j is only supplied from a potential location i for which the establishment of a storage facility is planned. In this so-called disaggregated formulation of the uncapacitated single-stage WLP, m x n constraints of Eq. 2 shall be taken into account. They can be replaced by exactly m auxiliary conditions:

$$\sum_{j=1}^{n} x_{ij} \leq n_i y_i \; with \; i = 1, \dots, m \tag{8}$$

Here n_i is the maximum number of customers that can be supplied from a warehouse at potential and economically reasonable location i. Since real-world WLPs are often large in scale and are not solvable to optimality within reasonable time and effort, WLPs represent a non-deterministic polynomial-time hardness problem, called an NP-hard problem (Zanjirani Farahani and Hekmatfar 2009, p. 525). Consequently, optimal WLPs that have a realistic dimension cannot be created in a reasonable period of time, hence exact models have little relevance in practice. Heuristic methods, which try to reach a good achievement of the target criteria in a reasonable time, without guaranteeing an optimal solution are mainly used in practice (Heger 2014, pp. 2–3). A multitude of heuristics have been developed to solve NP-hard optimization problems, in addition to exact methods. The ADD algorithm which is applied in this report to solve the WLP belongs to opening heuristics. The ADD algorithm is described more precisely in the next section.

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3.2. ADD Algorithm

The ADD algorithm belongs to the Greedy Algorithms and was one of the first scientific approaches for solving uncapacitated WLPs. In the following section, the ADD algorithm is briefly described according to Suhl and Mellouli (2013, pp. 259–260). The following notation is used for the description of the algorithm:

m	Number of all potential locations S = {1, …, m}
n	Number of customers n = {1, …, n}
$S0$	Number of finally prohibited locations
$S1$	Number of accepted locations
$VS0$	Number of temporarily prohibited locations
$VS1$	Number of temporarily accepted locations

For the parameters (S0, S1, VS0 and VS1), the locations are indicated whose corresponding y_i are finally or provisionally fixed at 0 or 1. With the ADD algorithm, the binary variable y_i with the greatest possible improvement of the target function is fixed to 0 or 1 in each iteration step.

At the start of the ADD algorithm, all potential locations are temporarily prohibited (VS0 = m, S0 = S1 = Ø), target function value Z := ∞). In each iteration, the location, for which the greatest possible reduction of the target function value based on Eq. 1 can be achieved, is finally included from VS0 to S1. The procedure is terminated as soon as no additional reduction of the target function value can be achieved by including a further location from VS0. The locations remaining in VS0 are finally prohibited.

To store information, a matrix W = (w_{mn}) is created. It contains exactly one column for each customer and exactly one row for each temporarily prohibited location m. w_{mn} indicates the transport cost savings for delivering to the n-th customer if in addition to all already included locations h ∈ S1, location s would also be included.

Correspondingly, the row sum $w_m = \sum_{n=1}^{i} W_{mn}$ indicates the total transport cost savings that would result if the potential location s ∈ VS0 is finally included in addition to h ∈ S1 at the current phase of the algorithm.

In each iteration, therefore, exactly one location s ∈ VS0 is finally included. Further locations s ∈ VS0 are finally prohibited if $w_s \leq f_s$ is true. The algorithm terminates if VS0 has become an empty set. The process of the ADD algorithm is illustrated in an activity diagram in Figure 4.

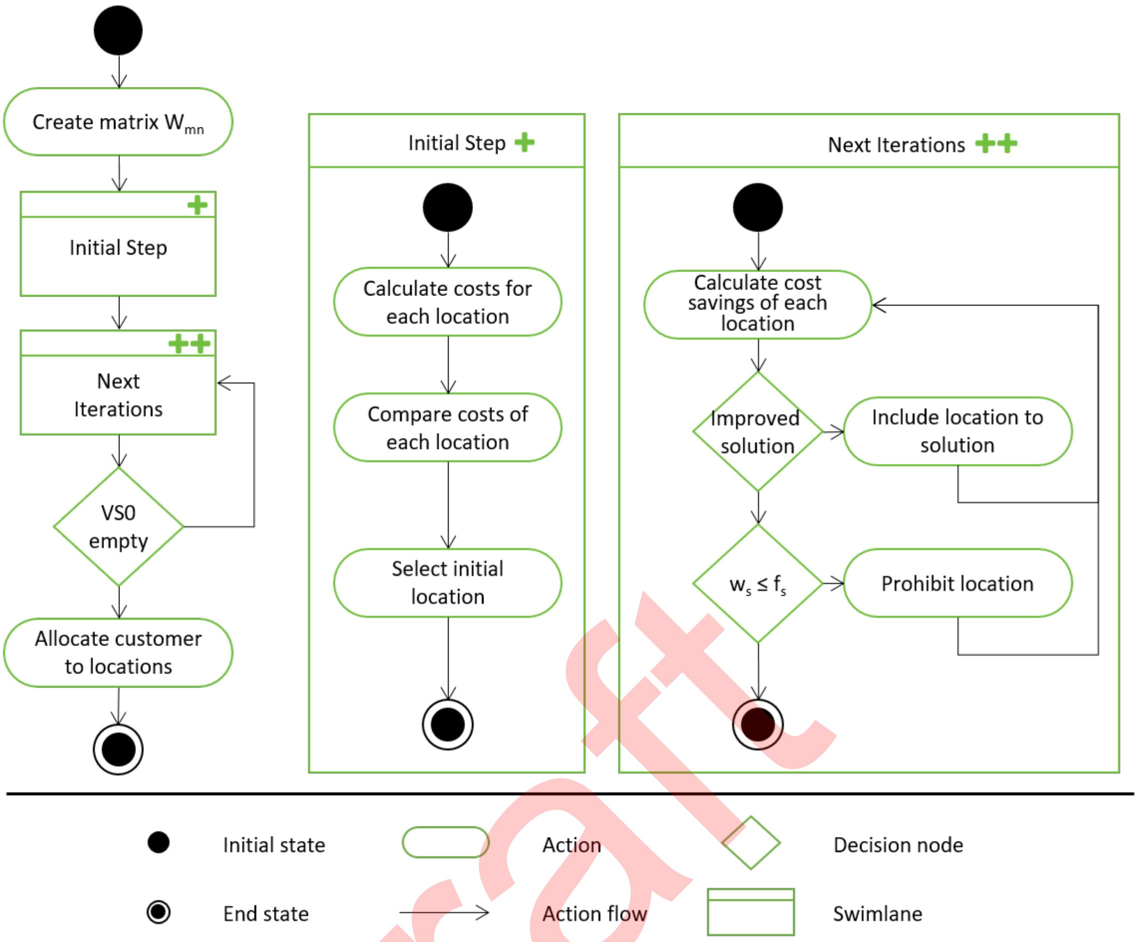

Figure 4: Activity diagram of the ADD algorithm

4. Description of the System of the Reverse Supply Chains

This chapter commences with an introduction of basic terms in systems theory. With the help of system theory as a proven tool for the presentation of complex systems, a description of the system with its subsystems and system elements, derived from the real reverse supply chain for the automotive spare parts and the white goods demonstrator as the subject of investigation of the present work follows. Thereby, the focus is on the description of the relationships between the system elements.

4.1. Systems Theory

In general, system theory describes the theory of the relationship between the elements of a system, between the structure and function of systems, and between the subsystems and overall systems (Ropohl 2009, p. 77). Systems theory is widely used in different scientific disciplines. In the field of engineering, system theory has proven effective to describe complex structures, such as production and logistics systems, using abstract models. In the following section, the term system theory is explained according to Gutenschwager et al. (2017, p. 11):

A system is fundamentally limited in its scope and defined by so-called system boundaries with regard to the environment (system environment). Using defined interfaces, a system can exchange matter, energy and information (input and output variables) at the system boundaries. The exchange from the environment into the system is described with input variables, otherwise with output variables.

Considering systems in production and logistics, the system interfaces and thus the influences of the system environment on the system are in many cases of high relevance. A system consists of system elements which can represent subsystems or can be considered as not further analysable. Thus, a machine, in themselves, can be part of a production system or considered as a system with its machine components being itself. The structure of a system results from the relationships between the elements of a system. These relationships may be determined by different influences of the system environment or system functionality.

Each system element has properties that are mapped using constant and variable attributes, also called state variables. The respective states of a system element are described by the values of constant and variable attributes at a time. The states of the system elements at a specific time in turn define the system state. The states of the elements may be subject to changes of one or more state variables due to a running process.

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In this context, the process is defined as the sum of all interacting processes in a system that transforms, transports or stores matter, energy, or information. Processes can interact in a sequential, parallel, concurrent and synchronised manner. The individual elements contain their sequential structure, which is characterised by specific rules regarding state variables and state transitions. The basic terms of system theory are shown in Figure 5.

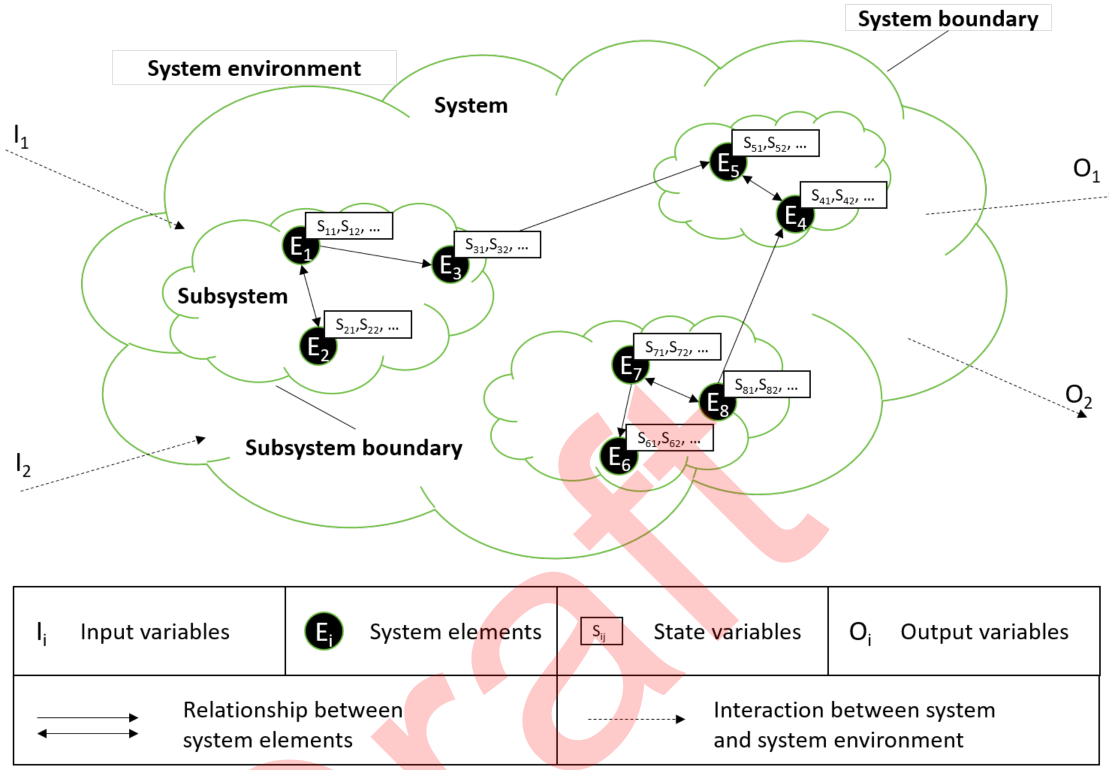

Figure 5: Basic terms on system theory based on (Gutenschwager et al. 2017, p. 12) and (Wiendahl 2010, p. 9)

In general, a distinction can be made between static and dynamic systems. According to Wunsch and Schreiber (2006, p. 73), the values of the output variables for static systems are generated at the same time as the values of the input variables. In system theory, dynamics is defined as the behaviour over time, which is determined by the system states and the state changes, hence the change of input and output per time unit. The behaviour of the environment is referred to as external dynamics, the behaviour of the system elements and subsystems as internal dynamics. In the following sections, the considered systems for the automotive spare parts and white goods demonstrator, with their subsystems and system elements are presented. Thereby, both systems can be assigned in principle to dynamic systems.

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4.2. Automotive Spare Parts Demonstrator

In general, the described system of the automotive spare parts demonstrator focuses on the physical and information flows between the main stakeholders, namely wholesalers and their outlets, C-ECO warehouses, and remanufacturers. Within this report, all core handling by C-ECO is performed under C-ECO's service brand for the automotive aftermarket CoremanNet. To simplify reading, it is nevertheless always referred to as C-ECO in the report.

Within the considered reverse supply chain of the automotive spare parts demonstrator, the outlets of the different wholesalers and the remanufacturers indicate a system boundary. The logistical relationship between outlet and workshop is considered optimal regarding costs and service. Consequently, the transport processes between outlet and workshop cannot further be improved and, hence, are not considered in this model. The forward supply chain is not considered in this system. Therefore, the system is delimited from its system environment by processes before outlets receiving cores and after the cores arriving at the remanufacturer. Furthermore, the system is divided into the subsystems 'Remanufacturer', 'C-ECO', 'Wholesaler A' and 'Wholesaler B'. The subsystem 'Remanufacturer' includes different remanufacturers. The system elements 'Warehouse 1' and 'Warehouse 2' are referred to as the subsystem 'C-ECO'. The subsystems 'Wholesaler A' and 'Wholesaler B' consists of several outlets.

The input variables of the system are the generated cores during the model run time arriving at the outlets of both wholesalers. The matching output variables are the sorted cores by the 'Remanufacturers', which leave the system.

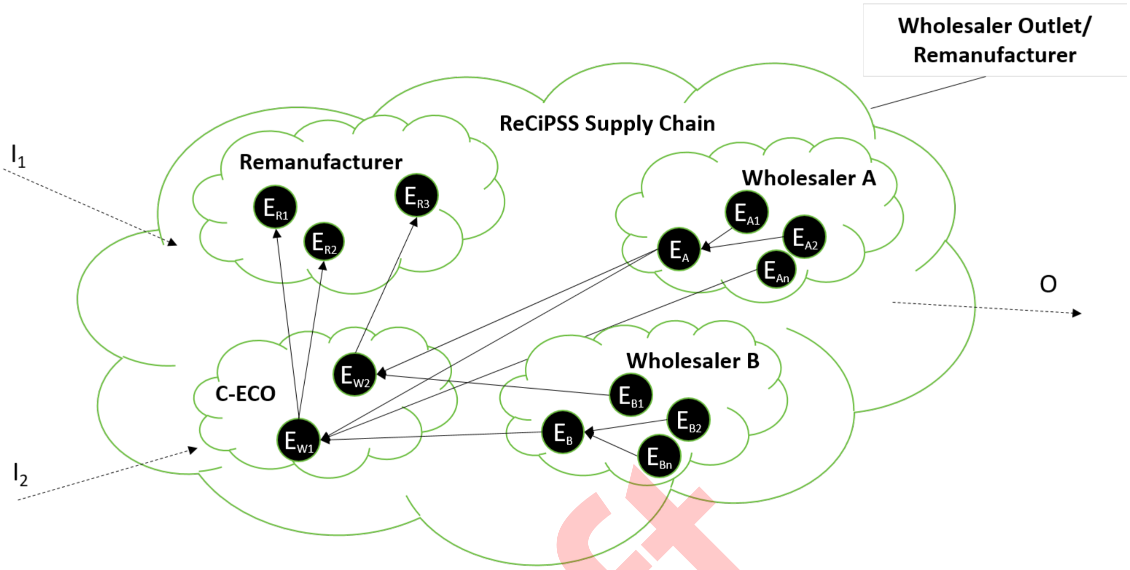
The subsystems of the 'Wholesaler A' and 'Wholesaler B' consist of the system elements 'Wholesaler Central' and several 'Wholesaler Outlets'. The 'Wholesaler Outlets' collect cores from their associated workshops. The collected cores are unsorted and stored in boxes. The cores differ, for example, in terms of their product groups, the manufacturer or the year of production. The 'Wholesaler Outlets' which have access to the cloud-based platform are selected during runtime to optimize the reverse supply chain processes. If a 'Wholesaler Outlet' has access to the cloud-based platform from C-ECO, the cores are identified and evaluated at the outlet. These cores are then picked-up by C-ECO and transported to 'Warehouse 1' or 'Warehouse 2'.

In case the 'Wholesaler Outlet' has no access to the cloud-based platform, the cores are first sent to the 'Wholesaler Central'. At the 'Wholesaler Central' the cores are finally identified and evaluated. The identified and evaluated cores are then transported to 'C-ECO'.

At the subsystem 'C-ECO' the arriving cores are again identified and evaluated. Furthermore, the cores are sorted by their respective remanufacturer. Based on the remanufacturers' demand the cores are transported to its location.

The subsystem 'Remanufacturer' receives the cores and does the identification and evaluation process of the cores one last time. The accepted cores will be remanufactured and later returned to the market.

The state variables of the system elements are described later in the course of the report. Figure 6 shows the reverse supply chain of the automotive spare parts demonstrator model and the described subsystems.



Symbol	Description	Symbol	Description
I_1	New cores at the outlets of Wholesaler A	E_A	Wholesaler A Central
I_2	New cores at the outlets of Wholesaler B	E_{A1}	Wholesaler A Outlet 1
O	Sorted cores at the remanufacturers	E_{A2}	Wholesaler A Outlet 2
E_{W1}	Warehouse 1	E_{An}	Wholesaler A Outlet n
E_{W2}	Warehouse 2	E_B	Wholesaler B Central
E_{R1}	Remanufacturer 1	E_{B1}	Wholesaler B Outlet 1
E_{R2}	Remanufacturer 2	E_{B2}	Wholesaler B Outlet 2
E_{R3}	Remanufacturer 3	E_{Bn}	Wholesaler B Outlet n

Figure 6: System of the reverse supply chain of the automotive spare parts demonstrator model with its considered subsystems and system elements

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4.3. White Goods Demonstrator

In general, the described system of the white goods demonstrator focuses on the physical and information flows between the main stakeholders, namely manufacturer, warehouse, customers, retailers and remanufacturers.

Within the considered reverse supply chain of the white goods demonstrator model, manufacturer and remanufacturer indicate a system boundary. The system is delimited from its system environment by processes before the manufacturer receiving customer orders for new washing machines and after the processes in which the washing machines can only be recycled and no longer be remanufactured. Furthermore, the system is divided into the subsystems 'Remanufacturer', 'Customer' and 'Retailer'. The subsystem 'Remanufacturers' includes the possible locations for remanufacturing the washing machines. The system elements within the subsystem 'Customer' represent different customers based on their choice of service package e.g. contract duration, service level, etc. and different behaviors in terms of premature contract termination and subscription renewal. Each system element of the subsystem 'Retailer' represents a possible location of a retailer for the ReCiPSS project. The system element 'Manufacturer' is not assigned to a subsystem. The 'Manufacturer' produces new washing machines based on customer orders. In addition, the system element 'Warehouse' is not assigned to a subsystem. The 'Warehouse' is responsible for distributing new and remanufactured washing machines.

The input variables of the system are the generated customer orders of a new washing machine and the created gold, silver and bronze customers. The matching output variables are the recycled washing machines and the customers leaving the system by terminating their contract.

The subsystem 'Customer' contains an initial number of 'Customers' based on the determined market potential in WP 2 for the PPW business model. The customer segmentation is divided into gold, silver or bronze contract options. The 'Customers' can renew or terminate their contract. They can also change their contract, e.g. from gold to silver.

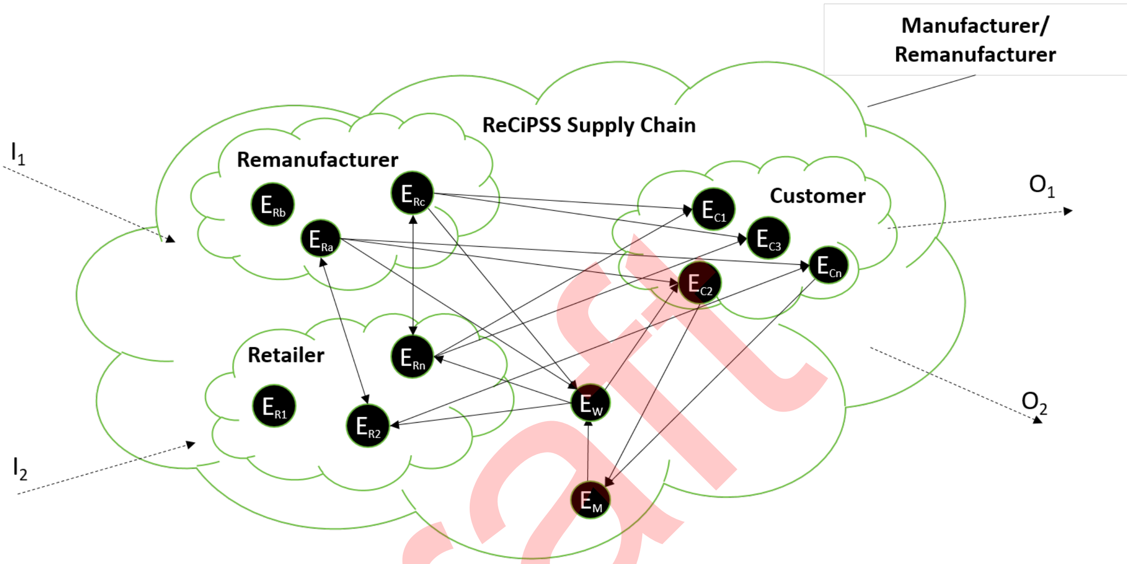
The 'Manufacturer' receives orders for new washing machines from the gold customers. After receiving the customer order, the 'Manufacturer' produces new washing machines and sends these to the system element 'Warehouse'.

From the 'Warehouse', the new washing machines are either transported to one of the system elements of the subsystem 'Retailer' or directly to the 'Customer'. The 'Warehouse' also receives remanufactured washing machines from the subsystem 'Remanufacturer'. If there is a customer order for a remanufactured washing machine, the 'Warehouse' has the option, depending on transport costs and service time, to transport the remanufactured washing machines either to one of the 'Retailers' or directly to the 'Customer'.

The subsystem 'Retailer' consists of several system elements. The system elements are selected during runtime to optimize the reverse supply chain processes. The subsystem 'Retailer' receives new or remanufactured washing machines from the system element 'Warehouse'. Furthermore, the subsystem 'Retailer' delivers these washing machines to the system elements of the subsystem 'Customer'. If the 'Customer' has a broken washing machine or wants to terminate his contract, the 'Retailer' sends a truck to pick up the washing machine. The used washing machine is then transported to a 'Remanufacturer'. In addition, the 'Remanufacturer' can also pick up used washing machines directly at the customer.

The subsystem ‘Remanufacturer’ consists of several ‘Remanufacturers’. The ‘Remanufacturers’ are selected during runtime to optimize the reverse supply chain processes. The ‘Remanufacturer’ receives used washing machines from the subsystem ‘Retailer’ or directly from the ‘Customer’. The ‘Remanufacturer’ remanufactures the used washing machines to a like-new state. The remanufactured washing machines are then transported to a ‘Retailer’, if there exists a customer order for a remanufactured washing machine. If there is no order of a remanufactured washing machine, the washing machine is sent to the ‘Warehouse’.

The state variables of the system elements are described later in the course of the deliverable report. Figure 7 shows the considered supply chain of the white goods demonstrator.



Symbol	Description	Symbol	Description
I_1	Customer orders of a new washing machine	E_{Rn}	Retailer n
I_2	Gold, silver and bronze customers	E_{Ra}	Remanufacturer A
O_1	Recycled washing machines	E_{Rb}	Remanufacturer B
O_2	Gold, silver and bronze customers	E_{Rc}	Remanufacturer C
E_M	Manufacturer	E_{C1}	Customer 1
E_W	Warehouse	E_{C2}	Customer 2
E_{R1}	Retailer 1	E_{C3}	Customer 3
E_{R2}	Retailer 2	E_{Cn}	Customer n

Figure 7: System of the (reverse) supply chain of the white goods demonstrator model with its considered subsystems and system elements

5. Simulation of the Reverse Supply Chains

This chapter commences with the description of general terms of simulation. The simulation software AnyLogic was used for the development of the simulation model. The software is introduced in this chapter and the simulation methods are presented that are applied for modelling the previously described automotive spare parts demonstrator model and white goods demonstrator model. Then, the simulation models in the as-is scenario and later in the to-be scenario for both demonstrators are described. Furthermore, the system behaviour is analysed based on the simulation results. The evaluation of the simulation results is based on the objectives defined in section 2.1.

5.1. Simulation Basics

In the systematic analysis of complex logistics, material flow and production systems, mathematical-analytical methods often reach their limits due to the diverse interdependencies within the considered technical system. In comparison, the German VDI guideline 3633 states that a simulation is able to examine and evaluate time-related behaviour of complex technical systems over a period of time on the basis of a simplified model of reality (VDI-Richtlinie 3633, pp. 3–4). According to the VDI guideline 3633 simulation is the "*representation of the system with its dynamic processes in an experimental model with the aim of reaching findings which are transferable to reality*" (VDI-Richtlinie 3633, p. 28).

There are different simulation methods for the simulation of dynamic systems. The VDI guideline 3633 differentiates these methods into continuous and discrete simulation concepts regarding simulation time and change of state of the underlying model (VDI-Richtlinie 3633, p. 29). In continuous simulation, the model state changes steadily with time, while in discrete simulation, state changes occur abruptly at discrete points in time because of a specific event.

The discrete simulation can in turn be subdivided into time-controlled and event-controlled simulation methods with regard to the control of the simulation process. Fixed or variable steps in the time-controlled simulation control the simulation time. Only the events between the last and the new point in time are executed. Regarding event-driven simulation, the simulation time always continues with the next temporal event, until the event is subsequently executed.

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Based on the modelling approach used, the event-driven simulation can be further subdivided into event-oriented, activity-oriented, process-oriented and transaction-oriented simulations (Mehl 1994, pp. 2–4). Figure 8 shows the classification of simulation methods according to Mehl (1994, p. 4).

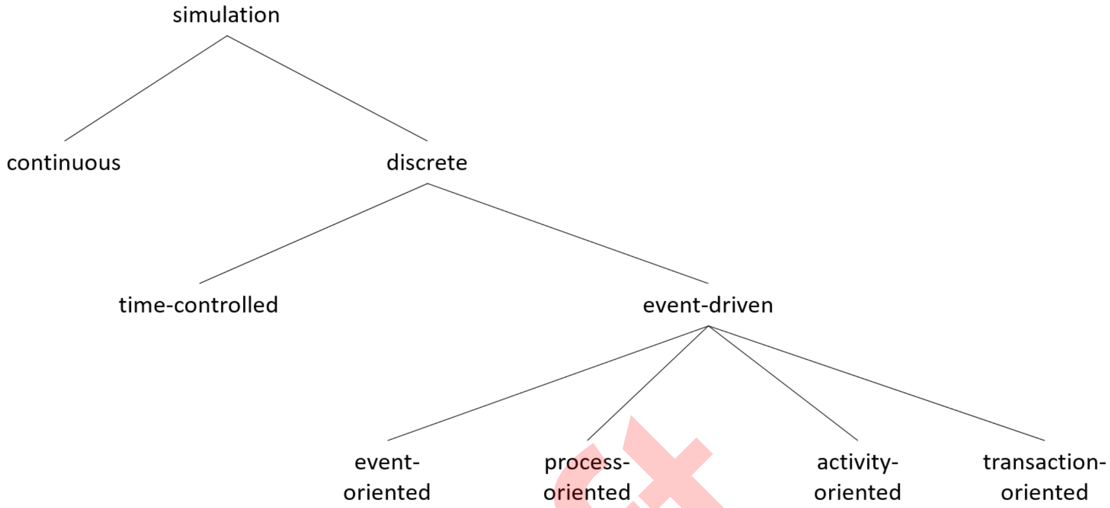

Figure 8: Classification of simulation methods (Mehl 1994, p. 4)

While in event-oriented simulation, changes in reality are displayed as events in the model, in activity-oriented simulation they are regarded as activities of a certain period, modelled by the activity of the beginning and end of an event. Process-oriented simulation is characterised by related state changes of the real world with a modelled process that represents a sequence of related events (Mehl 1994, pp. 4–5). Transaction-oriented simulation represents a special case of process-oriented simulation and will therefore not be elaborated further.

The simulation model of this deliverable report can be classified as a discrete simulation model based on an event-driven approach. In order to simulate the reverse supply chains of both demonstrators, a process-oriented simulation is applied for simulating the real system.

5.2. Simulation Software AnyLogic

AnyLogic provides a single platform in the field of dynamic simulation modelling. The simulation software offers three different simulation methods for the development of a simulation:

- Discrete event modelling
- Agent-based modelling
- System dynamics

These three methods can be used in any combination within the software, to simulate business systems of any complexity. The development platform offers a graphical drag-and-drop environment for the simple creation of models to insert new agents, functions, variables, parameters and other operations. Additionally, the AnyLogic software environment is fully mapped into Java code and linked with the AnyLogic Simulation engine, therefore becoming a completely independent stand-alone Java application. This enables AnyLogic models to be run on any Java-enabled environment or even in a web-browser as applets. Java is an object-orientated programming language with high performance to enable the modeller to define and manipulate data structures of any complexity as well as developing efficient algorithms (Borshchev 2013, p. 380).

5.2.1. Selection of the Simulation Methods

Simulation modelling is used in a wide and diverse range of applications. The various applications can be classified by their level of abstraction. The selection of an appropriate abstraction level is critical for the success of a modelling project. The abstraction level of a model can be linked with the corresponding simulation method. There are three existing simulation methods, each serving a particular range of abstraction level, namely system dynamics, discrete event modelling, and agent-based modelling. System dynamics is mainly used at a high abstraction level, often for strategic modelling. Discrete event modelling operates at a medium and medium-low abstraction level. The range of agent-based modelling supports a high abstraction level as well as a very detailed view. Figure 9 shows the different modelling methods according to their abstraction level (Borshchev 2013, pp. 35–36).

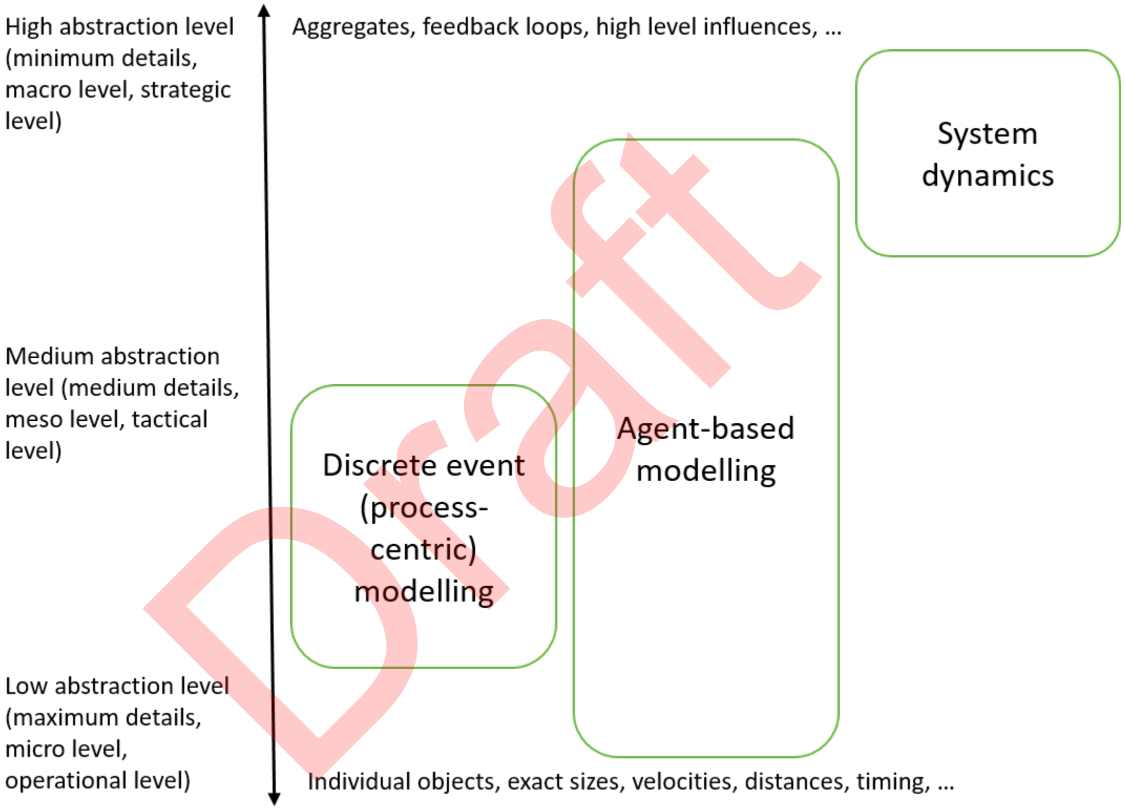

Figure 9: Methods in simulation modelling (Borshchev 2013, p. 36)

For this report, a multi-method approach is chosen to model the reverse supply chain processes. For the control of these processes, a high-medium abstraction level is chosen. Therefore, discrete event modelling and agent-based modelling are applied to the model. In the following section, the two simulation methods are described in more detail.

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5.2.2. Description of the selected Simulation Methods

With respect to this report, the term ‘method’ is understood as a general framework for mapping a real-world system to its model. The methods which are described in particular in the following section are discrete event modelling and agent-based modelling.

Discrete event modelling: This modelling paradigm considers real-world processes as an ordered sequence of events, although the system being simulated exists in continuous time. Changes in the simulation model take place at specific events, which occur at a specific point in time (Stewart 2009, p. 680). The discrete event modelling approach is applied especially for systems that can be described by a sequence of operations. AnyLogic provides the user with a process modelling library for modelling the specific system. With the help of the objects provided in the library, the real-world systems can be modelled in terms of agents (e.g. transactions, customers, products, parts and vehicles), processes (e.g. sequences of operations typically involving queues, delays and resource utilisation) and resources.

Agent-based modelling: From the viewpoint of practical applications, agent-based modelling focuses on individual objects and describes their local behaviour according to local rules. For the agent-based approach agents, such as people, companies, projects, vehicles, cities and products have to be identified and their behaviour, e.g. main drivers, reactions and memory has to be defined. Agents are able to interact with each other as well as with the dynamic environment (Borshchev 2013, pp. 49–50). Following the bottom-up approach, the global behaviour emerges as a result of the interactions of many concurrent individual behaviours. The behaviour of an agent can be represented by a number of variables, parameters and functions. To model the agent’s behaviour, AnyLogic provides its users with a set of agent components. The agent’s behaviour is defined with a statechart consisting of states and transitions (Borshchev 2013, p. 287).

5.3. Automotive Spare Parts Demonstrator Modelling

This section provides an overview of the current reverse supply chain of the automotive spare parts demonstrator. Thereby, the reverse supply chain operations of C-ECO are summarized and create the baseline for analysing the business model. Furthermore, the target figures mentioned in section 2.1 are also explained. In order to create an optimal reverse flow of the cores, the as-is scenario is compared with the to-be scenario. The as-is scenario represents the current reverse supply chain set-up of reverse logistics operations. With the to-be scenario, the aim is to integrate trade levels to optimize the reverse supply chain according to the defined target figures in section 2.1.

5.3.1. Overview

By introducing a new business model within the ReCiPSS project, the goal is to improve the reverse supply chain operations for the automotive spare parts demonstrator. The complexity of operations leads to redundant processes throughout the whole reverse supply chain and, hence, decrease the overall performance of the system.

One reason for the inefficiency in the reverse supply chain is that the OEM, e.g. Bosch does not have full control throughout all trade levels of the reverse supply chain. The reverse network with its stakeholders is decentrally organised resulting in poor coordination and exchange of information among them. The reason for this occurrence is that the trade levels operate independently in order to protect their business relationship. However, due to the lack of transparency in the reverse supply chain, cores are identified and evaluated several times, creating inefficiencies, additional transportation costs and uncertainty of availability and delivery times of the cores at the remanufacturer.

To counteract these inefficiencies in the reverse supply chain, a single-service provider, namely C-ECO, is introduced for dealing with the reverse supply chain operations. Operations like identification and evaluation of cores as well as transportation activities are reduced to a minimum through an increase of transparency in the reverse supply chain. In order to achieve a higher performance of the overall system, the inclusion or rejection of the different trade levels is crucial.

For the demonstrator phase, the as-is scenario, representing the current reverse supply chain set-up for reverse logistics operations is compared with the to-be scenario. Thereby, the to-be scenario analyses the depth of trade levels in order to optimise the overall system. These two scenarios were conducted to address the differences between the business approaches and to assess the effect of increased information transparency on the system performance.

For the demonstrator phase, the German aftersales market with two different wholesalers is taken into consideration. The scenarios are evaluated with regard to the logistic target figures stated in section 2.1. Therefore, the calculation of the target figures is briefly explained.

The system aims to minimize the reverse transport costs of a core, as one of the target figures. The reverse logistics costs include all transport activities from the wholesaler's outlets towards the remanufacturer. The transport costs are calculated based on Equation 9:

$$TC_{total} = TC_w \times d_w + TC_c \times d_c + TC_{wr} \times d_{wr} + TC_{cr} \times d_{cr} \tag{9}$$

with:	TC_{total}	*total transport costs of a core in* $[\text{€}]$
	TC_w	*transport costs of a core to the wholesaler in* $\left[\frac{\text{€}}{km}\right]$
	TC_c	*transport costs of a core to the C-ECO warehouse in* $\left[\frac{\text{€}}{km}\right]$
	TC_{wr}	*transport costs of a core from the wholesaler central to the remanufacturer in* $\left[\frac{\text{€}}{km}\right]$
	TC_{cr}	*transport costs of a core from the C-ECO warehouse to the remanufacturer in* $\left[\frac{\text{€}}{km}\right]$
	d_w	*distance from the wholesaler outlet to the wholesaler central in* $[\text{km}]$
	d_c	*distance from the wholesaler central to C-ECO warehouse in* $[\text{km}]$
	d_{wr}	*distance from the wholesaler central to the remanufacturer in* $[\text{km}]$
	d_{cr}	*distance from the C-ECO warehouse to the remanufacturer in* $[\text{km}]$

Another important target figure for the system is the transport time. It is important to ensure that remanufacturer orders are fulfilled promptly and that delivery times are met. If the core cannot be delivered in the desired time, storage costs and space required for the cores increase at the wholesaler. The transport time of a core is calculated as the difference between the date of arrival at one of the outlets of a wholesaler and the date of delivery at the remanufacturer.

$$TT = T_a - T_d \tag{10}$$

with:	TT	*transport time of a core in [days]*
	T_a	*date of arrival at the outlet of a wholesaler* $[days]$
	T_d	*date of delivery at the remanufacturer* $[days]$

From C-ECO's point of view, the minimisation of CO_2-emissions caused by transport activities is desirable, since one of the goals of the new business model is also to improve the CO_2-footprint of the entire company. Similar to the transport costs, the CO_2-emissions of a core are the sum of all CO_2-emissions from the wholesaler to the remanufacturer.

$$CO2_{total} = CO2_w \times d_w + CO2_c \times d_c + CO2_{wr} \times d_{wr} + CO2_{cr} \times d_{cr} \tag{11}$$

with:	$CO2_{total}$	*total CO_2-emissions of a core in* $[\frac{\mathrm{kg}}{\mathrm{t}}]$
	$CO2_w$	*CO_2-emissions of a core to the wholesaler in* $\left[\frac{kg}{t \times km}\right]$
	$CO2_c$	*CO_2-emissions of a core to the C-ECO warehouse in* $\left[\frac{kg}{t \times km}\right]$
	$CO2_{wr}$	*CO_2-emissions of a core from the wholesaler central to the remanufacturer in* $\left[\frac{kg}{t \times km}\right]$
	$CO2_{cr}$	*CO_2-emissions of a core from the C-ECO warehouse to the remanufacturer in* $\left[\frac{kg}{t \times km}\right]$
	d_w	*distance from the wholesaler outlet to the wholesaler central in* [km]
	d_c	*distance from the wholesaler central to C-ECO warehouse in* [km]
	d_{wr}	*distance from the wholesaler central to the remanufacturer in* [km]
	d_{cr}	*distance from the C-ECO warehouse to the remanufacturer in* [km]

5.3.2. As-Is Scenario

This scenario describes the current decentralized system of the reverse supply chain operations of a core. Thereby, all trade levels from the outlet of a wholesaler to the remanufacturer are considered. In the decentralized scenario, the cores are being sorted at each trade level. Hence, for the scenario in the German aftersales market, due to the trade-structures the cores are identified and evaluated by three different stakeholders (wholesaler outlet, wholesaler central, C-ECO warehouse) before the cores are finally inspected at the remanufacturer. However, due to the lack of transparency in the reverse supply chain, the stakeholders have different information and knowledge about the right to return a core and if it meets the quality criteria specified by the remanufacturer. This leads to higher complexity of returning a core logistically and commercially for the stakeholders.

In general, in the reverse supply chain, if a workshop orders a remanufactured part, the outlet delivers the remanufactured part on the same day and picks up the respective core. At the outlet, the core is inspected for the first time. Whether the inspected core is accepted or not, relies on the employee's expertise and provided print-outs, on which acceptance criteria for different product groups are specified by the remanufacturer. However, these print-outs from the remanufacturers might be outdated already, not showing the latest compliance criteria. This manual operation bears the risk that parts are either not identified or evaluated incorrectly.

The accepted cores are transported to the wholesaler central for a second identification and evaluation. The collected cores arrive at the wholesaler central unsorted and stored in boxes. The cores differ, for example, in terms of their product groups, the manufacturer or the year of production. At the wholesaler central, the cores are additionally sorted by the wholesaler according to the core's remanufacturer. The wholesaler is responsible for further logistics operations, e.g. packaging, documentation, contacting freight forwarders depending on the remanufacturer.

Once the cores arrive at the remanufacturer, the cores are inspected for the last time. The remanufacturer decides whether the cores are accepted or not. However, the wholesaler has no insight into the process of core-acceptance. The described as-is scenario is shown in Figure 10.

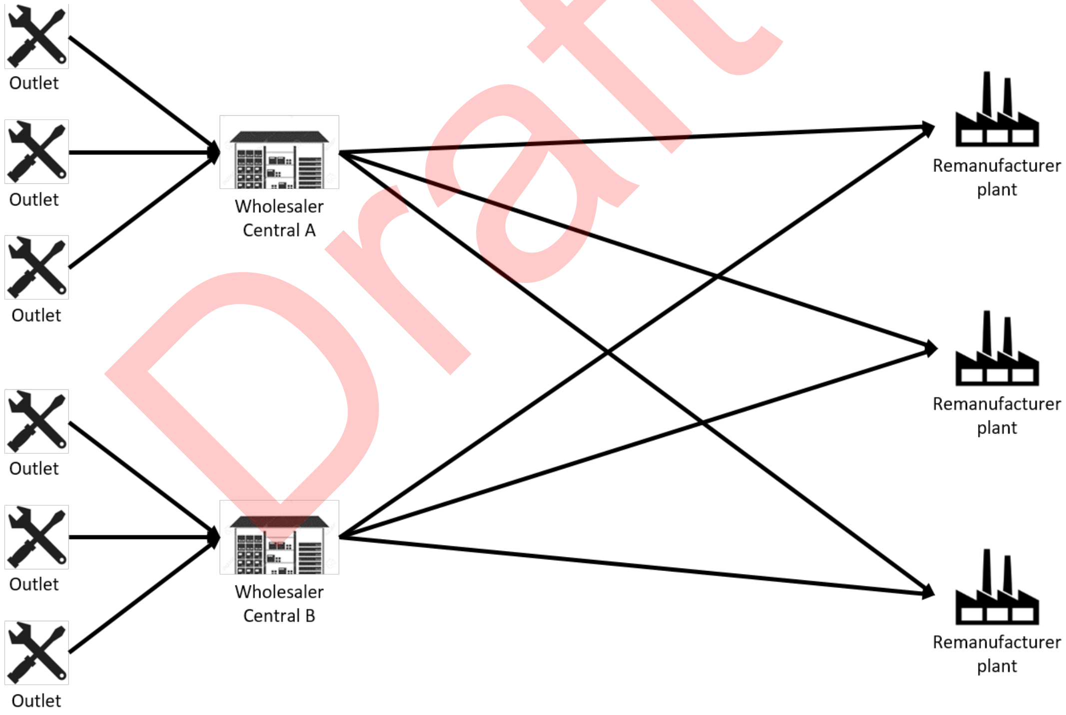

Figure 10: Reverse supply chain in the as-is scenario of the automotive spare parts demonstrator

5.3.3. To-Be Scenario

To increase transparency in the reverse supply chain, a cloud-based platform was previously developed in – WP 5 in the ReCiPSS project. With the help of this platform, the cores can be checked on the current information for a right to return of a core. The platform and the incorporation of a right to return as an option are the basis that the identification process can be outsourced.

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This enables stakeholders to outsource the physical core return process to a service provider, namely C-ECO. With C-ECO as a specialized service provider in the area of the reverse supply chain, the expertise and the necessary infrastructure exists. Once the cloud-based platform is implemented at the location of the stakeholders, it is possible to determine with the first inspection if the remanufacturer accepts the core, as well as the core's destination. Thus, through generating information about the core at an early stage of the reverse supply chain, the logistic activities can be optimized.

During the demonstrator phase, the wholesaler is still identifying and evaluating the cores in addition to the inspection at C-ECO warehouse. Hence, the wholesaler is still in control of the inspection process but receives more support by using the cloud-based platform. By double-checking the cores and their results, trust can be established between the business partners. By establishing trust, the wholesaler should be encouraged to outsource his reverse supply chain operations and not be afraid of possible disadvantages like an unjustified high rejection rate by C-ECO or losing the right to return cores.

In general, each location of the stakeholder within the reverse supply chain can be equipped with the cloud-based platform. C-ECO can then collect the cores directly at these locations. In the next step, C-ECO either bundles the cores in one of its warehouses or sends them directly to the remanufacturer.

For the to-be scenario, the existing infrastructure is equipped with the cloud-based platform. Thereby, it is important to determine suitable locations to achieve the best possible return flow of cores. The target criteria mentioned in section 2.1 are used to determine the locations of the different stakeholders which will be equipped with the cloud-based platform. With the help of an ADD algorithm, as described in section 3.2, the optimal infrastructure with regards to the described target criteria for the reverse supply chain can be determined. Figure 11 shows the reverse supply chain in the to-be scenario.

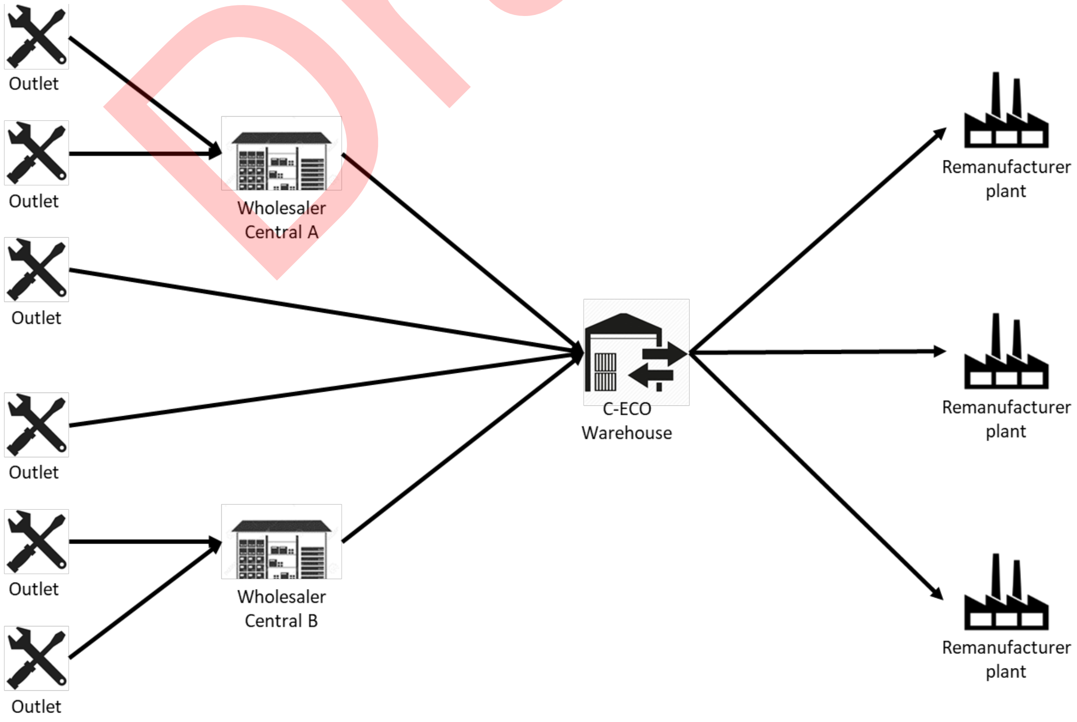

Figure 11: Reverse supply chain in the to-be scenario of the automotive spare parts demonstrator

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5.3.4. Result Analysis

Within the result analysis, the system behaviour of the as-is and the to-be scenario is analysed on the basis of the simulation results. The evaluation of the simulation results is based on the objectives of this deliverable report defined in section 2.1. Limitations of the model must be taken into account regarding the interpretation of the results.

In the following section, the total transport costs, transport time and amount of CO_2-emissions of the reverse supply chain of the as-is and to-be scenario were determined and compared. The values of the target figures shown in this section do not correspond to reality but only have a representative character. The duration of the simulation for both scenarios is 365 days. Thereby, the cores were delivered weekly to the wholesaler outlets. The number and locations equipped with the cloud-based platform are not mentioned in this report due to the non-disclosure agreement.

Transport costs: The transport costs in both scenarios increase continuously over the duration of the simulation period. In the as-is scenario, the transport costs add up to 731,372.901 € within one year. In the to-be scenario, transport costs are significantly lower due to the implementation of the C-ECO software at the wholesaler outlets and resulting increase of transparency in the reverse supply chain. Due to the increased transparency, the cores can be allocated to the remanufacturer at an earlier stage in the reverse supply chain. Thus, unnecessary transport routes to the wholesaler central can be avoided. In the to-be scenario, a total of 317,386.613 € is incurred for transport costs of the cores within one year. This means that the improvements in the reverse logistics processes have reduced the costs by 413,986.288 €. This corresponds to a reduction in transport costs in the to-be scenario compared to the as-is scenario of over approximately 56.6 %. The comparison of the target figure 'transport costs' of the two scenarios is shown in Figure 12.

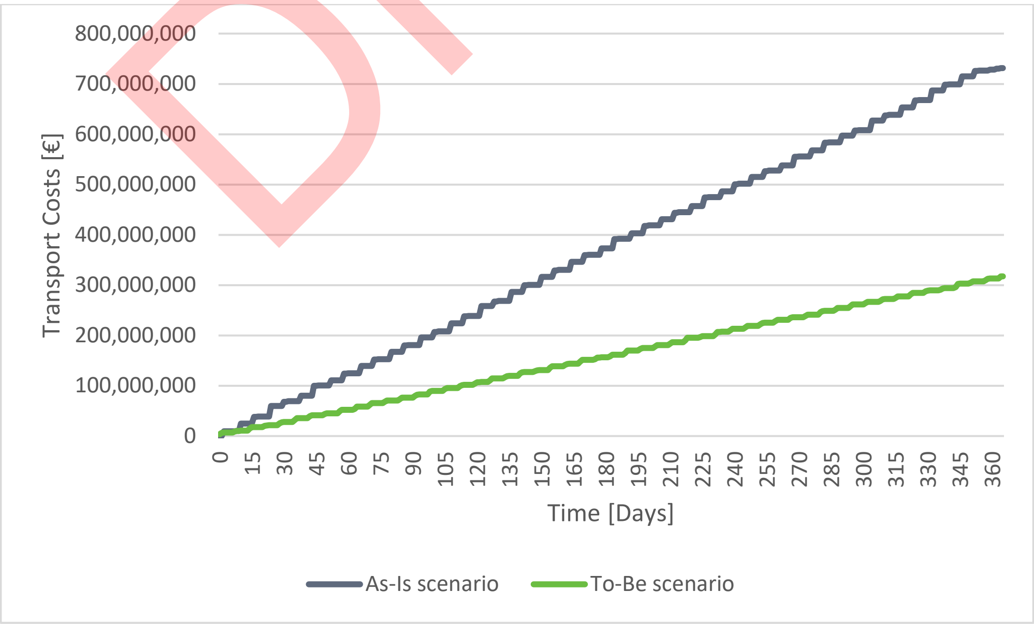

Figure 12: Comparison of the transport costs of a core in the as-is and to-be scenario

Transport time: Transport time is the average time of a core from the wholesale outlet to the remanufacturer. The transport time of a core during one year in the as-is scenario varies between 13.69 and 16.55 days. In the to-be scenario, the values of the transport time of a core vary between 16.34 and 17.77 days. The fluctuating values of the transport times for the cores are a consequence of the varying quantities of cores arriving at each outlet per week and therefore the transport frequency of picking up cores also varies. As a result, some cores have longer transport times, which can be seen in the sharp increases in average transport time in the line chart in Figure 13.

The average transport time for a core in the as-is scenario is 14.99 days. In the to-be scenario, the cores arrive at the remanufacturer after an average of 16.98 days. The transport time in the to-be scenario has thus deteriorated by 1.99 days. This deterioration in the transport time is due to the fact that not all of the wholesaler outlets are equipped with the cloud-based platform from C-ECO. The cores arriving at these outlets are therefore first sent to the wholesaler central and from there to a C-ECO warehouse.

Outlets without the cloud-based platform are usually supplied with only a few numbers of cores. Hence, the transport frequency between the outlet and the wholesaler central is also low, which has a negative effect on the simulation result of the transport time of a core in the to-be scenario. The comparison of the target figure ‘transport time’ of the as-is and to-be scenario is shown in Figure 13.

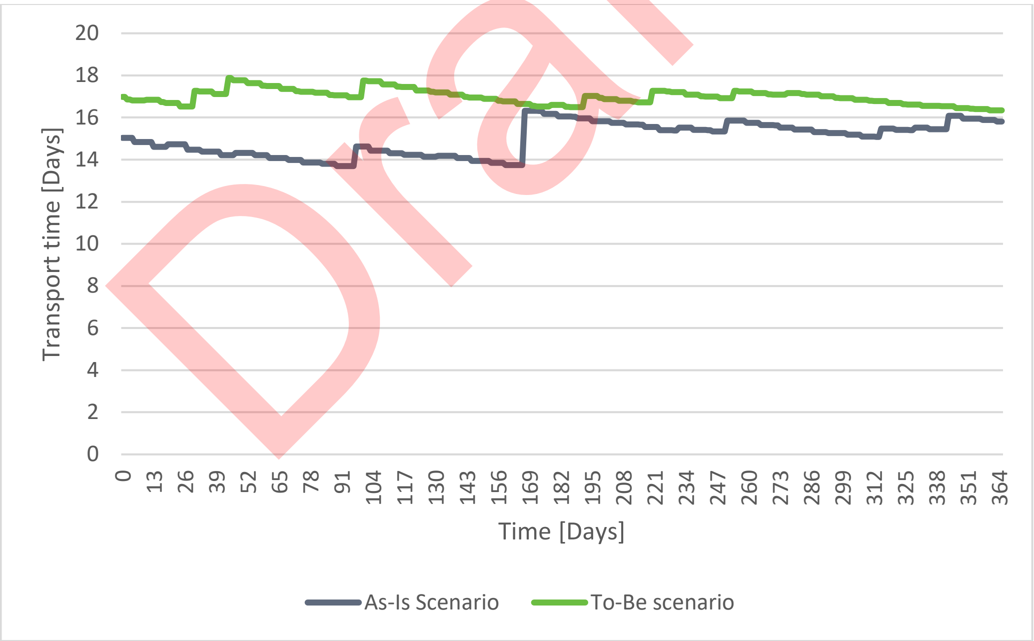

Figure 13: Comparison of the transport time of a core in the as-is and to-be scenario

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CO_2-emissions: As with the transport costs, the CO_2-emissions increase continuously over the duration of the simulation period. In the as-is scenario, the CO_2-emissions add up to 33,425.256 kg/t per year. In the to-be scenario, CO_2-emissions are lower due to a lower transport frequency and distance travelled. In the to-be scenario, a total of 29,875.481 kg/t is incurred for transporting the cores from the wholesaler outlets to the remanufacturer. Hence, the improvements in the reverse logistics processes have reduced the CO_2-emissions incurred by 3,549.775 kg/t. This corresponds to a reduction in CO_2-emissions in the to-be scenario compared to the as-is scenario of over approximately 10.6 %. The comparison of the target figure 'CO_2-emissions' of the two scenarios is shown in Figure 14.

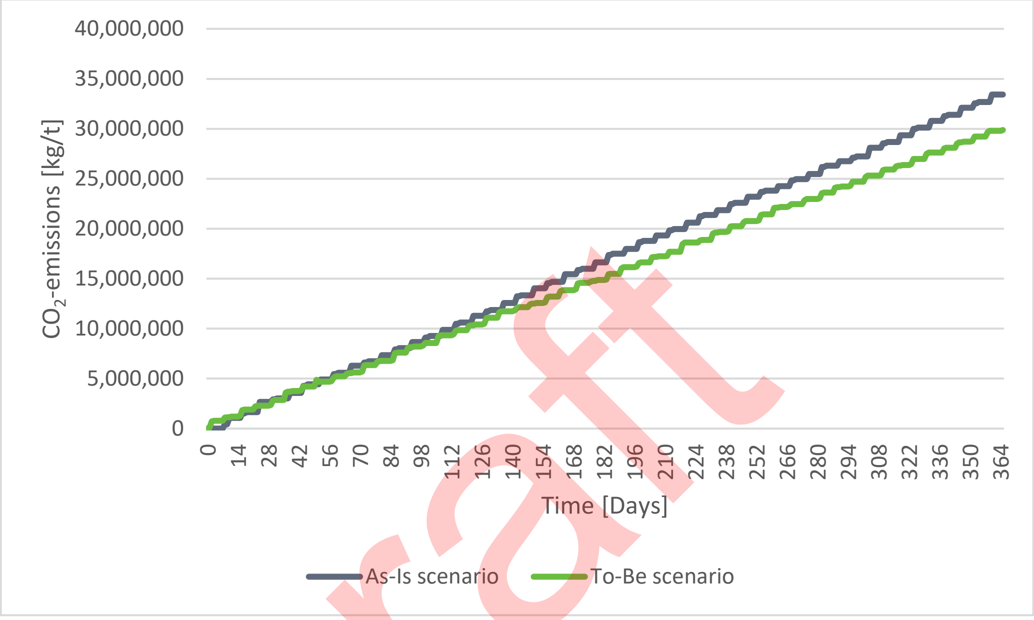

Figure 14: Comparison of the CO_2-emissions of a core in the as-is and to-be scenario

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5.4. White Goods Demonstrator Modelling

This section provides an overview of the current reverse supply chain of the white goods demonstrator. Thereby, the simulation model for the washing machine demonstrator is described and analysed. Furthermore, the target figures transport costs, transport time and CO_2-emissions, mentioned in section 2.1, are also explained. Then the scenarios in the different countries are described and analysed with regard to the target values mentioned before.

5.4.1. Overview

The goal of the ReCiPSS project is a successful introduction of a circular supply chain for the new white goods demonstrator model. However, for a successful implementation, the OEM, in this case Gorenje, must maintain full control over the complete stages (e.g. design, manufacturing, forward supply chain, customer use phase, reverse supply chain, recovery activities and redistribution) of the product life cycle of a washing machine. From today's point of view, in order to introduce the new business model, Gorenje must introduce reverse logistics in the company.

In this context, reverse logistics plays a key role in the implementation of a circular supply chain, since the additional expenses caused by increased transport activities and the resulting transport costs are significant. Crucial factors for reverse logistics are the determination of the distribution network and the location of remanufacturing facilities, the geographical dispersion of the customers as well as the information flows between the different stakeholders. If these factors are not sufficiently taken into account, additional costs are incurred and inefficient processes may result during the return of the cores.

For the demonstrator phase, four different markets, namely Slovenia, the Netherlands, Denmark and Austria, are initially selected to introduce the new PPW business model. The four markets for the ReCiPSS project have been chosen based on sales volume and existing supporting infrastructure. The market potential of the four countries was determined previously in WP 2. For each market, a simulation scenario was conducted in this report.

The scenarios are evaluated with regard to the logistic target figures stated in section 2.1. Therefore, the calculation of the target figures is briefly explained.

The aim of the system is to minimize the transport costs of a washing machine during the complete product life-cycle. The transport costs of a washing machine include forward and reverse logistics costs. The forward logistics costs include all transport activates towards the customer (e.g. transportation of new washing machines from the manufacturer to the warehouse, retailer, customer), while the reverse logistics costs include all other transport activities (e.g. transportation of the cores from the customer to the remanufacturer, retailer, warehouse). The transport costs are calculated based on Equation 12.

$$TC_{total} = TC_f + TC_r \tag{12}$$

with: TC_{total} *total transport costs of a washing machine in* [€]

TC_f *forward transport costs of a washing machine in* [€]

TC_r *reverse transport costs of a washing machine in* [€]

The forward transport costs of a washing machine consist of the transport costs from the manufacturer to the warehouse in the respective market. In addition, transport costs incur from the warehouse to a retailer and from there to the customer or directly from the warehouse to the customer.

$$TC_f = TC_{mw} \times d_{mw} + TC_{wret} \times d_{wret} + TC_{wc} \times d_{wc} + TC_{rc} \times d_{rc} \qquad (13)$$

with:	TC_f	*forward transport costs of a washing machine in* $[€]$
	TC_{mw}	*transport costs of a washing machine from the manufacturer to the warehouse in* $\left[\frac{€}{km}\right]$
	TC_{wret}	*transport costs of a washing machine from the warehouse to the retailer in* $\left[\frac{€}{km}\right]$
	TC_{wc}	*transport costs of a washing machine from the warehouse to the customer in* $\left[\frac{€}{km}\right]$
	TC_{rc}	*transport costs of a washing machine from the retailer to the customer in* $\left[\frac{€}{km}\right]$
	d_{mw}	*distance from the manufacturer to the warehouse in* $[\mathrm{km}]$
	d_{wr}	*distance from the warehouse to the retailer in* $[\mathrm{km}]$
	d_{wc}	*distance from the warehouse to the customer in* $[\mathrm{km}]$
	d_{rc}	*distance from the retailer to the customer in* $[\mathrm{km}]$

The reverse transport costs of a washing machine consist of the transport costs from the customer either to a retailer or directly to the remanufacturer. Additionally, reverse transport costs incur between the retailer and the remanufacturer as well as from the remanufacturer to the warehouse.

$$TC_r = TC_{cr} \times d_{cr} + TC_{cret} \times d_{cret} + TC_{rr} \times d_{rr} + TC_{rw} \times d_{rw} \qquad (14)$$

with:	TC_r	*reverse transport costs of a washing machine in* $[€]$
	TC_{cr}	*transport costs of a washing machine from the customer to the remanufacturer in* $\left[\frac{€}{km}\right]$
	TC_{cret}	*transport costs of a washing machine from the customer to the retailer in* $\left[\frac{€}{km}\right]$
	TC_{rr}	*transport costs of a washing machine between retailer and remanufacturer in* $\left[\frac{€}{km}\right]$
	TC_{rw}	*transport costs of a washing machine from the remanufacturer to the warehouse in* $\left[\frac{€}{km}\right]$
	d_{cr}	*distance from the customer to the remanufacturer in* $[\mathrm{km}]$
	d_{cret}	*distance from the customer to the retailer in* $[\mathrm{km}]$
	d_{rr}	*distance between the retailer and the remanufacturer in* $[\mathrm{km}]$
	d_{rw}	*distance from the remanufacturer to the warehouse in* $[\mathrm{km}]$

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Another important target figure for the system is service time to ensure that customer orders are fulfilled promptly and that delivery times are met. If the washing machines cannot be delivered at the desired time, customer satisfaction decreases. The service time of a customer is calculated as the difference between the date of order and date of delivery.

$$ST = T_c - T_d \tag{15}$$

with:	ST	*service time of a customer in [days]*
	T_c	*date of order of a customer* $[days]$
	T_d	*date of delivery of a washing machine* $[days]$

From the company's point of view, the minimisation of CO_2-emissions is desirable, since one of the goals of the new business model is also to improve the CO_2-footprint of the entire company. Similar to the transport costs, the CO_2-emissions of a washing machine are divided into forward and reverse logistics costs.

$$CO2_{total} = CO2_f + CO2_r \tag{16}$$

with:	$CO2_{total}$	*total CO_2-emissions of a washing machine in* $[\frac{\mathrm{kg}}{\mathrm{t}}]$
	$CO2_f$	*forward CO_2-emissions of a washing machine in* $\left[\frac{kg}{t}\right]$
	$CO2_r$	*reverse CO_2-emissions of a washing machine in* $\left[\frac{kg}{t}\right]$

The forward CO_2-emissions of a washing machine consist of the CO_2-emissions from the manufacturer to the warehouse in the respective market. In addition, CO_2-emissions incur from the warehouse to a retailer and from there to the customer or directly from the warehouse to the customer.

$$TC_f = CO2_{mw} \times d_{mw} + CO2_{wr} \times d_{wr} + CO2_{wc} \times d_{wc} + CO2_{rc} \times d_{rc} \tag{17}$$

with:	$CO2_f$	*forward CO_2-emissions of a washing machine in* $[\frac{\mathrm{kg}}{\mathrm{t}}]$
	$CO2_{mw}$	*CO_2-emissions of a washing machine from the manufacturer to the warehouse in* $\left[\frac{kg}{t \times km}\right]$
	$CO2_{wr}$	*CO_2-emissions of a washing machine from the warehouse to the retailer in* $\left[\frac{kg}{t \times km}\right]$
	$CO2_{wc}$	*CO_2-emissions of a washing machine from the warehouse to the customer in* $\left[\frac{kg}{t \times km}\right]$
	$CO2_{rc}$	*CO_2-emissions of a washing machine from the retailer to the customer in* $\left[\frac{kg}{t \times km}\right]$
	d_{mw}	*distance from the manufacturer to the warehouse in* [km]
	d_{wr}	*distance from the warehouse to the retailer in* [km]
	d_{wc}	*distance from the warehouse to the customer in* [km]
	d_{rc}	*distance from the retailer to the customer in* [km]

The reverse CO_2-emissions of a washing machine consist of the CO_2-emissions from the customer either to a retailer or directly to the remanufacturer. Additionally, reverse CO_2-emissions incur between the retailer and the remanufacturer as well as from the remanufacturer to the warehouse.

$$TC_r = CO2_{cr} \times d_{cr} + CO2_{cret} \times d_{cret} + CO2_{rr} \times d_{rr} + CO2_{rw} \times d_{rw} \qquad (18)$$

with:	$CO2_r$	reverse CO_2-emissions of a washing machine in $[\frac{\mathrm{kg}}{\mathrm{t}}]$
	$CO2_{cr}$	CO_2-emissions of a washing machine from the customer to the remanufacturer in $\left[\frac{kg}{t \times km}\right]$
	$CO2_{cret}$	CO_2-emissions of a washing machine from the customer to the retailer in $\left[\frac{kg}{t \times km}\right]$
	$CO2_{rr}$	CO_2-emissions of a washing machine between retailer and remanufacturer in $\left[\frac{kg}{t \times km}\right]$
	$CO2_{rw}$	CO_2-emissions of a washing machine from the remanufacturer to the warehouse in $\left[\frac{kg}{t \times km}\right]$
	d_{cr}	distance from the customer to the remanufacturer in [km]
	d_{cret}	distance from the customer to the retailer in [km]
	d_{rr}	distance between the retailer and the remanufacturer in [km]
	d_{rw}	distance from the remanufacturer to the warehouse in [km]

5.4.2. Scenario description for the market in Slovenia, the Netherlands, Denmark and Austria

In the simulation scenarios, the supply chain for the new PPW business model is described and analysed. The scenarios are initially considered individually for the four possible markets, namely Slovenia, the Netherlands, Denmark and Austria.

The introduction of the PPW business model will create additional logistical activities for the whole circular supply chain. Although Gorenje must develop a new system for the reverse supply chain for the new business model, it can build on existing physical infrastructure in the individual markets. Each market has its own Sales and Business Unit which is responsible for the deployment and management of washing machines. Furthermore, the reverse logistics infrastructure consists of a central warehouse and possible retailers as well as remanufacturers.

Depending on the existing infrastructure, the simulation model is used to determine in which cities the PPW business model should be introduced with regard to the defined logistical target figures. In addition, it must be determined which locations, i.e. which retailer and which remanufacturer, of the existing infrastructure, are to be included in the project in order to optimally achieve the logistical target figures.

For each country, three different simulations scenarios are conducted. In the first two scenarios, in each case, a city where the pilot project could start is selected and the optimal locations for the retailer and remanufacturer in the reverse supply chain are determined. In the third scenario, the customers are distributed randomly throughout the whole country and the effects on the reverse supply chain are analysed.

With the help of the target figures described in section 2.1, the three different scenarios are evaluated and compared with each other.

In the demonstrator phase, only gold customers, hence only new washing machines, will be used for the PPW business model. The new washing machines will be manufactured on demand in order to avoid unnecessary storage costs. As soon as the washing machines are available, they are first transported to the warehouse in the respective country.

At the warehouse, the washing machines are either transported directly to the customer or first to a retailer. The retailer is taking charge of the washing machine and is responsible for supplying the customer. In case of contract termination, the washing machine is collected by the retailer or the remanufacturer at the customer. If the retailer collects the washing machine from the customer, the remanufacturer will pick up the used washing machine from the retailer.

At the remanufacturer plant, the washing machines are remanufactured, thus returned to a like-new condition. In case of a demand for a remanufactured washing machine, the remanufacturer transports it to the respective retailer. Then, the retailer delivers the remanufactured washing machine to the customer. If there is no demand for a remanufactured washing machine, the washing machine is transported to the warehouse. Once there is a demand for a remanufactured washing machine, the washing machine is delivered directly to the customer from the warehouse or is transported to the retailer, from where it is transported to the customer. The forward and reverse supply chain of the PPW business model is shown in Figure 15.

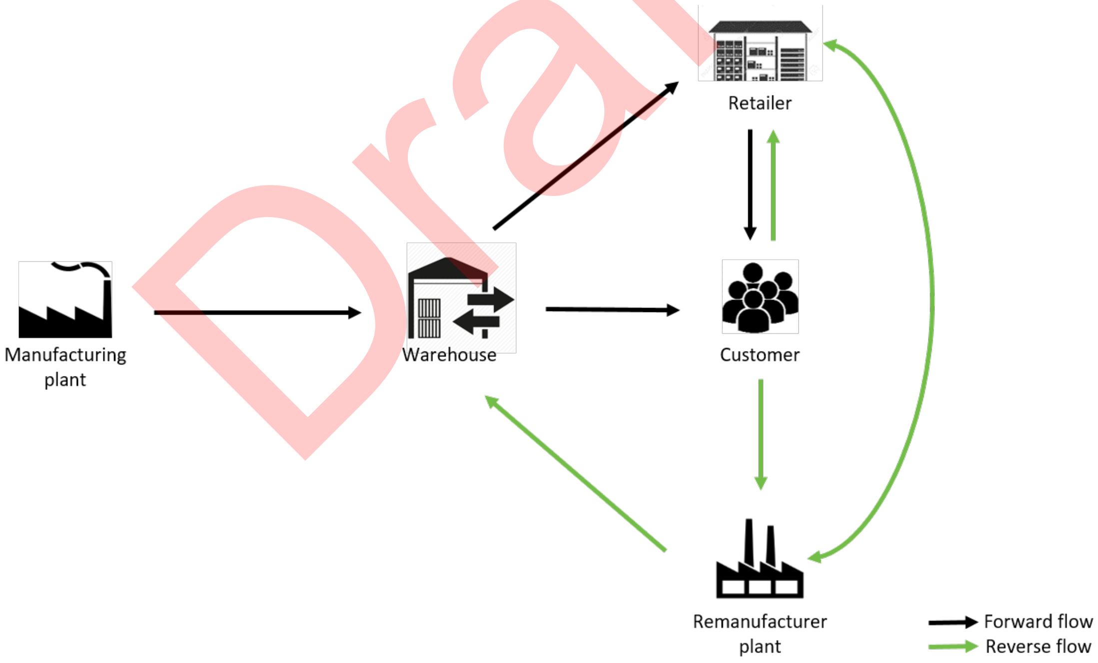

Figure 15: Forward and reverse supply chain in the pay-per-wash business model

5.4.3. Result Analysis

Within the result analysis, the system behaviour in the demonstrator phase of the PPW business model in each market is analysed on the basis of the simulation results. The evaluation of the simulation results is based on the objectives of this deliverable report defined in section 2.1. Regarding the interpretation of the results, limitations of the model must be taken into account.

In the following section, the total transport costs, service time and amount of CO_2-emissions of the circular supply chain of the three different scenarios exemplary for the Dutch market were determined and compared. The values of the target figures shown in this section do not correspond to reality but only have a representative character. The duration of the simulation for the three scenarios is 365 days. Each scenario was simulated with 50 gold customers for the demonstrator phase. The number and locations of the remanufacturers and retailers are not mentioned in this report due to the non-disclosure agreement.

For the three simulation scenarios, the following infrastructure in the Netherlands could be used for the new PPW business model. In the Netherlands, one warehouse is responsible for transporting the washing machines to the retailers and customers. With the introduction of the PPW business model, five possible retailers can be chosen from. For remanufacturing of the used washing machines three possible locations in the Netherlands exist.

The different scenarios in the Netherlands are described as follows. In the first scenario, 50 gold customers are randomly distributed in Amsterdam. In the second scenario, the PPW business model starts in Groningen with 50 gold customers. In the last scenario, the 50 gold customers are randomly distributed throughout the country. In the following section, the target figures mentioned above are analysed with regards to the different scenarios.

Transport costs: For the transport costs in the different scenarios, the forward transport costs and the reverse transport costs are summarized. Thereby, the transport costs for each tour of a truck are summed up, taking the travelled distance and travel time into account. In the first scenario with customers distributed in Amsterdam, transport costs of approximately 7,969.487 € are incurred over one year. For the second scenario with customers distributed in Groningen, 32,502.409 € of transport costs are incurred over the whole year. In the last scenario, with customers spread randomly over the whole country, 23,863.104 € transport costs are incurred throughout the year.

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Regarding the results of the different scenarios, the importance of determining the optimal location for industrial facilities regarding their logistic target criteria is emphasized. Comparing scenario 1, with customers in Amsterdam, with scenario 2, with customers in Groningen, 24,532.922 € less in transport costs incurred in scenario 1. In scenario 3, with customers distributed over the whole Netherlands, 15,893.617 € more in transport costs incurred compared with scenario 1. Thus, the transport costs incurred in scenario 2 are four times higher than in scenario 1. Regarding scenario 3, the transport costs are almost three times higher than in scenario 1. The comparison of the target figure 'transport costs' of the three scenarios is shown in Figure 16.

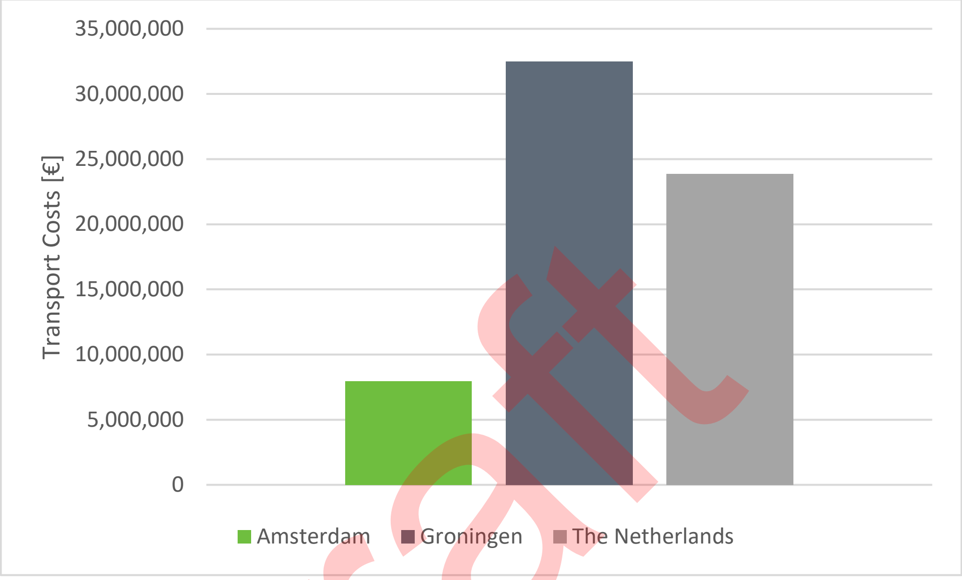

Figure 16: Comparison of the transport costs in the different scenarios

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Service time: The service time is calculated as the difference between the time of a customer request, such as an order for a new washing machine or a technician for repair work, and the time, the service was completed. Thereby, Gorenje's goal is to guarantee a service readiness for customers within the next 24 hours.

Regarding the service time in the first scenario, with customers in Amsterdam, the customer requests are fulfilled after 0.63 days on average, thus typically after 15 hours. Similarly, in the second scenario, with customers in Groningen, the customer requests are fulfilled on average after 0.63 days or after 15 hours. In the last scenario with customers distributed all over the Netherlands, the customer requests are fulfilled after 0.87 days, which is usually after 21 hours. In scenario 1 and 2, the customer requests are fulfilled in 0.24 days, thus, approximately 6 hours earlier than in scenario 3. Consequently, in scenarios 1 and 2, the customer requests are fulfilled approximately 40% faster than in scenario 3.

The service time in all three scenarios is on average below the desired 24 hours to fulfil a customer request. However, in scenario 3 the limit of 24 hours for fulfilment of a customer request was exceeded nine times within one year, in scenario 2 the limit was exceeded four times and in the first scenario only once. The comparison of the target figure 'service time' of scenario 1,2 and 3 is shown in Figure 17.

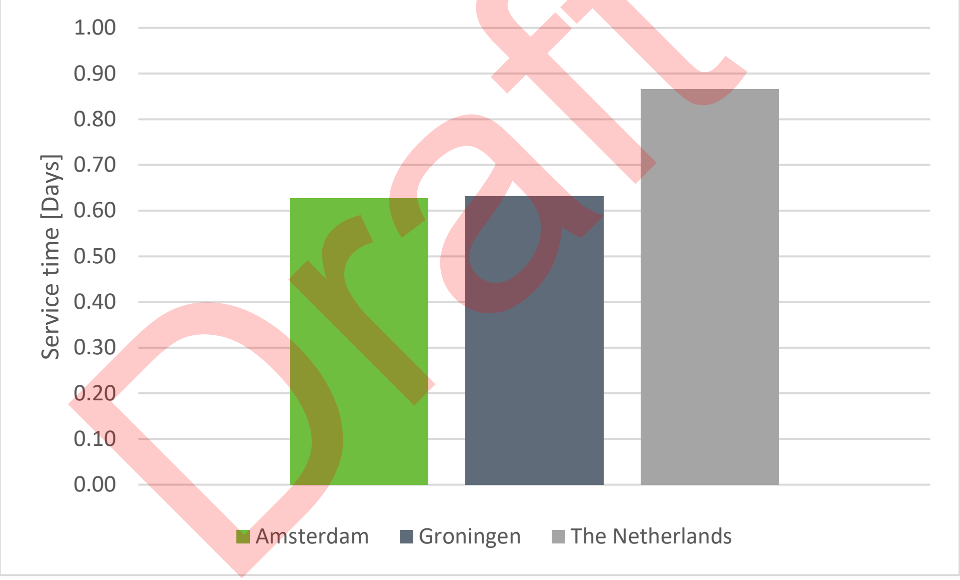

Figure 17: Comparison of the transport time in the different scenarios

CO_2-emissions: Regarding the results of the target figure 'CO_2-emissions' in the different scenarios, the CO_2-emissions incurred during the forward and reverse transport activities are summarized. In the first scenario, with customers distributed in Amsterdam, CO_2-emissions of approximately 1,964.147 kg/t are incurred over one year. For the second scenario, with customers distributed in Groningen, 24,142.793 kg/t of CO_2-emissions are incurred over the whole year. In the last scenario, with customers spread randomly over the whole country, 17,531.615 kg/t CO_2-emissions are incurred throughout the year.

Similar to the results for the transport costs, comparing the results of CO_2-emissions of the different scenarios emphasizes the importance of finding the optimal location for industrial facilities. Comparing scenario 1, with customers in Amsterdam, with scenario 2, with customers in Groningen, 22,178.646 kg/t less in CO_2-emissions incurred in scenario 1. In scenario 3, with customers distributed over the whole Netherlands, 15,567.468 kg/t more in CO_2-emissions incurred compared with scenario 1. Thus, the CO_2-emissions incurred in scenario 2 are 12 times higher than in scenario 1. Regarding scenario 3, the CO_2-emissions are almost nine times higher than in scenario 1. The comparison of the target figure 'CO_2-emissions' of the three scenarios is shown in Figure 18.

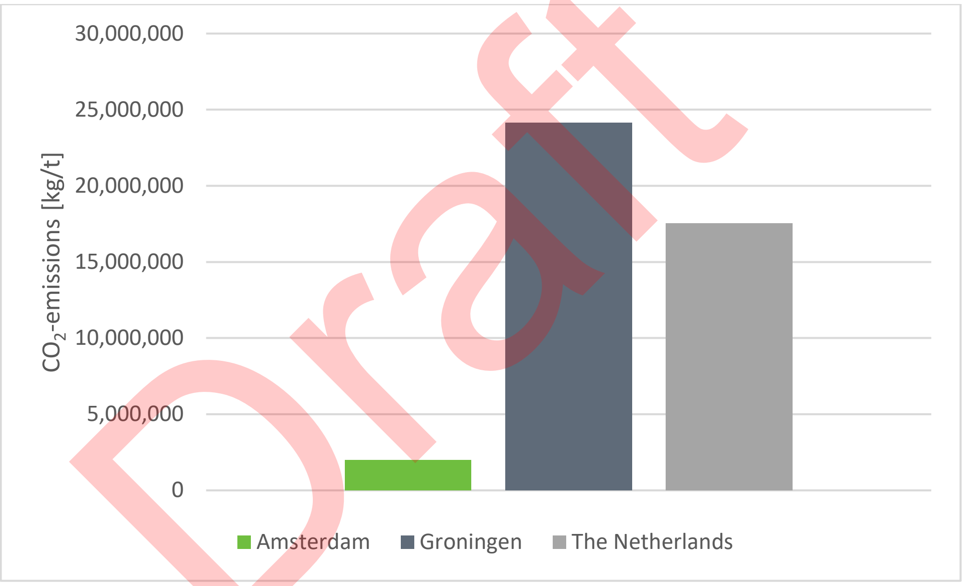

Figure 18: Comparison of the CO_2-emissions in the different scenarios

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6. Conclusion and Outlook

In Chapter 6, the findings and analysis of the simulation models are critically assessed with regard to the target figures in section 2.1. Furthermore, the chapter concludes with recommendations for further investigations for other WPs within the ReCiPSS project.

6.1. Conclusion

For the automotive spare parts demonstrator model and the white goods demonstrator model, simulation models were developed and analysed with regard to their target figures defined in section 2.1. Thereby, the ADD-algorithm was used to optimize the two systems regarding their logistic target figures.

For the automotive spare parts demonstrator model, a multi-method model was developed to evaluate the economic and environmental performance of the system as a result of increased efficiency and transparency of reverse logistic flow enabled by the cloud-based platform. Therefore, the as-is scenario, which represents the current business model, was compared with the to-be scenario.

With regard to the target figure ‘transport cost’, the transport costs in the to-be scenario could be reduced by 413,986.288 € compared to the as-is scenario. This corresponds to a reduction in transport costs of approximately 56.6 %. Also, the CO_2-emissions in the to-be scenario could be improved by 3,549.775 kg/t in comparison with the as-is scenario. Hence, the CO_2-emissions of the to-be scenario are 10.6 % less than in the as-is scenario. Due to the increased transparency in the reverse supply chain by introducing the cloud-based platform at the outlets of the wholesaler, the target figures ‘transport cost’ and ‘CO_2-emissions’ could be improved.

With the help of the simulation, it could not be proven that the transport time, the time of a core from the wholesaler outlet to the remanufacturer, improved due to the introduction of a cloud-based platform at the outlets. In the to-be scenario, the target value for transport time has deteriorated by 1.99 days compared to the as-is scenario. As already mentioned in section 5.3.4, in the to-be scenario, not all cores are transported directly to the C-ECO warehouse, but first to the wholesaler central. Direct delivery to the C-ECO warehouse which would result in a reduction in transport time depends on the number of cores arriving at the outlet. However, it is assumed that the transport time in the to-be scenario can be further reduced if a higher number of cores is transported.

Regarding the introduction of the new PPW business model, this report aims to figure out the optimal locations for storing and remanufacturing used washing machines with regard to the target figures mentioned in section 2.1. Thereby, the target figures ‘transport costs’, ‘service time’ and ‘CO_2-emissions’ of the circular supply chain were exemplary determined for the Dutch market. Therefore, three different scenarios were conducted. In scenario 1 the customers were distributed in Amsterdam, in scenario 2 in Groningen and in the last scenario the customers were randomly distributed throughout the country.

With regard to the target figure ‘transport costs’, scenario 1 with customers in Amsterdam is less expensive than scenario 2, with customers in Groningen by 24,532.922 € regarding a period of one year. Compared to scenario 3, in which customers are spread across the whole country, 15,893.617 € more transport costs are incurred compared to scenario 1.

Considering the target figure ‘service time’, the customer requests can be fulfilled in scenarios 1 and 2 within 15 hours on average. In scenario 3, customers typically have to wait 21 hours until their requests are fulfilled. In all three scenarios, Gorenje's minimum requirement of fulfilling the customer's request within 24 hours is reached on average, however, the 24-hour limit is exceeded nine times in scenario 3, four times in scenario 2, and once in scenario 1.

Regarding the target figure ‘CO_2-emissions’, 22,178.646 kg/t of CO_2-emissions incurred less in scenario 1 with customers in Amsterdam compared with scenario 2, with customers in Groningen. Compared to Scenario 3, where customers are spread all over the Netherlands, 15,567.468 kg/t more CO_2-emissions were incurred than in scenario 1.

Based on the results obtained from the simulation model, the importance of determining the optimal industrial locations for the new PPW business model is highlighted. In the considered scenarios for the Netherlands, scenario 1 with customers in Amsterdam performed most favourable.

6.2. Outlook

The findings obtained in this report can serve as a basis for further research activities within the ReCiPSS project. In this report, the automotive spare parts demonstrator model and the white goods demonstrator model were both observed during the demonstrator phase. Therefore, another approach would be to investigate the behaviour of both systems in a future scenario.

Regarding possible future scenarios of the automotive spare parts demonstrator model, additional stakeholders e.g. integrating new wholesalers or remanufacturers could be considered. Furthermore, expanding the model to other markets apart from Germany, such as France, could be another possibility to gain more sophisticated insights into the reverse supply chain. Therefore, the processes of the reverse supply chain of the respective country would have to be defined and analysed.

By upscaling the existing model, the effects on the defined target figures have to be taken into consideration. Thereby, analysing and determining possible existing and future infrastructures of C-ECO for the future scenario is necessary. For example, the need for a new warehouse, its location and size, could be evaluated.

Finally, the effects of the introduction of the cloud-based platform in the reverse supply chain can further be evaluated. By introducing the cloud-based platform, the different wholesalers are able to trade cores with each other, resulting in a competitive market among them. The wholesalers are able to buy or sell cores as well as buy or sell the option to return a core. This relationship among the wholesalers will create more dynamic in the reverse supply chain processes.

For a possible future scenario of the white goods demonstrator model, the model could be expanded with additional customers and thus washing machines. In this case, not only gold customers can be created compared to the demonstrator phase, but also silver and bronze customers. Due to the different customer types, the model becomes more dynamic because of, for example, different contract durations or more frequent contract changes.

By integrating silver and bronze customers, the focus is increasingly on the reverse supply chain activities. Thereby, the infrastructure for the PPW business model in each market has to be taken into consideration. In the future scenario, the number of retailers or remanufacturers in the system could change compared to the demonstrator phase.

In addition, further target figures for the future scenario could be introduced. For example, the target figure 'storage costs' could become more important in the future due to the return of used washing machines.

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