University of Twente
Faculty of Behavioural, Management and Social Sciences

Industrial Engineering and Management

REDESIGNING THE DUTCH RECYCLING SYSTEM FOR PACKAGING MATERIALS OF CONSUMER GOODS

Author:
Dhr. B.L.C. van Rooij

Supervisors University of Twente:
Dr.Ir. E.A. Lalla
DR. L. Fraccascia

Supervisor Jumbo Supermarkten:
Dhr. P. Krol - Supply Chain Effective Operations Manager

Date:
August 26, 2021

UNIVERSITY OF TWENTE.

JUMBO supermarkten

Management Summary

Secretary of State van Veldhoven announced the early introduction of legislation on cans as of 31 December 2022. This decision has been made because there seems to be no reduction of empty beverage cans in litter. To be able to guarantee a desired implementation of the phase-in of such a system and achieve the goal of reducing empty beverage cans in litter, Jumbo wants to investigate the possibilities for such a system. How such a system is designed, directly affects the business of Jumbo and other supermarkets by affecting the cost of investments, transportation and handling of these returned empty beverage cans.

We used a problem cluster to identify the core problem from the central problem, as perceived by Jumbo. The central problem is the fear of becoming waste centres in the future. This is a result of the idea of Jumbo that the Dutch Government will introduce more legislation on packaging materials in the near future. This however, is accepted to be an uninfluenceable problem. However, since there are already some legislations in place it could be obvious to add new legislations on packaging materials to the already existing system. This would not only lead to larger return volumes, space occupation and handling but also hygiene aspects and the possible attraction of diverse pests. An action problem is described as a perceived discrepancy between norm and reality. This discrepancy is that in reality there is currently no low-threshold unambiguous system that recycles packaging material taking the requirements of supermarkets into consideration. The norm is to recycle 90% of the sold beverages in cans in a way that is accepted by supermarkets, producers and the government. Therefore Jumbo wants to investigate the options of recycling packaging materials in several ways and thereby solving the core problem of not having this low-threshold unambiguous return system for empty packaging material. In order to solve this problem, the following main research objective was formulated for this study:

Designing and implementing the reverse logistics of empty beverage cans in a closed-loop cycle with the aim of minimizing costs while taking the requirements of the stakeholders into account

In order to find a starting point for this objective and find out the relevant stakeholders and their requirements, interviews have been conducted. Furthermore, several insights were gained from literature. Since this problem has not been described thoroughly in current literature, we had to pioneer through this process. Based on literature we decided to combine several problem solving methods for the supply chain network design. Interesting insights from facility location problems, reverse logistics, circular economy and optimization techniques were combined into a mathematical model. The model minimizes the total cost incurred for opening locations, installing RVMs and compactors at these locations and assigning a distribution centre to these locations all while taking capacity constraints into account. These capacity constraints can be broken by incurring a penalty cost. During some trial and error, we seemed to be unable to solve this mathematical model using a linear programming solution approach. We therefore divided our solution approach into two phases, thereby introducing our two-phase solving approach. In this approach we split the problem in two. In the first phase we optimize the technologies to be installed at the locations, for each of the scenarios. In the second phase, we use Simulated Annealing in order to find the best possible location-distribution centre combination which respects the capacity constraints.

The second-phase of the problem solving method used the Simulated Annealing method, one of the most popular iterative methods applied in research to many combinatorial optimization techniques. The SA method is based on random local search techniques inspired by principles of physics. Despite the fact that the use of SA in the design of reverse logistic networks is scarce, we proceeded with this approach due to its simplicity and speed over other proposed methods. In SA algorithms, neighborhood searches are used in order to evaluate the solution space of the problem. After some experimenting with several approaches, we proceeded with variable neighborhoods. The SA-VN algorithm was extended with a parameter k for regulating the change of the neigborhood structure. We apply the k-swap, that is given a solution, the swap neighborhood performs the transposition by swapping a location-distribution centre combination. When no better solution is accepted, we expand the neighborhood by increasing k.

The proposed SA-VN is of course tested before put to practice. For each of the scenarios the SA-VN was able to improve on the initial solution, as can be seen in the table below. Only for scenario 2, in which the use of compactors in prohibited, the SA-VN could not improve much on the initial solution. For the rest of the scenarios, the SA-VN was able to improve about 25%.

Table 1: Number of instances per scenario and the improvement on each of the initial solutions.

Scenario	Number of instances	Improvement on initial solution (in %)
1	700	28%
2	700	1%
3	1000	24%
4	1000	23%

We furthermore used Monte Carlo Simulation to study the robustness of the proposed designs and evaluate the effect of stochasticity on the solutions. The stochasticity was introduced on two parameters, namely the amount of returned used beverage cans and the actual capacity at both the locations and distribtion centres. Exceeding the capacity resulted in penalties, which influenced the total cost of the solution. The Monte Carlo Simulation was done extensively for 10.000 runs in order to eliminate the possibility that the results depend on the randomness of the simulation.

Table 2: Average of Monte Carlo Simulation experiments for each of the scenarios.

Scenario	Stochastic Parameter	Median	Penalty
1	UBC	73497200	16,16%
1	Capacity	72286952	10,93%
2	UBC	141302430	9,97%
2	Capacity	139312249	9,13%
3	UBC	115730031	24,52%
3	Capacity	113979252	22,64%
4	UBC	152333615	17,07%
4	Capacity	149594373	18,54%

It can be clearly seen from Table 2 that the scenarios 3 and 4 with more locations incur a higher cost. However, this can be partially explained by the fact that the same amount of distribution centres were used for this calculation, with the same capacity. It can further be noticed that the experiments with stochastic capacity on average incur a lower penalty cost as a portion of the total cost.

All things considered this study has been pioneering on the frontier of both literature regarding recycling systems and supply chain network design for such recycling systems. This study has presented a modification to existing solving methods for an extended facility location problem. More specifically, we presented a two-phase solving approach that can be extended to implement recycling systems on large scale. This study not only contributes to knowledge on recycling and supply chain network design, but also suggests various practical insights for managers of both public and private organizations such as supermarkets. This study considers the technologies to install at locations and thereby provides a starting point for studies on facilities, fleet size, vehicle allocation, route planning and further decision making. Based on these results we would suggest Jumbo to collaborate with other parties in getting further insights in possibilities. However, we would suggest to implement scenario 3 in which a nation wide solution is provided not only including supermarkets but also out of home sales locations. This with the use of compactors in order to provide efficient transportation of the used beverage cans.

Preface

Hereby I present you my Master Thesis, which finalizes my Master in Industrial Engineering and Management at the University of Twente. The past few years I have been a student in Enschede. I look back on a great time in Twente, but on the other hand I am happy that this Thesis marks the end of my studies. In the past years I have been able to develop myself in various ways, and now I can look back on a very enjoyable time. I am also looking forward to the future and all its challenges and opportunities it will provide me with.

First of all, I would like to thank Eduardo Lalla, which I first met during the Transportation and Logistics Management course and has been my supervisor for the last months. Despite his busy schedule, he always finds time to support me in providing a better Thesis. His support, belief and encouragement has enabled me to provide you with this report. Secondly, I would like to thank Luca Fraccascia for his expert view on the circular economy. During our Teams sessions, you always expressed unprecedented enthusiasm. In addition I would like to thank Pier Krol from Jumbo Supermarkten for providing me with this opportunity.

I would like to thank my girlfriend for her positivity during my studies. Last but not least I would like my mother, father and brother. Even though you didn't know what I was doing exactly, you always listened enthusiastically to my stories, provided me with encouraging words and helped me in every way you could. All four of you supported me through ups and downs during my studies.

I hope you enjoy reading this report. And remember, you can do anything if you keep pushing!

Best regards,

Bas van Rooij

List of Abbreviations

Abbreviation	Definition	First mention on page
PuP	Pick up Point	1
HD	Home Delivery	1
PET	Polyethylene terephthalate	1
RL	Reverse Logistics	2
UBC	Used Beverage Cans	2
GHG	Green House Gas	2
RVM	Return Vending Machine	3
DC	Distribution Center	3
CBL	Centraal Bureau Levensmiddelen	7
FWS	Nederlandse vereniging Frisdranken, Waters, Sappen	7
FNLI	Federatie Nederlandse Levensmiddelen Industrie	7
SRN	Stichting Retourverpakkingen Nederland	7
SAV	Stichting Afvalfonds Verpakkingen	7
EoL	End-of-Life	9
HACCP	Hazard Analysis and Critical Control Points	10
NFC	Near Field Communication	10
FTE	Fulltime-equivalent	10
JIT	Just in Time	10
MSW	Municipal Solid Waste	12
ISWM	Integrated Solid Waste Management	13
LCA	Life Cycle Assessment	13
WM	Waste Management	13
SCND	Supply Chain Network Design	14
MRS	Material Reutilization Score	17
MR	Material Reutilization	17
RC	Recycled Content	17
CVRP	Capacitated Vehicle Routing Problem	20
VRPTW	Vehicle Routing Problem with Time Windows	20
SCM	Supply Chain Management	20
FL	Facility Location	21
CLSC	Closed-Loop Supply Chain	21
ROI	Return on Investment	22
KPI	Key Performance Indicator	23
OEM	Original Equipment Manufacturer	23
SAA	Sample Average Approximation	25
SA	Simulated Annealing	25
VNS	Variable Neigbhourhood Search	25

List of Figures

Contents

1 Introduction

This report describes the result from my graduation assignment of the Master program Industrial Engineering and Management (IEM) at the University of Twente conducted at Jumbo Supermarkten (from here on: Jumbo). This research describes the redesign of the reverse logistics for products with legislation. More specifically, it focuses on the reverse logistics for empty beverages cans.

This chapter starts in Section 1.1 with an introduction of the company Jumbo. In addition, a research motivation is given in Section 1.2. Section 1.3 covers the problem statement including a problem cluster and definition of the core problem. Section 1.4 outlines the research objective including the main research question and scope. Section 1.5 finalizes and summarizes the chapter by describing the research design, questions, approach and deliverables.

1.1 Company introduction

It all started in 1921 when Johan van Eerdt opened his wholesale in colonial goods located in Veghel. Fast-forwarding to the 60s the first supermarket was opened under the name of Kroon by Karel van Eerd. During the 70s, several acquisitions of other wholesalers expanded the market area towards the provinces of Limburg, West-Brabant and Zeeland. The first supermarket using the name Jumbo opened in 1983 in Den Bosch, more followed later in the 80s. At the beginning of the 90s, Karels' children (Frits, Colette and Monique) made their entry into the business and together they develop the new Jumbo customer-centric formula: the seven daily certainties which are guarantees for the customer and at the same time provide tools for the employees to help these customers as good as possible. In 1997, one year after the introduction of this new formula, Jumbo is awarded the Gfk rapport which indicates that the customer appreciates the newly introduced formula. In 2007 the 100th Jumbo is opened and a year later the Jumbo private label is introduced. After several acquisitions throughout the years, the 500th Jumbo was opened in 2015 while shortly before the first Pick up Points (PuP) for online grocery orders are launched. From that moment on some changes follow each other in rapid succession such as several new acquisitions, the start of Home Delivery (HD) and Jumbo goes international and sets foot in Belgium. In 2021 Jumbo will celebrate its centenary being the second largest supermarket chain in the Netherlands with over 680 store locations, having almost 100.000 employees and an annual revenue of €9,68 billion in 2020 which accounts for a market share of 21,5% after showing incredible autonomous growth, which is displayed in Figure 1.1.

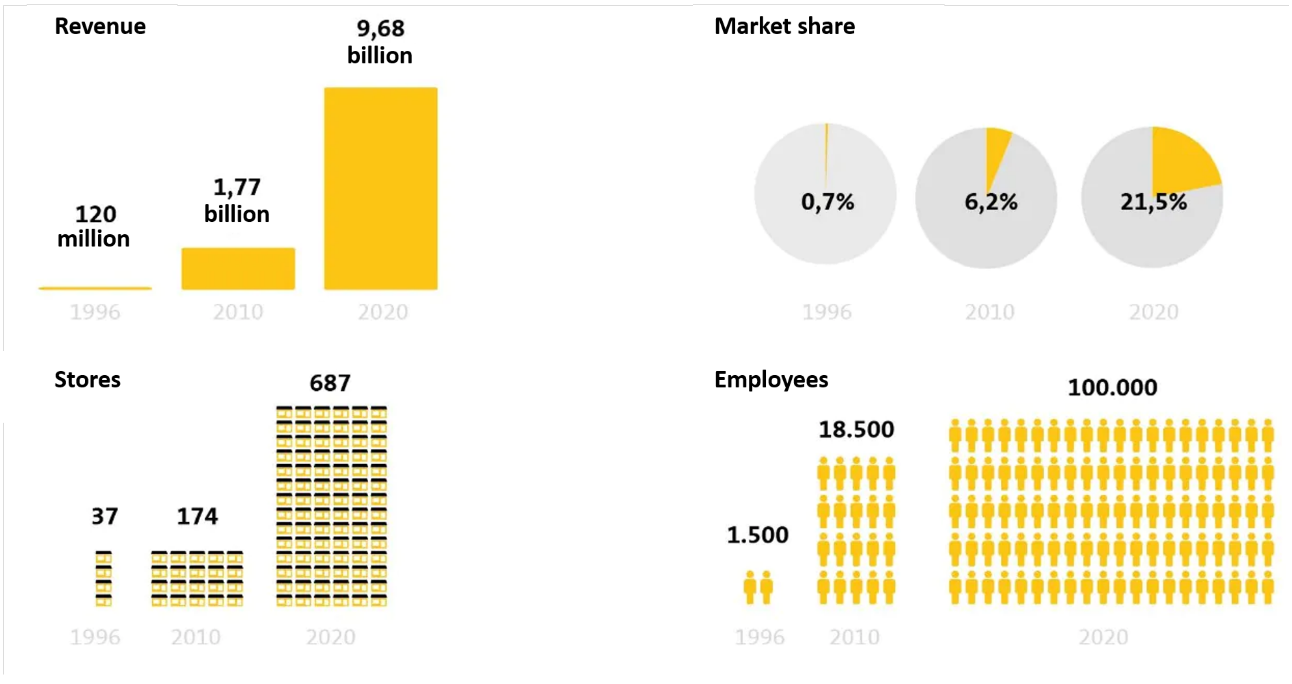


Figure 1.1: Growth of Jumbo throughout the years.

Although this assignment is performed at Jumbo, the results of this report are not only limited to Jumbo but can by applied to a nationwide system for the return of used beverage cans when legislation is in place.

1.2 Research Motivation

An area of increasing concern, both nationally and worldwide, is the potentially negative environmental damage due to improper waste disposal (Wright, Richey, Tokman, & Palmer, 2011). On behalf of the Dutch Government research is done in order to find the main indicators why litter should be dealt with, forming the foundation of the legislation on small polyethylene terephthalate (PET) bottles which is introduced at the first of July 2021. On top of that, as of the 3th of February 2021, it is stated that legislation on cans will be in place as of the 31th of December 2022. Resulting from the research done by the Dutch Government, the previously mentioned indicators are liveability, the health of humans and nature and circular economy (Warringa, Boeren, van de Water, Bergsma, & Rozema, 2018). In order to come up with these indicators, some definitions need to be provided. Litter is defined as "*waste that is intentionally or unintentionally thrown away or left behind at places that are not intended for waste disposal, with the exclusion of cigarette butts and chewing gum*". According to research done in the Netherlands, litter originates from different causes. It mainly stems from three reasons: (1) the lack of effective waste management i.e., absence or a lack of waste collection infrastructure on the streets, (2) apathic behaviour by people, and (3) a lack of knowledge about their potentially harmful behaviour. Liveability is defined as the "*degree to which the environment meets the requirements and wishes set by people*". The health of humans and nature concerns "*all harmful effects such as physical and chemical, on nature, the environment and human health caused by foreign substances in organisms*". The circular economy is specified as "*an economy in which raw materials are re-used efficiently in order to reduce to use of new raw materials*" (Hoppe, Bressers, de Bruijn, & Franco Garcia, 2013; Warringa et al., 2018).

Since the indicator of liveability was broadly set to meeting the requirements and wishes set by people, it can be said that it includes several social impacts such as reduced benefits from the environment and well-being losses from living in a polluted and degraded environment (Watkins et al., 2015). Besides reduced liveability, the taxpayer pays the bill of litter collection since most costs for cleaning pollution caused by litter are made by municipalities in the Netherlands. Moreover, most people are aware of the potential harmfull consequences of litter since it is in the top three of perceived environmental problems (Hoppe et al., 2013). Consciousness of the presence of litter matters a great deal to most people since the presence of litter lowers behavioural thresholds resulting in the thought that it is acceptable to leave litter behind themselves. Therefore, studies show that people are more prone to accept the idea that littering is socially acceptable and thus creating a vicious cycle (Forbes, 2009). Not only the aforementioned problems play an important role, additionally roadside litter is a significant source for accidents resulting in car damage and injuries (Hoppe et al., 2013).

Additionally, grazing livestock can swallow (parts of) cans, bottles or glass when they are in the pasture. In addition, many of these animals are fed with harvested grass which is mechanically chopped after harvesting which sometimes results in sharp parts that remain in the hay. The litter ends up in one of the stomachs of the cattle where it can subsequently cause injury known as "*sharp-in*" resulting in wounds, inflammation, other complications such as reduced milk production and even death. The consequences of the injury entail suffering for the animals and can cause financial suffering for farmers. Most farmers believe that injury and death of their livestock is caused by cans, PET and glass coming from passers-by and tourist who throw empty packages into nature. However, the scientific literature in this area is sparse (van der Bles, 2018). Despite the scientific sparseness, it cannot be denied that that litter causes problems in various areas. According to farmers the non-magnetic cans are in particular criticized as a major cause of the problem. Few farmers have a shredder with a magnet to attract metal objects and prevent that sharp metal pieces reach the grass used for feed, however since many cans are made of non-magnetic materials, such as aluminium, sharp materials still end up in the feed of the livestock (van der Bles, 2018). Besides serious injuries to livestock, litter is harmful to human beings in various forms, particularly causing physical injuries. For instance to people which collect litter in city centres and along roadsides, when accidentally hurting themselves during their work (Hoppe et al., 2013). On top of that, litter often accumulates in waterways that stream towards lakes and oceans forming the so called 'plastic soup islands' where these can break down into harmful small particles (Hoppe et al., 2013).

The current day linear economy in which resources are extracted to make products which are discarded at their end-of-life, is more shifting towards the concept of a circular economy (Niero, Negrelli, Hoffmeyer, Olsen, & Birkved, 2016; Niero & Olsen, 2016). This economy aims to decouple economic growth from resource constraints mainly because the linear economy faces two major problems, namely the increasing scarcity of resources for raw materials and secondly increasing amounts of waste. Besides commercial motivations for shifting towards a circular economy like enhanced reputation and closer relationships with customers, the business motivations are drivers too. As an example there are economic advantages such as cost reductions, new revenue sources and employment creation. However, there are several challenges associated with such a circular economy like non-adapted reverse logistics (RL). Single companies cannot establish a circular system on their own; they need other stakeholders to collaborate in the alignment across companies and support the newly formed financial models. Simple aspects include collaboration between packaging suppliers to use packaging materials developed for optimal recycling while maintaining the quality of the product. Aluminium cans are one of the packaging materials that are considered to have good circularity potential since these are simple products, meaning they do not need much processing in order to be recycled (Niero et al., 2016). Niero and Olsen showed a lower impact for working with used beverage cans (UBC) over producing new cans from aluminium as a scrap source (Niero et al., 2016). Besides tackling the scarcity of resources by using a closed-loop approach, the emission of greenhouse gases (GHG) and use of energy can be greatly reduced by recycling of post-consumer scrap. This is predominantly available in the form of UBC since packaging serves as the second largest source of aluminium scrap worldwide (Niero et al., 2016; Muchová & Eder, 2010). An increase in collection rate is suggested to be the most effective solution to reduce environmental impact of beverages packed in aluminium cans (Detzel & Mönckert, 2009; Stichling & Nguyen-Ngoc, 2009). In order to retrieve and recycle these packaging materials, efficient collection systems are needed since the consumption takes place far from their point of origin (EMF, 2013).

Both the previous paragraphs contained compelling arguments for the minister to introduce a new legislation on small PET bottles as stated in section 6 of the Dutch Decree on packaging and packaging waste which provides for a deposit-refund scheme for drinks packaging such as PET. Generally, these systems lead to high return rates and a reduction of littering. Nevertheless, the handling and administration costs can be substantial (Linderhof, Oosterhuis, van Beukering, & Bartelings, 2019). The legislation includes a deposit (Dutch: statiegeld) of €0,15 on PET bottles with a content smaller than 1 litre. The decision to implement this legislation puts an end to 20 years of discussion about deposits on plastic bottles and cans. Currently there is already a legislation of €0,25 on PET bottles larger than 1 litre and €0,10 on glass (beer) bottles. Before the legislation came into place diverse companies such as supermarkets, producers and wholesalers made agreements with the Association of Dutch Municipalities in order to reduce the plastic bottles in litter by at least 70%. If this was not achieved, a deposit would be introduced. Since this was the case, a deposit on small plastic bottles was introduced in order to keep plastic bottles out of the environment. Around 900 million small PET bottles are sold annually in the Netherlands of which an estimated 100 million end up in the environment. An estimated 90% of all plastic PET bottles will be returned using the deposit refund system. The next step against litter that is taken by the Dutch State Secretary of Infrastructure and Water Management is to reduce the number of cans in the environment by at least 70%. However, the Dutch State Secretary does not provide supermarkets, producers or consumers any information on how to achieve this. If it appears in the autumn of 2021 that these goals are not being achieved, a deposit will also be introduced on cans in 2022.

Secretary of State van Veldhoven announced the early introduction of legislation on cans as of 31 December 2022. This decision has been made because there seems to be no reduction of empty beverage cans in litter. In the Netherlands there are 2 billion cans sold annually of which about 150 million end up as litter in nature. This is in line with statistics of the plastic soup foundation. According to this foundations research done in 2013, one out of five sold cans end up in nature as litter (Foundation, n.d.). They furthermore claim that on average every Dutch inhabitant throws about 6 cans per year into nature. This foundation did extensive research and counted all of the empty beverage cans they encountered as litter. Red Bull, Heineken and Coca Cola account for over a third (36.5%) of all encountered cans. Resulting from these facts, several arguments of the research motivation and the inescapable legislation to be in effect, we define the exact problem statement in the next section.

1.3 Problem Statement

Using a problem cluster, several connections between core problems and their causes can be identified in order to find a solution to these problems. The identified core problems are the source of the central problem (Heerkens & van Winden, 2017). From the problem cluster, it can be concluded that there is no single cause for any of the problems within the cluster. Furthermore, the complex cause-and-effect relationships make it very hard to pinpoint the core problems. The problem cluster can be found below in Figure 1.2.

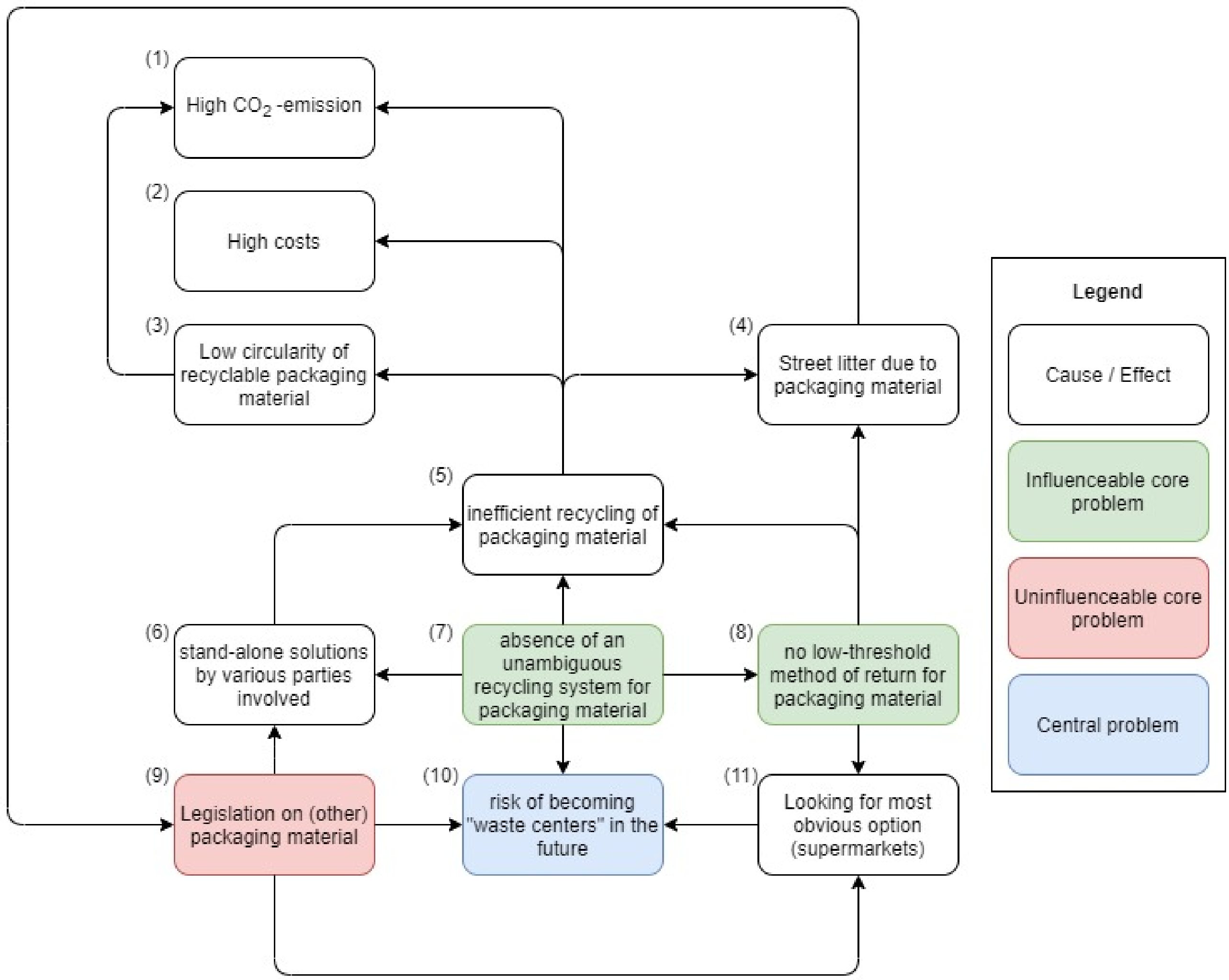


Figure 1.2: Problem cluster of Jumbo

The central problem arises from several aspects which are not explicitly stated in the problem cluster. Several hygiene aspects such as food safety is one of the reasons why Jumbo would prefer to investigate options for the return of packaging material outside of the supermarkets. Since for example empty beverage cans almost always have some residue left inside, this sticky and sugary residue can attract pests such as wasps or in worse cases mice and rats. Since supermarkets and their distribution centres deal with a lot of food often in close proximity of these empty cans this can have disastrous effects on the safety of this food. As a result, supermarkets need to invest more in the hygiene and cleaning of these return vending machines (RVM) and processing locations within the distribution centres (DC). Therefore, the central problem in this research depicted in blue is described as (10) the risk of becoming waste centres in the future.

At Jumbo they foresee that the Dutch Government will introduce more legislations on packaging materials (9) in the future. However, this is accepted to be an uninfluenceable problem by the fact that the government decides on this and therefore the problem is marked red. Since there is already a working legislation and return system for PET bottles currently in place, it could be obvious to add new (11) legislations on packaging material to the already existing system. This would lead to larger return volumes, space occupation and the forementioned attraction of diverse pests.

Furthermore, adding new legislations on packaging material could possibly lead to (6) stand-alone solutions by various parties involved which in turn could lead to (5) inefficient recycling of this packaging material. Since there is no (7) unambiguous recycling system for packaging material the (8) threshold for recycling packaging materials can be too high for consumers resulting in (4) more street litter or processing in normal waste.

In order to achieve the Dutch governments' intended environmental lightening, the proposed manner of returning packaging material should have a low threshold (Warringa et al., 2018). An introduction of such a (8) low-threshold method of return for packaging material could possibly be (11) looking for the most obvious option which is returning this material to the supermarkets, marked as a green influenceable core problem. This is exactly (10) what supermarkets see as a risk, that they become the waste centres in the future. Therefore, Jumbo would like to encounter this problem by introducing a new kind of low-threshold method for returning empty packaging material.

Beside this risk for supermarkets, (5) inefficient recycling of packaging material leads to (3) low circularity of this recyclable material which in turn leads to (2) high CO_2-emissions, (1) high costs and possibly (4) more street litter which strengthens the introduction of (9) new legislations on packaging material.

An action problem is described as a perceived discrepancy between norm and reality. This discrepancy is that in reality there is currently no low-threshold unambiguous system that recycles packaging material taking the requirements of supermarkets into consideration. The norm is to recycle 90% of the sold beverages in cans in a way that is accepted by supermarkets, producers and the government. Therefore Jumbo wants to investigate the options of recycling packaging materials in several ways and thereby solving the core problems of not having this low-threshold unambiguous return system for empty packaging material. The resulting action problem from this problem cluster is combined of (7) the absence of an unambiguous recycling system for packaging material and (8) the absence of a low-threshold method of return for packaging material. The resulting core problem of this action problem as described in the problem cluster, is the (10) risk of becoming waste centres in the future.

1.4 Research Objective

Based on the problem described in the previous section, the goal of this research is to provide a quantitative and qualitative comparison of different methods for the reverse logistics of empty beverage cans in a closed-loop system. Therefore the main research objective is described as:

Designing and implementing the reverse logistics of empty beverage cans in a closed-loop cycle with the aim of minimizing costs while taking the requirements of the stakeholders into account.

Due to time restrictions, the research is focused on designing and implementing the reverse logistics of empty beverage cans rather than redesigning the complete reverse logistics of all possible packaging material, such as for example PET bottles and glass jars.

1.5 Research Design

The central problem emerges from multiple core problems of which some are hard to influence and therefore are not in the scope of this research. For solving the research objective as stated in Section 1.4 above, the following questions have to be addressed:

1. **What are the requirements and constraints of the proposed system according to the different stakeholders?**
   1.1. *What is the current situation regarding legislation on consumer beverage goods, and how does the reverse logistics work?*
   1.2. *Which stakeholders are involved in the process of recycling empty beverage cans?*
   1.3. *What are the requirements and constraints in the process of recycling empty beverage cans according to these stakeholders ?*

   Chapter 2 will cover the answers to question 1 and its sub-questions. In order to investigate possible solutions to the problem, a good clarification of the requirements and constraints by all stakeholders is needed. Furthermore, answers to these questions will shape the current situation regarding important information such as the volumes of cans the system has to be able to deal with and, as mentioned before in Chapter 1, important indicators like hygiene aspects.

2. **What information is available in current literature regarding the circular economy, reverse logistics, supply chain network design and multiple criteria decision making?**
   2.1. *What are characteristics of the circular economy and how do they fit into a system for the reverse logistics of used beverage cans?*
   2.2. *What elements of reverse logistics are applicable for the return of used beverage cans?*
   2.3. *What elements of Supply Chain Network Design are applicable to a reverse logistics system for used beverage cans?*
   2.4. *What key performance indicators relevant to reverse logistics are commonly used to optimize?*

2.5. *What optimization techniques are available in literature for reverse logistic systems?*

Chapter 3 consists of a comprehensive literature review to provide answers to question 2. By answering sub-questions 1, 2 and 3, several essential insights about the available information are obtained. These insights together with the requirements and constraints from Chapter 2 result in key performance indicators for which several possible optimization techniques will be evaluated in sub-questions 4 and 5 respectively. Finally some methods of multiple criteria decision analysis will be evaluated in order to score the possible outcomes for such a system.

3. **In what way can the found information in literature be used to propose a closed-loop system for the reverse logistics of empty beverage cans?**

3.1. *What elements from the literature regarding closed-loop systems, reverse logistics and supply chain network design can be used and applied to a solution for the system of recycling used beverage cans?*

3.2. *Which key performance indicators should be included in the proposed solutions and how should the system be optimized?*

The literature found in the previous chapter will be used to develop several systems for the return of empty beverage cans, which will be discussed thoroughly in Chapter 4. As a result of this question, several options will be presented which are discussed in the next chapter.

4. **What outcomes can be expected from the proposed solutions found in the previous question?**

4.1. *Which solution is most robust to changes?*

4.2. *What capacity is required in the proposed solutions?*

4.3. *What costs are associated with the proposed systems?*

The outcomes of the solution designed in Chapter 4 will be presented and discussed in Chapter 5. Furthermore, a Monte Carlo Simulation is conducted to analyse the robustness of the presented solutions.

2 Current Situation and Stakeholder Analysis

This chapter starts with description of the current situation regarding legislation on consumer beverage goods and the reverse logistics concerning these goods in Section 2.1. Next, a stakeholder analysis is done in Section 2.2 in order to identify potential key players within the project. Each of these stakeholders can have different requirements and constraints. This chapter will provide an answer to the following research question:

- **What are the requirements and constraints of the proposed system according to the different stakeholders?**

2.1 Current Situation

What is the current situation regarding legislation on consumer beverage goods, and how does the reverse logistics work?

The consumption of packaged beverages has risen steadily in the last years and therewith the amount of empty beverage packaging has also increased. According to several statistics, these beverage packaging accounts for up to 63% of the urban solid waste and about a quarter of the marine garbage (Foundation, n.d.). The increased amount of these empty beverage has risen major environmental challenges. Simultaneously, empty beverage packaging has resource value if it is possible to collect and recycle these effectively. To provide the collection and recycling of the empty beverage packaging, many countries including the Netherlands have built economic instruments such as a deposit-refund system which is the main desired method since it has good economic benefits while effectively recycling a large number of beverage packaging. The basic principle of all beverage packaging deposit-refund systems is similar, that is to return the deposit that the consumer pays when they bring the empty beverage packaging at a recycling location. The deposit-refund system needs participation of all stakeholders in order to succeed.

The aim of all legislation systems is to encourage consumers of beverages to increase and facilitate the redemption of empty beverage packaging such as UBC. The deposit-refund system needs to be a complete system for the empty beverage packaging. Several key success factors, as described in Section 3.1, are critical to the succeeding of the system. The reverse logistics mode depends mainly on existing logistics of the system, therefore the pressure on transportation is fairly low. On the other hand, the responsibility of the producer is higher in such a system. Since this requires recycling at the retailer level, it increases the convenience for consumers but retailers need to allocate certain space for recycling. The retail recycling mode can be relatively small and therefore the burden on retailers can be reduced. This mode of recycling is very convenient for consumers, especially those who redeem small numbers of empty beverage packages. It is also cost-effective since most retail facilities are already set-up for some type of recycling. However, the burden on transportation can be high. The kerbside recycling mode can reduce the burden on retailers since new collection sites must be built. The consumer convenience depends on the number of collection sites built and their proximity for the customers.

Currently, as stated in the introduction in Section 1.2, there is already a legislation on PET bottles in the Netherlands. At present these PET bottles and beer crates are handed in at Return Vending Machines (RVM) in supermarkets which are transported back towards DCs of these supermarkets. From there on, the PET bottles which are collected in BigBags are sent towards counting centres where they are further processed. This system will be extended with small PET bottles as of the first of July of 2021. Most RVMs in the Netherlands look the same, with an opening for bottles and a lower part for crates of beer. A typical RVM can be seen in Figure 2.1 shown below. After a consumer returns the empty PET bottles, they are taken in by the RVM. Most of the sorting is done automatically nowadays by a special bottle elevator. What happens behind the scenes of a RVM is illustrated in Figure 2.2. By use of an automated bottle elevator or by hand, the PET bottles will be put into a standardized BigBag for transportation. This BigBag can be seen in Figure 2.3.

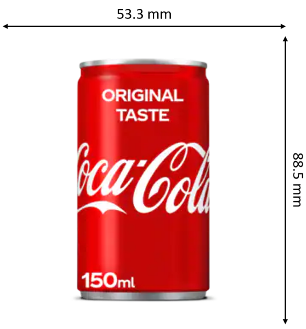
On top of that the legislation will be extended towards beverages sold in cans as well. It is not yet sure if the current system will be extended with cans or that cans will be taken back in a new system. It is yet unclear which beverage cans will be subject to legislation. It could be possible that beverages in the dairy, fruit and vegetable drinks are an exception to the legislation. Furthermore, it could be possible that only cans with a minimum volume of 250ml will be subject to legislation. In Figure 2.4, we can see the different sort of cans

Figure 2.1: Typical RVM inside a Dutch Supermarket

Figure 2.2: Behind the scenes of a typical RVM

Figure 2.3: Standard 800L BigBag with label

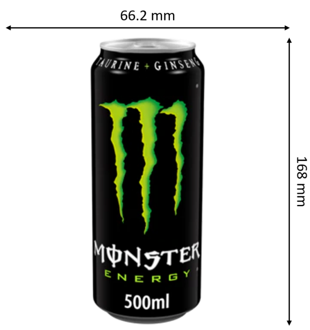
that the (new) system has to be able to deal with. The cans will have volumes ranging from the smaller 150ml to the well-known 250ml can and up to the 500ml versions including everything in between. The height and width of the cans as displayed in the figure, are based on the information provided by Ball Packaging which is the world's leading provider of innovative and sustainable aluminum packaging for beverage.



(a) Small can of 150ml.

(b) Average can of 250ml.

(c) Average can of 330ml.



(d) Big can of 500ml.

Figure 2.4: Illustration of the different cans sold in the Netherlands.

2.2 Stakeholder Analysis

Which stakeholders are involved in the process of recycling empty beverage cans?

A stakeholder is defined as: "*any individual or group that can affect or be affected by an organization*" (Freeman, 1984). Stakeholder analysis is an approach for generating knowledge about the role of different participants involved in the process. The information gained from this analysis can be used to facilitate the implementation of projects and support decision making regarding these projects. The level on which the analysis takes place - local, regional, national or international - influences who to consider as a stakeholder (Varvasovszky & Brugha, 2000). The role of the stakeholder is identified using the three attributes: power, legitimate and urgency (Mitchell, Agle, & Wood, 1997). Power can be described as the possibility to carry out your own will, or to get another actor to do something that this actor normally would not have done. This power can be based on coercive, utilitarian or normative power. Legitimacy is defined as the assumption that the actions of an stakeholder are desirable or appropriate within some socially established system of norms, which implies that legitimacy is a social good. Urgency is defined as the relationship being important or critical to the stakeholder, which is based on time sensitivity and criticality. In other words, urgency is the degree to which the stakeholder claims call for immediate attention (Mitchell et al., 1997; Co & Barro, 2009).

The first step of the stakeholder analysis is to identify the different elements of the problem so that the positions of the stakeholders relative to this problem can be mapped out. The stakeholders can roughly be classified as consumers, producers and wholesalers (mentioned as suppliers in Table 2.1), sales location and others. From several expert opinions and looking carefully at sales data from Jumbo we can distinguish several stakeholders which are grouped according to the following table:

Table 2.1: Overview of the found stakeholders. The asterisk (*) behind several stakeholders indicates that an interview with this stakeholder has been conducted.

Sale locations	**Suppliers**	**Others**
Out-of-Home	Bidfood	Central Bureau for Food Trade (CBL)*
Catering Companies	Coca-Cola*	Dutch Association of Soft Drinks, Water, Juices (FWS)
Fast Food and Cafetaria	CRAFT Breweries	Dutch Federation of Food Industry (FNLI)
NS-Stations	Dutch Breweries	Dutch Government
Petrol Stations	Lekkerland*	Dutch Return Packaging Foundation (SRN)*
Supermarkets	Sligro	Packaging Waste Fund Foundation (SAV)
Albert Heijn	Unilever	
Aldi	United Soft Drinks	
Jumbo*	Vrumona	
Lidl*		
PLUS*		

These stakeholders are not all of equal importance. Therefore as a second step, the found stakeholders will be prioritized by assessing their level of interest and influence. The influence of and impact on stakeholders is determined according to expert opinions, which are determined via interviews.

2.3 Requirements and Restriction Analysis

Both requirements and restrictions have a lot of overlap, for instance one stakeholder beliefs that something is a requirement, the other beliefs this to be a restriction of the system. Due to this contradiction, both the requirement and restriction analysis are done in the same section. Therefore, this section provides an answer to both of these research questions:

- *What are the requirements for such a system for each of the stakeholders?*
- *What are the constraints or restrictions for such a system according to each of the stakeholders?*

In order to answer both questions, as stated before, several interviews were conducted with stakeholders in which their input is treated anonymously and confidential. Therefore it will not be stated what is exactly said by whom, but the interviewee are rather called "*producer*", "*supermarket*" or "*organization*". In total seven interviews were conducted.

First of all an interesting argument about litter was mentioned by one of the organizations. In the previous chapter, litter was defined as waste that is intentionally or unintentionally thrown away or left behind at places that are not intended for waste disposal. This organization however stated that not all waste that is left behind intentionally or unintentionally should be classified as litter. For instance, some activists clean up city centres or roadsides. In the view of this organization, this should not be classified as litter since it is eventually cleaned up. They define litter as "*waste that is really not cleaned up*". Furthermore it was mentioned that primarily legislation underlies for the requirement to recycle about 90% of the used beverage cans. However, when do we count an UBC to be recycled? After direct disposal in a for this purpose intended machine, or when someone who scrapes the city centres and roadsides hands in these UBC in a for this purpose intended machine?

One commonly heard argument mostly from the supermarket side is that the hygiene aspects are considered a bottleneck when the UBC are returned in a RVM in the supermarket. Since a UBC cannot be sealed after use and almost always has some residue left inside, supermarkets are concerned that Hazard Analysis and Critical Control Points (HACCP) will be difficult to live up to. This however is countered from by an organization saying that in the Nordic countries such as Norway, Sweden and Finland as well as Germany, empty beverage cans are a part of the system for many years now and they handle these HACCP standards as well while returning UBCs via RVMs in supermarkets. On top of that, the current PET needs HACCP standards as well. Besides that, the HACCP standards do not change if we take back UBC in RVMs outside or inside of the supermarket. However, when taking the reverse logistics in account we can take the UBC to DCs by the same transport as other return goods. However, again due to the residue the semi-trailers need more intensive and frequent cleaning in order to meet the HACCP guidelines. Especially in the Nordic countries this is arranged through a cost and process effective manner. On a side note, the Netherlands has relatively more smaller supermarkets compared to both the Nordic countries and Germany, especially in city centres. Most of these supermarkets do not have the luxury of unused square footage for extra RVMs and space occupation for the returned UBCs. This is agreed upon by both organizations and supermarkets.

Regarding the accessibility for consumers both supermarkets and organizations agree that threshold should be low in order to succeed with a 90% collection rate. Both stakeholders bring forward that the relationship between legislation on UBC and the moment of use is of critical importance to succeeding. In order to obtain high customer satisfaction and therefore participation, one organization beliefs that we should keep an accessible system. One of the ideas was for instance to introduce high-tech payment methods, for instance using near field communication (NFC) or return pins when a consumer returns the UBC. On the other hand, we cannot exclude customers who are new to this sorts of technology. Therefore the traditional paper receipt will probably not disappear yet.

Another point that was mentioned by supermarkets and organizations is the counting of UBCs taken up by the RVMs. This is mostly an important financial structure which should be robust enough to tackle fraud. In order to overcome the problem of possible fraud, the returned UBC can be compressed which reduces the potential value of the UBC to zero. Furthermore, if we use barcode scanning in order to identify the UBC, the scanning of the barcode has been made impossible. On top of that this, partly tackles the problem of space occupation as well. Additionally, the UBCs account for large volumes. When transporting these uncompressed we transport a lot of air which is inefficient. Both suppliers and supermarkets mention that compressing these UBCs at the supermarket level could be crucial, depending on the volumes. However, it is known that this increases the risk of filth leaking out of the UBCs. On top of that, a compressing machine is an expensive investment while compressing higher up in the chain, for instance at a DC, can be more efficient due to scaling.

From a customers' point of view a good working system requires sufficient locations where these customers can hand in UBC, for instance on out-of-home locations such as petrol and train stations where consumption of beverages in cans is assumed to be higher. Due to the fact that a can which is opened is not sealable, hygiene aspects play a more important role. Nobody wants to carry around a leftover can of coke the whole day. Furthermore it is important that we provide a nationwide solution. If we buy a can at a location of supermarket X, we should be able to hand this in at a location of supermarket Y. This should of course not only account for supermarkets, but other sale locations as well.

In order to succeed one of the stakeholders pleated for an integral working method in which all stakeholders are involved with clear steps throughout the process. In order to identify possible no-go's, this stakeholder also pleated for an approach which categorizes advantages and disadvantages during a risk alliance.

Both supermarkets, suppliers and organizations mentioned the fact that hygiene is of greater importance with UBC than with (small) PET bottles since the UBC cannot be sealed and will in most cases leak some residue. As been stated in the requirements, this is one of the things the system has to be able to cope with. On the other hand, this is one of the restrictions the system has to deal with.

Several supermarkets mention the fact that the Dutch Government wants to promote circularity in the economy by for example recycling packaging material. Most, if not all, supermarkets support this statement. However, the Dutch Government arranges this by obliging producers to charge a deposit for every produced bottle. The supermarkets are thereby bombarded into becoming return locations. This deviates vastly from their core business. This could lead to inefficient handling of these jobs. Furthermore, the transition towards a system with a deposit on beverages in cans is a serious operation which requires at least 4 to 5 fulltime-equivalent (FTE) per involved organization, according to one of the supermarkets. This emphasizes the fact that legislation on used beverage cans is an enormous operation.

According to some supermarkets, the hygiene rules in the Netherlands are far more restrictive than abroad in for instance Germany. Furthermore, supermarkets in the Netherlands are on average smaller than abroad resulting in smaller floor spaces for these supermarkets. Therefore there is a smaller floor space available which can generate sales. In order to have as much square meters which can generate sales, most warehouses inside these supermarkets are small in relation to the floor space of the supermarket itself. In order to overcome lack of space, Dutch supermarkets have become fairly efficient and deliveries are most of the time just-int-time (JIT).

Waiting times for customers cannot become too long, therefore the waiting time is a restriction. In order to overcome this restriction, the return locations must have sufficient capacity. In Germany for instance, a lot of these return locations are at supermarkets but at the outsides of these supermarkets. Most of them claiming well over 20 square meters of the total floor space. Since the average floor space of Dutch supermarkets is about 950 square meters, this would indicate that over 2.1% of the total floor space is dedicated to these RVMs. To place things in perspective, the average floor space for small supermarkets in Germany is about 1095 square meters up to almost 7000 square meters for large supermarkets which would conform to about 1.8% down to 0.3% respectively.

The input from all interviews and arguments considered, it is clear that all supermarkets, organizations and wholesalers agree upon the fact that litter caused by empty beverage cans should be dealt with. They also agree on the fact that circularity is an important issue in order to provide a sustainable future for the next generations to come. However, especially supermarkets and wholesalers disagree on the question who should take care of the return process and how this return process should look like. Besides the obvious involved costs, the hygiene, space occupation and ability to cope with the extreme volumes seem to be important factors on which consensus is needed.

3 Literature Review

This chapter will cover the answer to the second research question by carrying out a literature review. First in Section 3.1 the characteristics of the circular economy, especially circularity concerning beverage cans are described. The possibilities for the reverse logistics of packaging material is covered in Section 3.2. Next, Section 3.3 covers the theory behind supply chain network design. The fourth Section 3.4 covers relevant key performance indicators. Several optimization techniques which are available for solving such problems are discussed in Section 3.5. This chapter will provide an answer to the following question:

- **What information is available in current literature regarding the circular economy, reverse logistics, supply chain network design and multiple criteria decision making?**

3.1 Theoretical Framework

As described in both Chapter 1 and Chapter 2, there is currently no system for deposit-returns on UBCs. However, the Dutch Government has accepted a proposal for amendment of the law, introducing legislation and thereby deposit-refund on UBCs as of the 31th of December 2022. In addition to the aforementioned problems in the problem cluster, we have to design a system that is accepted by all stakeholders. This chapter presents the questions that need to be answered and suggests possible directions for models, solutions and support for the decision makers. The decisions to be made are on the strategic level, which cover long-term structural decisions.

A lot of research has been conducted on improving the understanding of recycling. The growing world population requires more and more foods, which consequently leads to an increase in the amount of packaging wastes. Depending on the type of food and its packaging material, the environmental impact of this packaging material might be up to 45% of the food value (Simon, Amor, & Földényi, 2016). Due to ever growing awareness of sustainable development, it is no longer acceptable to deal with municipal solid waste (MSW) as an adverse flow of materials to be disposed or left to litter. MSW contains diverse products for which recycling is a viable option from which more environmentally desirable strategies emerged (Baeyens, Brems, & Dewil, 2010). This section will be devoted to outline several interesting works and scope the further literature review. Furthermore, this section will introduce several interesting works, components and solution directions. But first we will introduce some important definitions and processes.

Recycling is a solid waste management strategy which is the environmentally preferred method of solid waste management. The general perception of what recycling is, often remains limited to a vague understanding that it is good for the environment because materials are used again and do not end up as waste. Recycling therefore occurs mainly for social, economic and legal reasons. The social aspect stems from the persuasion to protect the environment and to conserve resources. The economic aspect is due to the economic value of recyclable materials. Lastly, governments impose a variety of economic and civil penalties and incentives in order to encourage recycling (Baeyens et al., 2010).

The initial success of recycling programmes will depend on how it is integrated in the existing waste management. The ultimate success will depend on the participation of the consumers, where some of them will participate due to environmental incentives and others due to economic incentives. Since litter is a serious issue, we can conclude that the environmental incentives of most consumers is not enough to tackle the problem. Therefore, legislation is certainly a key factor in tackling this problem. In order to succeed with the implementation of a recycling venture, short- and long-term targets are needed to guide this implementation and assess its progress and effectiveness. The short-term targets focus on planning and orientation to include all stakeholders involved. Long-term targets will deal with for instance the effectiveness of the program (Baeyens et al., 2010).

The success of the recycling process depends on the ability to consistently turn the discarded waste products into high-quality end products in a cost-effective manner. Therefore, quality control is essential at all stages of the process. Contaminants should be avoided throughout the recycling process. Besides consumers' education, an adequate process design and well-managed operations are critical success factors in order to produce high-quality recyclable materials. Several quality control problems can arise during the stages of recycling of which cross-contamination and health and safety hazards are most applicable to the recycling of packaging materials (Baeyens et al., 2010).

Aluminium is very abundant natural element which is extracted from bauxite. Aluminium is a valuable material with light weight, strength, corrosion resistance, durability, ductility, formability and conductivity. Furthermore, aluminium is 100% recyclable without loss of quality since the recycling process does not affect the metal structure. Due to these characteristics it makes this element suitable for various applications such as packaging material in the form of cans. As a result of the characteristics, the beverage industry is a major user of aluminium. It is a very convenient, safe and practical material to use for packaging liquids. It does not easily break but is still light weight, easy to open, compact and chills quickly (Baeyens et al., 2010).

The UBCs are processed to remove the interior lacquer coating and the outside product painting inks. The cans are shredded and this shred is passed through a magnetic drum separator to remove magnetic contaminants. Afterwards, the lacquer is decoated from the cans by blowing hot air through the shreds. The pure aluminium scrap can be remelted and rolled into sheets with only 5% of the energy needed to produce the primary metal, if the scrap is of appropriate quality. On top of that, for every tonne of recycled aluminium, the use about 8 tonnes of bauxite and 4 tonnes of chemicals are saved. Recycled aluminium UBCs are used again for the production of new cans, which already occurs in almost 50% of the produced cans in Europe. Furthermore, this also leads to substantial savings in waste management costs (Baeyens et al., 2010).

The management of municipal solid waste (MSW) distinguishes itself through a great diversity of schemes that are used worldwide. Some countries, for example Switzerland, have achieved both risk prevention and enhanced source separation through integrated solid waste management (ISWM), with high collection rates for recyclable waste. However even these well-functioning ISWM systems continuously face challenges. First of all, the quantities which systems have to deal with steadily increase due to increasing population and economic growth and therefore consumption. Secondly, the composition of waste is continuously becoming more complex. A third challenge arises from the fact that demand patterns are not stable (Meylan, Seidl, & Spoerri, 2013).

The support for choosing a MSW management relies on different analysis and assessment methods, of which life cycle assessment (LCA) is still dominating the comparing of different MSW management systems. The goal of these LCAs is to choose which MSW management system should be implemented. However, this approach commonly fails to consider up-scaling and future developments. Given these shortcomings, Meylan et al. argued for approaches that consider the future of waste disposal as a result of the interaction between the broader economic, political, and social contexts of MSW based on scenario analysis. It focusses on glass-packaging disposal as a basis for informing societally robust decisions (Meylan et al., 2013).

The goal of qualitative system analysis is to identify the drivers that crucially affect upcoming transitions and thus provide the foundation to construct scenarios. Historical evidence shows that upcoming transitions are co-shaped and constrained by past developments. Therefore, these drivers can be reconstructed. Drivers interact through restricting or promoting influences and if strong enough, influences or combinations of influences can lead to a transition in which new drivers appear and others disappear (Meylan et al., 2013).

In recent years we have seen the goal of waste management shifting from safe disposal to environmental and economical attractive options. This is partly inspired by the growing focus of the circular economy in which "*the value of products, materials and resources is maintained in the economy for as long as possible*". There are already several efforts of strategic network design in waste reverse supply chains by means of combinatorial optimization models. It is expected that in the future the relevance for waste management and its reverse logistics will grow. Recent geopolitical developments such as the decision of China to close its borders for certain waste streams also highlight the importance of waste reverse supply chains. In order to extract economic benefits or dispose waste in an environmentally friendly way, waste should be at the right place at the right time. This involves transportation between waste generators and waste processors (England, Beliën, Boeck, & Jager, 2020).

There are two large areas in scientific literature that describe this subject, namely reverse logistics (RL) and waste management (WM) which clearly show overlap. RL is defined as "*the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, inprocess inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing or creating value or proper disposal*". While WM is defined as "*characteristic activities which include (a) collection, transport, treatment and disposal of waste, (b) control, monitoring and regulation of the production, collection, transport, treatment and disposal of waste and (c) prevention of waste production through in-process modifications, reuse and recycling*". As derived from this definitions, it can be seen that both fields study the flows of discarded products leaving the end consumer. Based on the existing definitions of both RL and WM, Van Engeland et al. specified a definition for a waste reverse supply chain as: "*a network consisting of all entities involved in the flow of disposed products leaving the point of consumption. It includes collection,* *transportation, recovery and disposal of waste. Its purpose is to recapture or create value and/or proper disposal*" (England et al., 2020). Following this definition it explicitly requires products to be used or consumed, and therefore wrong deliveries or damaged packaging are out of scope since these are part of reverse logistics in common. Even the overlap on both fields (RL and WM) is still very large, we focus specifically on the strategic network design which is the highest level that can be distinguished in supply chain planning problems. This includes long term decisions on for instance locations, capacities and technologies. Therefore, the choices on the strategic level have a large impact on the eventual performance of a supply chain. Throughout the rest of the section, we will give a complete overview of the literature on strategic network optimization models in waste reverse supply chains.

The recovery options in a waste reverse supply chain determine what waste types can be dealt with. Therefore, when designing a reverse network, the waste streams should be taken into consideration. Since we are dealing with UBCs in our case, the options reuse, repair, refurbish and remanufacturing are no feasible options. Therefore, the only option left is recycling. At this point, no initial parts of the original product are retained and only the material content of the original product is recovered. There are several levels of a waste reverse supply chain. When moving towards the material level, higher capital investments are needed and the recovery technology gets more complicated (England et al., 2020).

When dealing with waste streams, separation is a key factor. When a waste stream is separated at the consumer level, so called source separation, it can be transported directly towards processing facilities. However, even with this kind of separation, additional sorting in specialized facilities might be required due to improper disposal at the source. In current day literature, there is yet no research done on source separation in combination with direct flows versus no source separation which is followed by separation in a specialized plant. The waste reverse supply chains can be open or closed loop networks. In a closed loop the flow of products returns to the same market after recycling. The open loop differs in the fact that the final disposal option can be in a market different from the initial (England et al., 2020).

The proposed network structure directly translates into decision variables. Since we are dealing with a strategic network design, the first type are decision variables regarding strategic decisions. These are typically binary decision variables indicating the opening of a location or installation of a certain technology. Different levels of capacity can be modelled through discrete sets, continuous decision variables or the possibility to install more than one unit at one location. Tactical decisions are represented by decision variables as well. Some papers consider the simultaneous optimization of strategic and tactical decision. An important advantage of optimizing strategic and tactical decisions at the same time, is that subtoptimal solutions can be avoided. However, this makes the problem harder to solve. Common constraints in strategic Supply Chain Network Design (SCND) models are flow conservation, meeting demand, capacity constraints and a minimal or maximum number of opened facilities. This can be extended towards proximity of collection points, collection frequencies or for instance minimal spacing between processing facilities.

After the network is described and modelled accordingly, a selection has to be made on which objective to optimize. Most commonly this is a single objective such as minimizing costs. However, multiple objective functions are used in literature as well. For instance a commonly used objective in waste reverse supply chains is minimization of environmental impacts or maximization of environmental benefits. To solve for these multi objective models, several approaches can be used. The no-preference methods do not require any kind of choice, as the name suggests. An a priori method uses the preference of a decision maker provided before solving the model. For instance by raking the objective function in order of importance. In a postiori methods, this is somewhat the other way around. The model is first solved, after which the entire range of efficient solutions is presented to the decision makers. Usually there are several solutions of which one objective can not be improved, without simultaneously worsen another one. This is the so called Pareto set (England et al., 2020).

When modelling real life situations, a key factor is uncertainty. For instance future product returns, especially the amount and timing of these returns, are subject to uncertainty. Again this uncertainty can be incorporated directly into the model, or handled a posteriori. The later can be achieved by conducting a sensitivity or scenario analysis in which the model is rerunned with a different set of parameters. Uncertainty directly incorporated into the model can be achieved by stochastic programming, in which probability distributions of parameters are taken into account. The main disadvantage of this method is that these distributions need to be known. However, there is a way to overcome this problem which is the use of fuzzy parameters. This method adopts a distribution which represent the upper and lower possible bounds and a most probable value.

The method of solving a model to optimality depends on several of the characteristics of the model, as discussed above. Depending on the preferences of stakeholders involved and different factors like the complexity of the model, priority can be given to exact or heuristic solving approaches. Solving to optimality often takes too long. Therefore, heuristics are used to find reasonable good solutions in acceptable and limited amount of computation time. However, these do not guarantee optimal solutions.

The paper by Simon et al. is an extensive analysis on greenhouse gas and compared PET with aluminium cans both in different volumes (Simon et al., 2016). The results of this analysis can be seen in Table 3.1, in which the scenarios were modelled such that they obtained an average GHG emission. The differce in the last column is calculated as less GHG emission with recycling compared to incineration.

Table 3.1: Analysis of GHG emission for different type of packaging, as provided by Simon et al.

Type of packaging	**GHG emission**		Difference (%)
	With recycling	With incineration	
Aluminium can 330ml	153	1170	- 86,92%
Aluminium can 500ml	134	991	- 86,48%
PET bottle 500ml	275	1070	- 74,30%
PET bottle 1000ml	151	822	- 81,63%
PET bottle 1500ml	85	537	- 84,17%

As can be seen in Table 3.1, the most reduction in GHG emissions can be obtained by recycling of aluminium cans. Table 3.2 compares the different packaging material based solely on CO_2-emission in the different life cycle stages of the material. As can be concluded from both tables, the recycling option would generate the lowest GHG emissions. All displayed GHG and CO_2-emissions are in kilograms per 1000 litre of packaging volume. The recycling of aluminium cans allowed the highest energy and related GHG saving by use of secondary materials. From both tables it can be concluded that production and distribution contributed the most to GHG emissions. Furthermore we can see in Table 3.2 that the waste collection for aluminium cans is substantially better by kerbside collection than a deposit-refund system. This in contrast to PET, in which the deposit-refund system is significantly better than kerbside collection.

Table 3.2: Overview of GHG emissions during whole life cycle, as provided by Simon et al.

		Al 330ml	Al 500ml	PET 500ml	PET 1000ml	PET 1500ml
Production		535.8	449.5	325.8	173.2	135.6
Distribution		46.4	45.9	46.2	46.0	45.8
Waste collection	deposit-refund	1.1	0.9	1.5	1.1	0.8
	kerbside bag	0.5	0.5	1.2	1.1	1.1
	collection point	1.2	1.1	2.8	2.7	2.6
Waste treatment	recycling	18.3	15.4	5.9	3.2	2.1
	incineration	585.5	493.4	733.4	553.3	373.0
Potential credit		444.3	374.2	156.6	85.4	66.4

A noticeable finding is that recycling is found to be beneficial in terms of GHG emission, particularly in the case of aluminium cans due to significant energy savings as explained in Section 3.1. As described by Simon et al., the dominance of PET-bottles in literature compared to aluminium cans might indicate the need for undertaking new research in (new) packaging materials different from these PET-bottles. Encouraging consumers in selective collection is important, especially if we take the findings of Simon et al. into consideration that kerbside bag collection showed one of the lowest impacts. On top of that, this method of collection could ease the consumer participation in selective collection leading to higher participation and therefore even lower impacts. Current day literature suggest different methods of the recycling process:

1. The existing system of supermarkets represent a potential way for a selective waste collection in combination with a deposit-refund system. This system is currently in place in the Netherlands with PET-bottles.
2. Collecting at collection points can be modelled by the kerbside collection where the consumers bring their empty cans to containers, which are located at the street sides for instance on busy locations. The containers are systematically emptied by smaller trucks. A well-known example are glass containers currently in use in the Netherlands.
3. Another modification on the kerbside collection is bag collection, where consumers collect the packaging materials in bags at home and these are collected systematically by a truck. An example of this is plastic and or other garbage collection in the Netherlands.

The conclusion of this short literature review is that there are several reviews on mathematic modelling in the fields of WM, RL and a combination of both. However, further research is needed since it often are very complicated subjects. It can be concluded that in general the elements of a circular economy are important. One of the goals is to improve resource efficiency and make the (development of) economy less dependent on virgin materials through for instance recycling.

3.2 The Circular Economy

What are characteristics of the circular economy and how do they fit into a system for the reverse logistics of used beverage cans?

In order to find an answer to this question, a literature search is conducted using the keywords "*circular economy*", "*closed-loop cycle*", "*life cycle assessment*" and "*closed-loop supply chain*" with these modifications: searching for articles in the English language sorted by relevance with no limitations on the time range. However, the more recent papers were preferred. The used search engines are the Google-scholar search engine and the FINDUT search engine of the University of Twente. After reading several papers which were found through these search results, the expression "*Used Beverage Can*" came by regularly. Therefore another search was done with the keywords "*used beverage cans recycling*" which yielded several interesting papers. On top of that there was a specific attempt to search for "*aluminium can closed loop cycles*" but this did not generate other articles than before.

The concept of the circular economy is not something new, since it has been gaining attention for over 40 years since the late 1970s as an important point on the agenda of policymakers such as the European Circular Economy package and the Chinese Circular Economy Promotion Law. Furthermore, there is a steep increase in the number of articles covering the topic of the circular economy since the last decade. Even several companies see opportunities in the circular economy and have started to realise its value potential for themselves and their stakeholders. However, the circular economy as in UBCs and its reverse logistics remains a totally unexplored field of research (Geissdoerfer, Savaget, Bocken, & Hultink, 2017). The issue of resource scarcity is gaining more and more attention lately because the consumption of energy and material resources is increasing rapidly in both the industrialised and developing countries. When the world economy keeps growing at this rate, the total impact of energy consumption, resource usage and waste production is estimated to be a 10-fold increase. In other words, when the system does not change, we need 10 times more resources and energy to manage the waste produced in order to maintain our current status of impact (Rashid, Asif, Krajnik, & Nicolescu, 2011). Therefore, the idea of circular economy is gaining more attention lately. The circular economy is described as "*an industrial economy that is restorative or regenerative by intention and design*" (EMF, 2013) and *"realization of a closed loop material flow in the whole economic system*" (Geng & Doberstein, 2008). The closed-loop system is considered as a solution to resource scarcity (Rashid et al., 2011). Whereby a closed-loop recycling flow is described as "*incorporating material from used containers in new containers*" (Chilton, Burnley, & Nesaratnam, 2010). All things considered the circular economy can be defined as: "*as a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, re-manufacturing, refurbishing, and recycling*" (Geissdoerfer et al., 2017). The circular economy is often mistakenly confused as being the same as sustainability. Both are indeed about sharing concerns regarding current industrial production and consumption which might jeopardise the future. They both stress the importance of harmonizing environmental and social aspects with economic growth. However, sustainability is more unrestricted than the circular economy. In order to provide a clarification, the circular economy and sustainability are two concepts that are used interchangeably but according to the vast majority of researches these concepts differ in some elements. The modern definition of sustainability is being described as "*able to be maintained at a certain rate or level*", in which three pillars of sustainability play an important role: people, profit, and planet. This triple bottom line has been referred to as the balanced integration of economic, environmental and social performance. These three elements are systematically intertwined and continuously affect one another through mutual causality and positive feedbacks. Based on this Geissdoerfer et al. framed the term sustainability as "*the balanced and systematic integration of intra and intergenerational economic, social, and environmental performance*". Both concepts employ approaches to better integrate non-economic aspects into development, which often conclude that system designs and innovations are the main drivers for reaching their ambitions. In addition, both concepts view coorperation between stakeholders not only as desirable, but as an absolute necessity to reach their expectations. Besides some similarities, there is a range of differences as well. The circular economy goes mainly hand-in-hand with a closed-loop system. The closed-loop system has the intention to fulfil three major demands of sustainable product development, namely maximizing of expended resources and thereby minimizing the use of energy, new resources and environmental impacts. The main differences are the goals and prioritized systems. The goal of the circular economy is to ensure a closed-loop ideally eliminating all resource leakage out of the system, while sustainability is more open-ended and has multiple goals depending on the considered agent. The prioritized system in the circular economy is logically the economy, while the triple bottom line which is discussed before is the prioritized system in sustainability.

At the end-of-life (EoL) of empty beverage cans the decision on reuse, remanufacture or recycle can be made based on the quality of the product. Reuse and remanfacturing are the preferred EoL management strategies as they conserve materials, energy usage and the environment by extending the life of (components of) these products. Recycling has a higher energy consumption but is marginally better in environmental and economic efficiency compared to discarding the products at their EoL (Rashid et al., 2011).

The circular economy aims at a closed loop in which all resource inputs and waste emission leakages of the system are eliminated. It focuses on the idea that resources could be used in a better way and instead of linear make-use-dispose systems, reduce emissions and waste by introducing circularity (Geissdoerfer et al., 2017). Based on the idea of a linear economy in which resources are extracted, made into products and then disposed at their EoL, two problems arise. Firstly the resource availability with increasing economic growth and secondly the production of large amount of waste (Stewart, Niero, Murdock, & Olsen, 2018). Besides benefits for the environment expressed through less resource depletion and pollution, society can benefit from a circular economy as well by creating (manual) labour opportunities and fairer taxation. The circular economy seems to prioritise the economic system with primarily economic and environmental benefits with emphasis on governments and companies. Current day literature considers that the responsibility for the transition towards a circular system belongs primarily to (private) businesses, regulators and policymakers. The goal of the circular economy is a closed loop with better use of resources and ideally eliminating all waste and leakage in order to benefit the economy and the environment. Circularity is seen as one of a few opportunities to foster sustainability of the system. Not only benefits but also costs should be balanced to avoid creating a circular system with negative value. On top of that an efficient system is needed in order to overcome possibilities of worsening the emission of GHG and, as a result, accelerate global warming due to inefficiencies (Geissdoerfer et al., 2017; Stewart et al., 2018).

Companies who intent to implement a circular economy strategy can expect to face major challenges regarding geographical scattering of goods, non-adapted RL and difficulties to control quantity, quality and delivery time of resources. Furthermore, aligning all stakeholders to collaborate can be hard since some companies have a disinterest for this non-core business or resist due to high interests in the current business setting (Stewart et al., 2018).

The goal of decoupling economic growth or development from the utilization of finite resources is recurrent in the reviewed circular economy literature. Non-renewable resources are depleting resources by definition. Regarding the renewable resources, such as a lot of metals, in order to maintain sustainable development the extraction rate should be lower than the regeneration rate of those resources. Regeneration is a main driver of the circular economy. One practical strategy to achieve this is promoting and improving downcycling, recycling and upcycling of waste through take-back systems, reverse logistics and the use of advanced technologies (Suárez-Eiroa, Fernández, Méndez-Martínez, & Soto-Oñate, 2019).

Aluminium cans are one of the packaging materials that are considered to have a good circularity potential, at least from an environmental point of view. Aluminium cans are relatively simple products since they consist of two different aluminium wrought alloys, namely one for the body and one for the lid. A closed loop system which produces new cans from UBC has a lower impact than using mixed aluminium packaging scrap as mentioned before. However any company willing to implement a circular economy strategy can expect to face major challenges in terms of resource management, stakeholders' management, regulatory issues, and financial issues. The challenges associated with resource management include geographical dispersion of goods, non-adapted reverse logistics infrastructure, difficult control over quantity, quality and delivery time of resources, and complexity of materials. In order to have a continuous loop of materials packaging needs sustainable development, which means that packaging needs to be efficient in its practical necessities, efficient in material and energy usage, cyclic and recoverable at the EoL and finally safe for people and the environment (Stewart et al., 2018).

The theory behind the circular economy is built on the idea that it consists of two types of cycles: biological and technical. The biological cycle aims to reduce excessive extraction of resources. Technical cycles focus on extending the life of products through for instance reuse and recycling. One of this technical aspects is that the implementation of the circular economy requires the remanufacturing of a sustainable business model besides the design of products as described before. Critical to a favourable outcome of this process are technical, economic and legal issues such as the functionality, convenience and authorization of the system. An overview of critical success factors is given in the table below, with a score that is given by the stakeholders determined in section 2.1. On top of these factors, there should be an emphasis on the measuring of the performance in order to obtain a sustainable supply chain (Sehnem, Jabbour, Pereira, & de Sousa Jabbour, 2019). Which performance indicators to measure and how to optimize these will be discussed in Section 3.5 and Section 3.6 respectively.

The ability to recycle certain materials can be expressed via a score. The so-called Material Reutilization Score (MRS) quantifies the material reutilization (MR). The MRS (equation 3.1) includes two variables: the percentage of the product that is considered to be recyclable at least once after its initial use stage (RCC) and the percentage of recycled content (RC).

$$MRS = (2 \times RCC + \frac{RC}{3}) \times 100 \tag{3.1}$$

In order to obtain a high MRS in the case of aluminium cans, a prerequisite is to ensure recyclability through optimization of the closed loop. Suggested options for potential optimization are the breakdown of the material composition in terms of alloys and the identification of components. The eco-efficiency concept is based on adding maximum value while minimizing pollution and the resource usage. Reduction in environmental impacts has often been pursued through product life extension such as longer product life, refurbishment or components reuse. However for beverage packaging, product life extension is not a feasible option because of the short duration if its use stage. Except for returnable packaging in the form of legislation on this packaging. The recyclability rate of packaging material relies on two important conditions, that is the ease with which materials can be reprocessed and the availability of facilities to collect, sort and reprocess this material. This dual reliance requires for a close collaboration between several stakeholders as described in Section 2.1. Furthermore the circular economy is not only about resource scarcity and impact on the environment, but also economic benefits. Both economic and environmental perspectives should be incorporated into a framework. The outcome should be a list of prioritized actions regarding the technologies to invest in, (reverse) logistics, waste management and consumer awareness in order to implement the most efficient and effective strategy for the recycling of beverage packaging. A fair distribution of costs and benefits through producers, distributors, consumers and recyclers is needed (Stewart et al., 2018).

In order to better understand potential obstacles in the adoption of a circular economy, the critical success factors should be determined. Critical success factors are described as those specific factors that require monitoring and action when these factors deviate from the goal by the management in order to maintain competitiveness. When companies try to adopt a circular economy approach they often encounter barriers. Identifying these success factors is needed in order to encourage organizations to prioritize resources and adopt the circular economy principles (Sehnem et al., 2019). These factors are, but not limited to:

1. Stakeholders' belief in the system
2. Engagement of stakeholders
3. Technological innovations needed for implementing the system
4. System functionality
5. System Convenience
6. Costs and revenues of the system
7. Reduction of emissions

Concluding from this section is that the circular economy is not something new, but has been gaining more attention lately due to ever rising consumption of energy and resources. In order to make a circular economy work, it needs the participation of consumers which depends on several factors. Critical to the success of a circular economy are, besides costs, the engagement of all stakeholders and their belief in the system. It therefore is important, to take all of their requirements into account when designing such a system.

3.3 Reverse Logistics

What elements of reverse logistics are applicable for the return of used beverage cans?

The research question is answered by conducting a literature search. In order to find this answer the keywords "*reverse logistics*" and "*supply chain reverse logistics*" were used in the Google-scholar and FINDUT search engines. The search had no limitations on the time range except for the fact that more recent papers were favored. Furthermore the search engine was set to find articles written in the English language. In order to find good starting articles the list of references of good review papers were checked to find more papers to read.

The traditional view on supply chains did not include anything beyond the sale and delivery of the final product. The supply chain was mainly seen as a network of facilities that produce materials and transform them into final products, which are delivered to customers through a series of distribution systems (Geyer & van Wassenhove, 2005). However reverse logistics has gotten substantial attention in the recent years due to a combination of environmental, economic and social aspects. These aspects have contributed to the adoption of various approaches with respect to supply chains. The environmental considerations encompass efforts to minimize the carbon footprint of the supply chain. Moreover, special attention has been focused on recycling products considering the high economic returns. Therefore, governments have imposed legislations that obligate companies to take back returned products. Due to the regulations and the potential financial benefits to remanufacturing used products, companies are stimulated to invest in their reverse logistics.

Reverse logistics is specified as "*the series of operations that initiate at the consumer level with the collection of products and terminate with the re-processing of these products at remanufacturing locations*" (Alshamsi & Diabat, 2015). This includes the process of planning, implementing, and controlling the efficient, and cost-effective flow of materials and related information from the point of consumption to the point of origin with the intention of recovering value or proper disposal (Bernon, Tjahjono, & Ripanti, 2018). The reverse logistics aim at recovering a part of the original value of the used goods and thereby producing economic, environmental, and social advantages.

Traditional forward supply chains produce output which is customized for downstream processes. Closed-loop supply chains rely on EoL products which are used as production inputs. These closed-loop supply chains have to be organized in order to cope with the uncertain timing of the return of these EoL products and the uncertain recoverable value, in other words their quality. For these reasons the closed-loop supply chains, and therefore the reverse logistics, are much more likely to be constrained than forward supply chains.

The circular economy has been described before in Section 3.1 and reverse logistics clearly fits with this philosophy and therefore becomes a major component of the circular economy. Reverse logistic activities within the circular economy encompass the management of product recovery activities such as recycling.

Since the circular economy uses a system approach from design through cycle the reverse logistics management is a fundamental factor (Bernon et al., 2018). One crucial component in the management of reverse logistics is understanding the difference between forward and reverse logistic systems. Several key factors that produce differences are the reverse logistic transport systems being 'many-to-one' rather than 'one-to-many', the fact that costs are not directly visible in the reverse logistics and a higher supply uncertainty than traditional forward logistics, as can be seen in Figure 3.1 (adapted from: (Pishvaee, Kianfar, & Karimi, 2009)). Furthermore, companies and investors bear a high risk during decision making in the design phase of the reverse logistic system due to the costs associated with transportation, facility locations and several other factors. Furthermore the development of the complete reverse distribution channel as well as the information requirements for reverse logistics are two important issues to consider (Bernon et al., 2018; Alshamsi & Diabat, 2015).

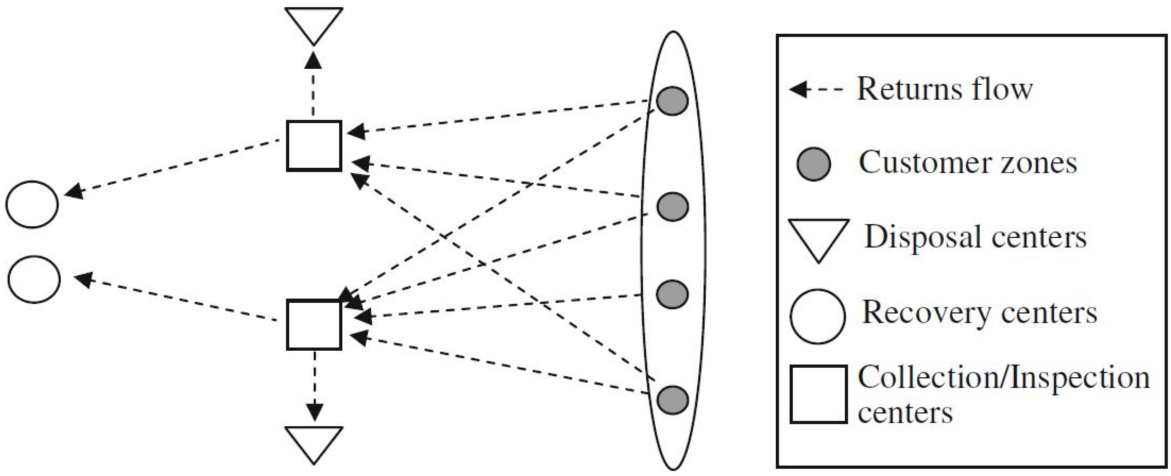


Figure 3.1: Structure of traditional reverse logistics network.

As previously described, the recycling process faces major obstacles. The lack of a regulated reverse distribution system and the vast costs of collection and transport are two of these issues. The reverse logistics can take place through the initial forward logistic channels, through a separate reverse channel or through a combination of both. The development of reverse logistics includes the identification of activities that are carried out within the reverse distribution channel and the allocation of these activities to appropriate actors. These actors may or may not already be involved in the forward distribution. The level of integration of reverse logistics with forward logistics depends on the final destination of the returned product. When the product disposition is selected, a list of necessary activities can be made. In the case of empty beverage packaging the product disposition is recycling. A thriving reverse logistics program relies heavily on gathering and understanding relevant information that can help manage the return process while regulating the costs. It is therefore important to sufficiently focus on information flow between and across all actors in the reverse logistics (Ferguson & Browne, 2001). The information that is required for efficient product disposition can be classified into roughly five categories:

1. Product related information: this is mainly static in nature, i.e. the information does not change over the life cycle of the product. Furthermore, since it applies to UBC it does not change a lot over the years. The capacity content does not change since these are universal measures. However, the future can bring new sort of cans or cans with different volumes and measurements which should be able to be added to the system.

2. Location related information: this relates to the specific location of the RVM and the quantity of the UBC's at this RVM available, which is important information with respect to the collection activity and the planning and control of the whole recycling activity. Automatic identification technology is making dynamic data collection possible by building in product identification via for instance barcode scanning.

3. Utilization related information: as mentioned above, an item is scanned to determine the original manufacturer which is an example of utilization related information.

4. Market information: one critical issue in the reverse flow of UBC is to receive the highest possible value for the products in accordance with any restriction or constraint. Therefore the market information is important, but this will be out of the scope of this research.

5. Process information: this relates to the availability and quality of the UBC which can be combined with sales data of beverages in cans in order to forecast possible return of UBC. Furthermore reverse vending machines can be equipped with automated tellers to keep track of returned UBC per machine.

Since most return vending machine locations only hold small amounts of UBC of which the volume can be very low if the UBC is compressed when it is handed in, one truck can visit multiple locations before it reaches its maximum capacity. Therefore, the routing problem looks like a reverse logistics vehicle routing problem. The truck that picks up the UBC from the return vending machine is restricted to a certain capacity. Therefore the problem can be extended to a Capacitated Vehicle Routing Problem (CVRP). Since, in practice, the pick-up of material in city centers can be restricted to certain time-windows, the routing problem can be extended to a vehicle routing problem with time windows (VRPTW).

3.4 Supply Chain Network Design

What elements of Supply Chain Network Design are applicable to a reverse logistics system for used beverage cans?

In order to find an answer to this research question, a literature search was conducted. This search started with the keywords "*supply chain network design*", "*reverse logistics network design*" and "*network design*" in the Google-scholar and FINDUT search engines. The search had no limitations on the time range except for the fact that more recent papers were favored. Furthermore the search engine was set to find articles written in the English language. In order to find good starting articles the list of references of good review papers were checked to find more papers to read.

Supply Chain Management (SCM) was introduced in the early 80s as a response to the growing and fierce competition among companies. During this period a growing number of companies realized the significance of integrating their activities into key supply chain processes. The SCM is defined as "*the holistic management approach for integrating and coordinating the material, information and financial flows along a supply chain*" and "*the process of planning, implementing and controlling the operations of supply chain in an efficient way*". Due to several issues such as increasing and changing of customers' expectations and new technologies, the SCs of businesses has changed a lot. A SC is a complex network of organizations and facilities which are a synchronized series of intertwined activities throughout the network (Govindan, Fattahi, & Keyvanshokooh, 2017).

A SC network converts raw materials into final products which are delivered to customers. This process includes various types of facilities of which each fulfils a specific role in the network. An layer or echelon are all facilities with the same task and type. The number and type of layers and the layers in which location decisions are determined hold a crucial aspect of SCND. As stated by Melo, Nickel and da Gama, the strategic planning for RL networks has many similarities with forward logistics networks (Melo, Nickel, & da Gama, 2008). Primarily the type of facilities and the direction of flows are different. In RL networks, the reverse flows are generally started by collecting used products from customers and their final destination is usually any of the discussed options in the previous Section 3.2.

Supply Chain Network Design (SCND) is considered one of the most crucial parts of the planning process in SCM, which shapes the infrastructure and physical structure of a SC. SCND has been proven to be a suitable solution for facility location (FL) models over the recent years. The decisions in designing a SC are usually very difficult since they have long-term effects on the performance of a SC and once these decision are made, the SC is hard to change afterwards. Furthermore, large investments are usually required for decisions regarding the design of a SC. The decisions in a SCND are therefore mostly of a strategic nature, with determining the locations and number of facilities, capacities and size of these facilities and which technology to install at these facilities as the most common decisions to make. Often when companies have been influenced by these decisions, a lot of parameters such as demand, capacity and costs can have significant fluctuations. Due to the fact that enormous volumes of data can be gathered (and often are gathered), inaccurate forecasts are one of the risks when facing the SCND. Therefore, SCND under uncertainty has gained significant attention over the years.

Designing reverse logistics (RL) networks is another type of optimization problems. These are often designed with the intention of collecting used products from customers by carrying out some recovery activities. As described in previous passages due to strict pressures from environmental regulations, companies have been confronted with the challenges to return these products to some point of origin and are thereby forced to cope with the design of RL networks. Locating facilities somewhere in the network is one of the key strategic decisions that have to be made in this design problem. These facilities are expected to operate accurately over many years under uncertain environments due to uncertainty in parameters as return quantities and other parameters, as stated in Section 3.2. According to Govindan, Fattahi and Keyvanshokooh it is noteworthy that the RL problem has many similarities to the SCND in terms of optimization approaches. Furthermore, the forward and reverse logistics are often integrated in so called closed-loop supply chain (CLSC) networks (Govindan et al., 2017).

It is clear that several parameters of the SCND problem are inherent to uncertainty. Think of parameters such as costs, demand and supply. Furthermore SC networks can be heavily affected by major (man-made) disruptions. However, the likelihood for these events to occur in the Netherlands are of such low probabilities that these are out of the scope of this research. However it is worth noting that the impact of for instance earthquakes, floods or economic crisis on the performance of the SCs can be substantial and prominent. Therefore, the objective of SCND under uncertainty is to achieve a configuration so that it can perform sufficiently under any given possible realization of the uncertain parameters. To start with, the definition of performing sufficiently is already subject to inconsistency since the viewpoints of decisionmakers can be different. Based on this, the uncertain environments for the SCND problem can be categorized according to the following groups (Govindan et al., 2017):

> Group 1: decision-making environments with random parameters in which their probability distributions are known for the decision maker. These parameters are called stochastic parameters and in SCND described by either continuous or discrete scenarios. One example of a stochastic parameter is the customers' demand, which is often modelled through the normal distribution with known mean and variance. Again, it is noteworthy to mention that RL activities are harder to predict.
>
> Group 2: decision-making environments with random parameters in which the decision maker has no information about their probability distributions. For these SCND problem instances, robust optimization models are often used with the purpose of optimizing the worst-case performance of the SC network. Again the random parameters in this problem are divided into continuous or discrete. In order to model both of these parameters, different approaches can be used. To model the discrete parameters, scenario based approach can be used. In order to model continuous parameters, pre-defined intervals can be used.
>
> Group 3: fuzzy decision-making environments in which two types of uncertainties exist, namely ambiguity and vagueness. The first one indicates the conditions in which the choice among multiple alternatives is undetermined. The second term indicates the absence of sharp and precisely defined boundaries for the domain of interest. Fuzzy mathematical programming could assist in handling the diverse uncertainty ranges of coefficients for instance.

By analyzing several papers, the most frequent studied uncertainty parameters in the RL network design are: the return quantities in a RL or CLSC network, costs of activities, capacity of network facilities and transportation links, demand for the RL outputs in a RL or CLSC network, proportion of returned products for different activities in a RL or CLSC network and the disposal rate of returns. Decision making on these parameters depends on the available information for these parameters and their source of uncertainty.

The planning decisions can be divided into three categories, including long-term strategic, mid-term tactical and short-term operational time windows. Due to the complexity of SCND in today's business environment, it is important to consider these. Depending entirely on the nature of the SC, the time span for certain levels can vary for different SCs. At the strategic level, several crucial design aspects have to be decided on, such as the number and locations of facilities and which technologies and capacities to install at these locations. Both tactical and operational level decisions are rarely integrated with SCND (Govindan et al., 2017). SCND is one of the most important strategic decisions in SCM. In general this consists of the determination on the numbers, locations and capacities of facilities and the quantity of flow between the facilities. Since the opening and closing of a facility within the network is a costly and time-consuming operation making it nearly impossible to act in a short time period and therefore is considered as a strategical decision. According to Pishvaee, Kianfar and Karimi investments on the strategic level such as SCND have a higher return on investment (ROI) in comparison with the tactical and operational levels. Furthermore, since strategic decisions are made before tactical and operational decisions, the configuration of the SC will become a constraint for tactical and operational level decisions (Pishvaee et al., 2009).

Distribution networks are often the ending part of a SC network and consist of product flows from depots to customers or retailers in the forward logistics case. However, as explained in previous sections the RL network is more than often quite similar to the forward logistics but in reverse order. The design of such a network requires solving two hard combinatorial optimization problems, including the determination of locations and vehicle routes to serve customers. Solving both problems separately can lead to sub-optimal solutions.

The fundamental goals of a SC consist of meeting customers' demand, functionality of the SC processes and the accessibility of the resources. For years it was commonplace to achieve this goals economically. However, due to changes in the business environment these goals have shifted towards being responsive and green, while at the same time minimizing costs. A suitable design of the SC enables companies to achieve these goals while gaining competitive advantages.

Besides the economic goals, several companies strive for responsiveness of their SC as another goal to realize competitive advantages. The definition of responsiveness vary among companies: the ability to meet short lead-times, cope with a wide range of products or meet a high service level. All things considered the most widely agreed definition of responsiveness is a SC that is highly flexible to changes of market or customer requirements. The increasing importance of environmental issues have resulted in integrating green factors into SCND, rather than solely focussing on economic goals. This expresses itself in for instance environmental measures in the objective function or environmental constraints in the mathematical models of the SCND (Govindan et al., 2017). According to Meade, Sarkis and Presley increased interest and investments in the RL processes of businesses can be divided into two incentives: environmental and business factors (Meade, Sarkis, & Presley, 2007). The first one not only encompass the environmental impacts of used products and legislation, but growing environmental consciousness of both customers and businesses as well. Business factors are related to the economic benefits of using the returned products. In fact, companies could also gain economic benefits by gaining more profit indirectly through liberal return policies leading to higher customer satisfaction (Pishvaee et al., 2009).

Single or multiple objectives can be considered for a numerical optimization of a SCND model. Two criteria for solving these SCND problems are efficiency and effectiveness, which are defined as "*a way to attain the SCs goals through taking minimal resources and thereby achieving the cost-related advantages*" and "*obtaining pre-determined SC goals even in the face of inverse conditions or unexpected events*" respectively. The components to measure SCs performance can be different in various optimization problems. An overview of possible and often used components in objective functions is listed below:

- Location costs of facilities: fixed costs of opening/closing facilities.
- Operating costs of (active) facilities: operating costs of facilities when these facilities are opened. This can be fixed or depending on the volume and range of products.
- Transportation costs: the costs of transporting products among different entities of a SC network.
- Processing costs: the costs of handling products in facilities of a SC network.
- Capacity costs of facilities: the costs of establishing, expanding or relocating the capacity of different facilities within the SC network.
- Technology selecting costs: the costs of selecting a technology for SC facilities.
- Recovery activity costs: the costs related to recovery activities in a RL network. These costs are dependent on the type of RL activities within the SC network.

One of the essential challenges facing a SCND problem is that the design of the network often has to be made according to required processes in this industry. However due to difficulties in collecting, preparation and aggregation of extensive data sets, only some papers have investigated real-life case studies. Furthermore due to the NP-hardness nature of SCND problems an optimal solution cannot always be guaranteed since meta-heuristics are often used to solve these problems. Simulation is a powerful tool to validate obtained policies in decision-making environments, this however is not yet broadly examined in SCND.

3.5 Key Performance Indicators

What key performance indicators relevant to reverse logistics are commonly used to optimize?

A literature search using the Google-scholar and FINDUT search engines was conducted in order to find an answer to the research question. The search engines were given the several search terms such as "*key performance indicators in reverse logistics*", "*key performance indicators for supply chains*" and "*supply chain network design key performance indicators*". The search results were filtered on articles written in the English language. There was no limitation on the time range except for the fact that the more recent papers were favored over older ones. Furthermore, references of found papers were checked for relevant information as well.

As described in the previous Section 3.3, the forward and reverse logistics differ greatly. Therefore, the design and implementation of reverse logistics is very different from forward logistics as well. Since reverse logistics mainly revolves around the recovery of returned products from consumer to a recovery point, the design and implementation of this reverse logistics is very distinctive from the forward logistics. The reverse logistics start with the collection of, in this case, UBC from customers. The reverse logistics can be divided into three stages phases: collection, inspection and sorting, and product recovery.

Collection, which refers to all activities regarding UBC availability and physically moving them to some point where further handling is conducted, is the first and arguably the most important element of the reverse logistics. Several decision variables within the collection issue arise. A lot of literature in the area of collection in reverse logistics is related to location-allocation of collection centers. Diverse key performance indicators (KPIs) are identified for these location-allocation decisions in reverse logistics. The costs of collecting and processing items are important KPIs. Together with the value added recovery this can indicate if recycling is worth considering from a financial perspective. If we add the KPIs energy usage and waste generation we can consider its environmental potential. The KPIs customer satisfaction and level of social acceptability give an indication of the social aspects of the location-allocation decision in reverse logistics.

Within these reverse logistics, there are several methods of collection. Literature suggests three methods of collection: by original equipment manufacturer (OEM), collection with retailers or with third party logistics. All three options have advantages and disadvantages. Furthermore, the suitable collection method depends upon the type of industry and the size of collection in addition to KPIs regarding the location-allocation of collection sites such as value added recovery, operating cost and customer satisfaction. An industry-wide collection system has the advantages of economies of scale while not disarranging the forward supply chain. However, an individual company has limited control over this type of collection system.

One other important KPI for the collection decision is the initial investment. Furthermore the KPI return volume can be of major importance to several stakeholders as well. As stated before, the operating cost is considered another KPI, as well as the supply chain control and customer satisfaction. Since the upscaling of a method of collection can reduce the amount of trips needed to collect the UBC from the return vending machines, the KPI environmental impact is examined as well. Different modes of collection bring along different levels of health and safety issues and therefore is examined as KPI as well. After collection, inspection and sorting is needed. This can be done centralized or decentralized. But since UBC are simple products, decentralized inspection is not worth considering. Furthermore, sorting should not be necessary since the return vending machines only take back UBC.

3.6 Optimization Techniques

What optimization techniques are available in literature for reverse logistic systems?

In order to formulate an answer to this research question an literature search was conducted using the following terms "*optimization techniques supply chain network design*", "*optimization techniques for recycling location decision*" and "*optimization techniques for location decisions*". As search engine Google-scholar and FINDUT were used with no limitations on the search results. The results were filtered for papers written in the English language and more recent papers were preferred over older articles. References of interesting papers were checked in order to find more relevant information. There exist many techniques to obtain an optimal solution or design, or to improve a current solution. These techniques are described in literature. This section describes some of these techniques which fit to the SCND problem. This section will provide an answer to the research question above.

In its simplest form, an optimization problem consists of minimizing or maximizing a real function by using a technique which systematically chooses input values from within an allowed range of values and computing the value of the function. Adding more than one objective to an optimization problem adds complexity. For example in the case of reverse logistics of UBC, to optimize the structural design, one would desire a design that is both optimized for lowest costs and GHG-emissions while not interfering with customer satisfaction. When two objectives confilct a trade-off must be considered. However, there may be an infinite number of designs that are some compromis of these factors. Large problem instances often can not be solved to optimality. Such problems are called NP-hard. Therefore these problems often find the best available values of some objective function given a certain input. The set of trade-off designs that improve upon one criterion at the expense of another is known as the Pareto set. When a curve is created by plotting one variable against another, the best designs are known as the Pareto frontier.

In this section, several techniques for solving problems ranging from problems in their simplest forms to the NP-hard problems are discussed. The following techniques will be described: mathematical models and approximation algorithms and heuristics.

Mathematical models such as stochastic optimization and linear programming are often used to solve problems to optimality. An optimization model usually consists of several elements. First there is the objective function with the goal to maximize or minimize, depending on the problem. Secondly we have decision variables on which, as the name suggests, decisions have to be made. Lastly these decision variables are restricted by constraints which prohibits these decision variables to attain certain values. In other words, linear programming is a technique for the optimization of a linear objective function which is subject to linear constraints. Many real-life practical problems can be expressed as such linear programming problems and due to this advantage this technique is widely used in the field of optimization. Nonetheless, due to non-convexity, large-scale realistic problems cannot be solved in a reasonable amount of time.

Stochastic optimization methods are optimization methods for minimizing or maximizing an objective function that use random variables. Over the last decades, these models have become an essential tool in engineering. There is no single method that works well for all stochastic optimization problems. However there is a distinction between single stage and multiple stage problems. Single stage problems try to find a single and optimal decision, such as the best set of parameters for a statistical model. Multistage problems try to find an optimal sequence of decisions over a, for instance, five year period.

Many (integer) programming models cannot be solved efficiently due to NP-completeness. Therefore approximation algorithms exist. Approximation algorithms provide output with an upper or lower bound from the global optimum for the minimization or maximization problem respectively. This implies that the approximation algorithm will perform at most a certain factor worse compared to the best solution. This in contrast to heuristics, which provide good but not bounded solutions to a given problem.

One popular approximation method to discuss is Sample Average Approximation (SAA), which is an approach for solving stochastic optimization problems by the use of Monte Carlo simulation. This is done by approximating the expected objective function of the stochastic problem by a sample average estimate which is derived from a random sample. Hence the name Sample Average Approximation. The resulting SAA problem is solved afterwards by deterministic optimization techniques, which is repeated with different samples in order to collect candidate solutions and statistical estimates of the optimality gap. A solution approach whereby SAA is combined with a heuristic algorithm are very scarce in literature (Fattahi & Govindan, 2016).

Another popular method in literature is the Simulated Annealing (SA) method which is a probabilistic technique for approximating the global optimum. More specifically, it is a metaheuristic which approximates the global optimum in a large solution space for an optimization problem. It can be used for problems in which finding an appropriate solution in a reasonable amount of time, is more important than finding the precise (local) optimum. The SA algorithm is used to escape from local optima and find better solutions. The name and idea behind the algorithm stem from annealing in metallurgy in which heating and controlled cooling of a metal is conducted in order to get a stronger structure. The algorithm starts with an initial solution, which can be generated completely at random. Furthermore it needs a starting temperature and a cooling factor. A new solution is generated by making slight adjustments in the current solution. The new solution is accepted if it is better than the current solution. If it is worse, it still has a probability to be accepted as a region to explore. The acceptance of a worse solution is based on the Boltzmann probability distribution and this is used to escape local optima. The idea behind the Boltzmann probability distribution is that in the beginning of the SA algorithm, when the temperature is high, many (worse) solutions are accepted in order to explore the solution space. When the temperature gradually decreases, the chance for a worse solution to be accepted decreases as well. These processes are called diversification and intensification respectively. SA as a local-search based meta-heuristic for stochastic SCND is discussed by several authors in different settings, but stochastic models for SCND remain scarce in the related literature (Fattahi & Govindan, 2016).

4 Solution Design

This chapter answers research question 3 stated in Section 1.5 by applying the found literature in the previous Chapter 3 to the situation at Jumbo. The first Section 4.1 discusses the current situation with the requirements and constraints regarding the design. Section 4.2 covers the network design, including the mathematical model and the solution approach. Afterwards, the results are discussed in Section 4.3. The chapter is finalized in Section 4.4 with conclusions. This chapter will provide an answer to the following research question:

- **In what way can the found information in literature be used to propose a closed-loop system for the reverse logistics of empty beverage cans?**

4.1 Situation, Requirements and Constraints

The previously described literature in Chapter 3 has built the foundation for a solution which will be presented in this chapter. This section will be devoted to the elements of literature which will be applied to the model. Furthermore, the requirements and constraints of the model regarding the current situation will be evaluated in this section.

As can be read in the previous chapter, optimization of the closed loop is an important issue for the future. One of the critical success factors is to ensure availability of recycling locations. There seem to be two suitable options in order to obtain high availability of recycling locations. First of all, by using the retail method UBCs can be recycled in a method that is believed to be convenient for customers since most of us visit the supermarkets regularly. Secondly we can obtain high availability of recycling locations by using the kerbside collection method of building new collection sites for instance outside of the supermarkets. In this way, the convenience of handing in the UBCs for customers is believed not to be affected while simultaneously not place a burden on supermarkets. Furthermore, the kerbside collection method can be extended further by placing recycling centres closer to the point of consumption of beverages sold in cans. An important aspect relevant to both options are the cost of the system.

The literature describes that reverse logistics is more constrained than traditional forward logistics. However, supermarkets have become efficient in both their forward and reverse logistics by integrating forward and reverse logistics into a closed-loop supply chain. Both the kerbside collection and retail method should be able to cope with the uncertain timing and quality of returned UBCs. The various types and numbers of facilities are important strategic decisions in both recycling methods. When constructing the network design for the return of UBCs, it is suggested in literature to optimize for certain KPIs. In both methods of recycling the costs, customer satisfaction, burden on retailer and return volume are of great importance. Not all important KPIs can be modelled through a mathematical model for the design of a supply chain network. The next section discusses this mathematical model for the network design.

The scope of this research is limited to the trajectory of the reverse supply chain from collection points in the Netherlands to the reprocessors within the Netherlands. These reprocessors could be, depending on the scenario, DCs of the various supermarkets in the Netherlands, or locations of a (newly to form) organisation in the Netherlands.

In our scenarios, we can have different types of separation, namely source-separation or post-separation. Source-separation means that the UBCs are sorted from other waste at the household level after which the UBCs are transported for further processing at specialized plants. Post-separation means that UBCs are not sorted from other types of waste at the household level and need to be transported to separation centres together with other waste to be sorted. After this separation the sorted UBCs are transported for further processing at specialized plants. Source-separation requires the cooperation of consumers and extra infrastructures, therefore it is assumed to be more difficult and expensive to apply. Extra infrastructures to install at locations could be bar code scanners for instance. Furthermore, when the system does not accept a returned UBC, consumers need help in the form of staff. This makes, among others, source separation more expensive. In contrast, post-separation is easier to apply and can yield higher separation rate due to the fact that separation by machines is more efficient.

Our research starts by forming a list of scenarios first, after which the network modeling results will be compared of these scenarios. The scenarios are designed after interviews with various stakeholders. Source-separation seems to be applicable for all scenarios, as this is possible since the cans will have legislation and therefore need to be returned at specific locations. However, evaluating on scenarios in which the UBCs are mixed in with the current PET bottles in which a kind of post-separation is still needed, could be possible as well. According to the scenario study approach, the scenarios used in the modeling are designed as described in Table 4.1. Based on the current situation, we investigate the impacts of various strategic alternatives, furthermore these options (among others) are visualized in Figure 4.1:

1. Adopting a system that takes back UBCs via the supermarket (scenario 1 and scenario 2).
2. Adopting a system that takes back UBCs, not via but near supermarkets. Petrol stations and NS-stations are included in this model as well. These scenarios are similarly to the current glass containers (scenario 3 and scenario 4).

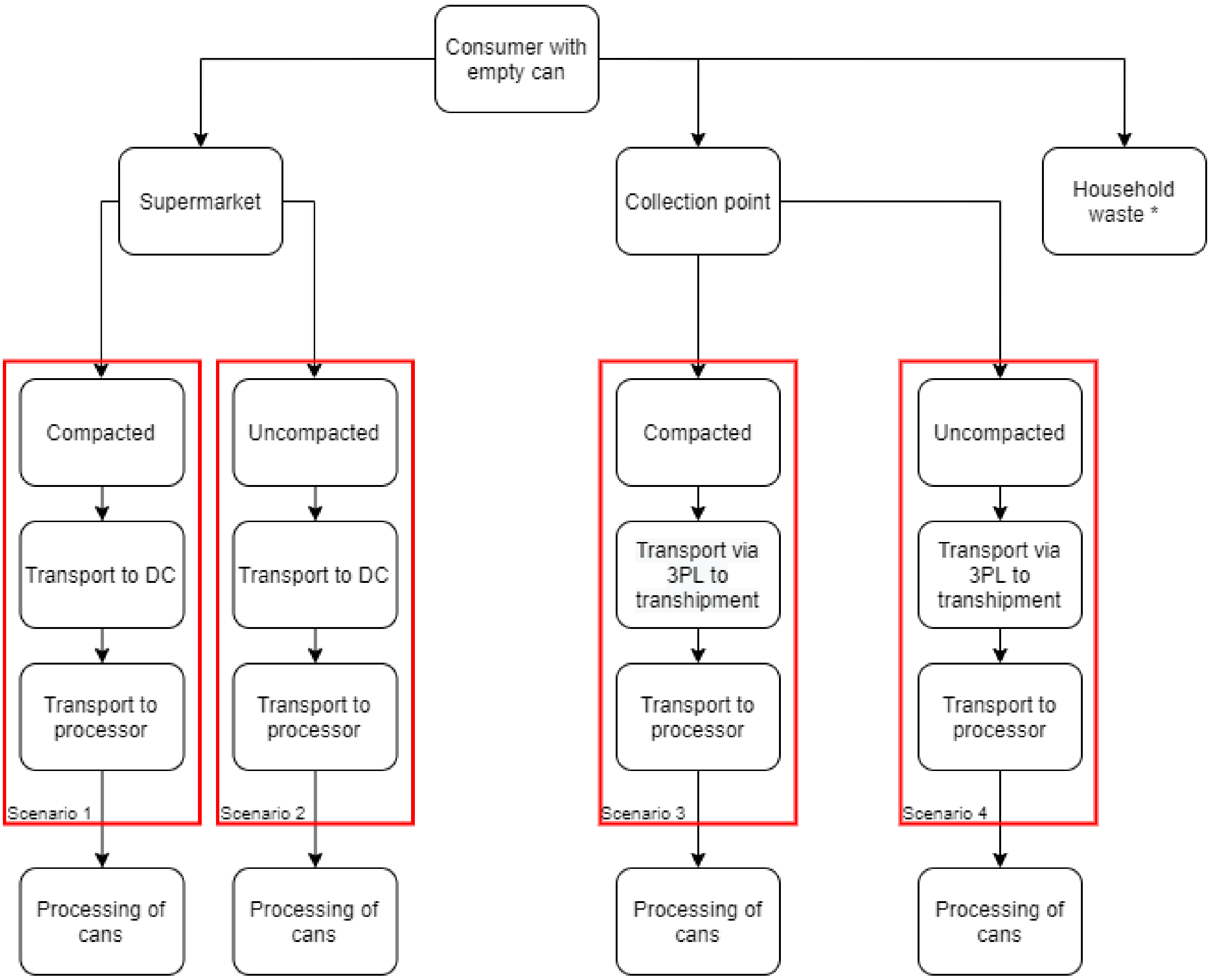


Figure 4.1: Flow of possible scenarios, the asterisk (*) indicates a scenario which is not considered in this research.

Resulting from both Figure 1.2 and the scenario input in the previous paragraphs, we created four scenarios. In order to clarify these scenarios, we evaluate these in Table 4.1 below:

Table 4.1: Overview of scenarios

Scenario	Recycling method	Separation	Compactor
Scenario 1	Supermarket	Source	Yes
Scenario 2	Supermarket	Source	No
Scenario 3	Kerbside	Source	Yes
Scenario 4	Kerbside	Source	No

These strategic alternatives take the differences in several important characteristics of the systems into account and are able to find a balanced solution for the stakeholders. This scenario study includes the building of a model according to these scenarios, with various assumptions for each of these scenarios with the aim to provide decision support for the decision of a network design for a system with deposit-refund on UBCs. As described in literature, there are several options for solving these problems. Mixed integer linear programming (MILP) is used in this network design problem. The objective of this MILP is to minimize the costs while simultaneously minimizing environmental impact. In each scenario, different layouts of the network and assumptions are used.

4.2 Network Design

The objective of this RL network design is to choose which collection centres to open and what capacity to install at this location. The capacity depends on both the installation of a RVM, which is automatically done by opening the collection centre, and the installation of a compactor which increases the capacity. Furthermore, the locations need to be assigned to a DC where the returned UBCs are transported to. The proposed solution can be seen in a smaller example in Figure 4.2 below.

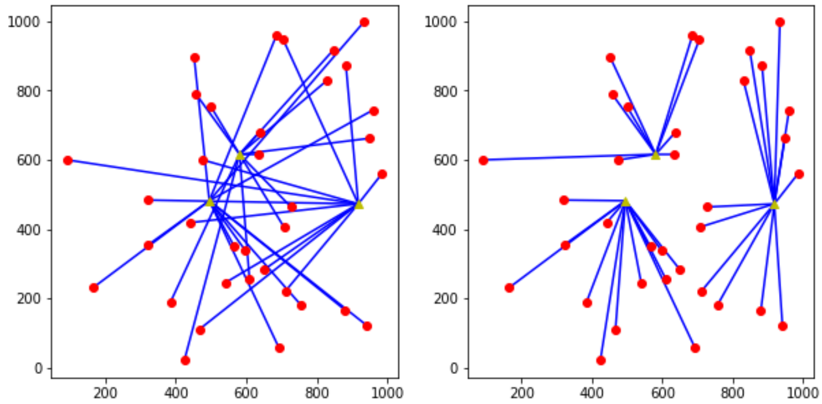


Figure 4.2: A small example of the proposed solution in which locations are assigned to distribution centres, according to the capacity of these distribution centres. The starting layout can be seen at the left, while at the right the final solution is shown.

At the left side of the figure we can see the unsolved model, at the right side we can see a proposed solution for the solved model. The red dots indicate locations which are connected with blue lines to the distribution centres indicated with yellow triangles. At each of these red dots, a certain amount of RVMs and compactors are installed.

4.2.1 Mathematical Modelling

As shown in Figure 3.1, the UBCs are returned by customer zones into collection centres. These collection centres can be located both inside and outside of supermarkets. The returned UBCs are transported from collection centres towards distribution centres. This RL network has a convergent structure from customers to recovery centres and distribution centres. In order to specify the model, several assumptions are made:

1. All of the returned UBCs presented to the collection centres by customers, must be collected. No UBCs are rejected because of quality issues such as cans which are (severely) dented.

2. The capacity of technologies such as the RVMs and compactors at locations is known in advance. The capacity of distribution centres is also known in advance. It can however happen that the capacity at locations or distribution centres are exceeded. The location or distribution centre that exceeds its capacity, will incur penalty costs. These costs consists of, but are not limited to, for instance the allocation of extra space. Furthermore, extra work and loss of productivity are also part of these penalty costs.

3. The volume of the returned UBCs (mostly 25cl, 33cl or 50cl) are irrelevant for the capacity of both the collection centres and distribution centres.

4. There is no difference in efficiency between the same type of facilities and machines.

The objective of this RL network design is to choose which collection centres to open and determining which facilities will be equipped with compactors, this with the aim of minimizing the total costs. First, the sets will be introduced and described, followed by parameters and decision variables. Finally the model, including its objective function and constraints, is formulated and explained afterwards. The following notations are used in the formulation of the model. The model can be found on the next page.

Sets	Description and indice(s)
S	set of candidate points for collection centres
D	set of distribution centres
T	set of reprocessing centres

Parameters		Description
q_s	=	amount of returned UBCs at collection point s
f_s	=	fixed cost to set up a collection center at location s
caf_s	=	capacity of the RVM at the collection center s
cac_s	=	capacity of the compactor at the collection center s
cp_s	=	fixed cost to install compactor at the collection center s
c_{sd}	=	transportation costs from location s to location d

Variables		Description
X_{sd}	=	amount of transported UBCs from collection centre s to distribution centre d
Z_{dt}	=	amount of transported UBCs from distribution centre d to reprocessing centre t
W_t	=	amount of UBCs processed at processing centre t
Y_s	=	$\begin{cases} 3 & \text{if 3 RVMs are installed at location } s \\ 2 & \text{if 2 RVMs are installed at location } s \\ 1 & \text{if 1 RVM is installed at location } s \\ 0 & \text{otherwise} \end{cases}$
P_s	=	$\begin{cases} 3 & \text{if 3 compactors are installed at location } s \\ 2 & \text{if 2 compactors are installed at location } s \\ 1 & \text{if 1 compactor is installed at location } s \\ 0 & \text{otherwise} \end{cases}$

Objective Function:

$$min \left(\sum_{s \in S} f_s Y_s + \sum_{s \in S} cp_s P_s + \sum_{s \in S} \sum_{d \in D} cs X_{sd} + \sum_{d \in D} \sum_{t \in T} cd Z_{dt} + \sum_{t \in T} ct W_t \right) \tag{4.1}$$

Subject To:

$$\sum_{d \in D} X_{sd} = \sum_{p \in P} q_s \quad \forall s \in S \tag{4.2}$$

$$\sum_{d \in D} \sum_{t \in T} Z_{dt} = \sum_{d \in D} X_{sd} \quad \forall s \in S \tag{4.3}$$

$$\sum_{t \in T} W_t = \sum_{t \in T} Z_{dt} \quad \forall d \in D \tag{4.4}$$

$$\sum_{d \in D} X_{sd} \leq caf_s Y_s + cac_s P_s \quad \forall s \in S \tag{4.5}$$

$$P_s \leq Y_s \quad \forall s \in S \tag{4.6}$$

$$Y_s - P_s \leq My \quad \forall s \in S \tag{4.7}$$

$$P_s \leq M(1-y) \quad \forall s \in S \tag{4.8}$$

$$Y_s, P_s \in \{0, 1, 2, 3\} \quad \forall s \in S \tag{4.9}$$

$$X_{sd}, Z_{dt}, W_t \geq 0 \quad \forall s \in S, \forall d \in D, \forall t \in T \tag{4.10}$$

In this model, the objective (4.1) is to minimize the total costs incurred by opening collection centres and thereby installing RVMs, the installation costs of a compactor and transportation costs between the facilities. As stated, the model has the ability to increase the amount of RVMs and compactors placed at a location. The maximum amount of RVMs and compactors to be installed at a certain location is limited to three. The installation of these extra RVMs and compactors comes with extra costs. However, a trade off can be made between incurring extra costs for the installation of these extra machines and the reduced costs for transportation. The first term in the objective function determines the costs of the amount of RVMs installed at the opened locations. The second term regulates the costs of the installed compactors. The last two terms of the objective function describe the costs of transportation.

Constraint (4.2) ensures that all returned UBCs are collected by the collection centres. This means that all UBCs presented to the system at this location, have to be accepted at this location. It is assumed that no UBCs are rejected due to quality issues such as dented cans, since it is expected that this fraction is negligibly small.

Constraint (4.3) and (4.4) assure the flow balance from collection centres towards distribution centres and flow balance between distribution centres and reprocessing centres respectively. The capacity at these distribution centres is assumed to be sufficient at all times. Furthermore, there is no restriction on which distribution centre to choose. A location does not need to have a fixed distribution centre to which the UBCs are transported. However, the flows are not splitted.

The capacity of a collection centre should be sufficient for the amount of returned UBCs, which is regulated in constraint (4.5). This constraint prohibits the UBCs being returned to a location that has not been built and it also ensures that the amount of returned UBCs does not exceed the capacity of the location. Extra capacity can be created by installing a compactor. A compactor cannot be placed in a location which is not opened, this is regulated by constraint (4.6). Constraints (4.7) and (4.8) regulate the exact amount of compactors to be zero, or equal to the amount of RVMs. This constraint is needed since we cannot have 2 RVMs with only 1 compactor, for instance. However, we can have 2 RVMs without any compactor. If we decide to install compactors on a location, we need the exact amount of compactors to be equal to the amount of RVMs at that location.

Finally, constraints (4.9) and (4.10) enforce the binary and non-negativity restrictions on the corresponding decision variables. The resulting model is a MILP with continuous and binary variables and several constraints. The NP-hardness of the (reverse) logistics network design has been proved in many researches.

4.2.2 Context Analysis and Data Generation

This subsection is devoted to the explanation of the parameters, context and data generation. Furthermore, the value of the parameters can vary among the different scenarios which will be used for solving the model. The parameters will be explained together with a clarification of how these values are derived and determined. Furthermore, the data generation will be explained.

The reverse logistics network discussed in this research is a multistage logistics network including customers, collection points, distribution centres and disposal centres of which some have a limited capacity. As shown in Figure 3.1 and described in the scenarios in Figure 4.1, returned cans are collected from customer zones into collection points. These UBCs are then transported to distribution centres and disposal centres. The disposals may include any form of recycling, but this is out of the scope of this research. As stated in the section before, the objective of this reverse logistics network design is to choose the locations of collection points and to determine the number of RVMs and compactors on these locations taking transportation between facilities into account, such that the lowest possible costs are incurred. It is worth noting that the returned amount of cans depends on the success of the collection activities. However, supply of these UBCs can be estimated based on the consumption of new products. The return flow can therefore be based on the sales of beverages sold in cans. Considering several cases in literature, we consider several parameters. These parameters are subject to stochasticity, which is accounted for in several runs of the model.

Since there are currently about 700 Jumbo stores and even more other supermarkets and possible sale locations, we want to test for scalability of our proposed method. In order to test for scalability of our approach, we first solve the model with data that contains increasing instances. To assess the performance of our model, several numerical experiments are implemented and conducted. The related results are reported in Section 4.2.3. To this aim, six test problems with increasing sizes are considered and for each size, the experiments are performed under deterministic levels of returned UBCs as can be seen in Table 5.3. In order to test for scalability, the first 50 locations are selected at random. Next, the first 50 locations remain the same and we select another 50 new locations at random resulting in a total of 100 random locations. In the next step, we remain the same 100 locations and select another 50 new random locations resulting in a total of 150 random locations. This process is repeated until we have 250 random locations, after which we perform one more run at 350 locations. Besides comparing the used algorithms, we can test our approach for scalability.

Data collection on parameters for building up the model took place in cooperation with experts in the (food) retail field through interviews as described in Section 2.3. Considering cases in literature, we consider several parameters of which some are subject to stochasticity. The data for the parameters in the instances was generated as follows:

1. In practice, the transportation costs of UBCs is subject to stochasticity and therefore range between an upper bound (UB) and lower bound (LB). However, we assume deterministic transportation cost. The costs are expressed as costs per can. The total costs are based on expert opinions. The transportation costs include fuel and the hourly wage of the truck driver. Furthermore the capacity of a truck is assumed to be 33 containers with each container having the capacity of one UBC BigBag. On top of that the average distance from a recycling location to a DC is assumed to be 35 kilometres, based on expert opinions. Including hourly wage and fuel the average cost per kilometre is €1. Therefore based on these numbers, the average cost per transported UBC is assumed to be €0.007. This costs is expected for both scenarios 2 and 4. For scenarios 1 and 3, we assume that the compactors result in less transport needed and therefore the costs are assumed to be €0.0035 per can, or we can say that using a compactor, transportation gets twice as efficient. This assumption is based on the fact that transportation can be arranged more efficiently in these scenarios. Transportation between different facilities is assumed to be equal for all scenarios.

2. The amount of returned UBCs were determined according to a uniform distribution between an upper bound (UB) and lower bound (LB). These UBs and LBs are different for the low, medium and high scenarios in order to analyse the impact of seasonality. As discussed before, the amount of returned UBCs depends on several factors. Expert opinions suggest three possible scenarios: low, medium or high volumes of returned UBCs. These scenarios will have a different percentage of the sold UBCs being returned, with 75%, 85% and 93% respectively. For instance, in summer we see more consumption of beverages and therefore more returns. The amount of returned UBCs is based on the current returns of PET bottles. Due to interviews with stakeholders, it is assumed that cans and PET bottles will somewhat have the same return volumes. The expected return volumes of UBCs are based on yearly data of almost 700 Jumbo supermarkets. In order to generate these data points, randomly drawn numbers correspond to a certain value of UBCs.

3. The fixed costs of installing RVMs and compactors at locations can in practice vary. The variation in costs that are caused by this method can be seen as variable costs during installation of RVMs and compactors caused by (minor) incidents. However, we assume prices to be deterministic. In the current retail method of recycling for PET, there are already RVMs in place. With minor adjustments to current RVMs these could be compatible for many more years when returning UCBs trough the retail method. However, this does not hold for all RVMs in the supermarkets. Furthermore the kerbside option requires to operate the RVMs in all weather conditions such as rain and frost but high temperatures as well. The costs of the installation of RVMs in the kerbside method therefore is more expensive. The depreciation is expected to be around 8 years, this is however not accounted for in the model. The assumed costs for a RVM in the retail method is €20.000 compared to the assumed costs of a RVM in the kerbside collection method of €30.000. The compactor can be installed at locations with already existing RVMs or at newly built RVMs. There is no price difference for these options. However, a compactor on its own doesn't work and therefore a RVM has to be built. The depreciation is expected to be around 8 years, this is however not accounted for in the model. The cost of installing a compactor is assumed to be equal in both retail and kerbside collection method, since the kerbside collection method already accounts for a location to be suitable for operating in all weather conditions. The costs for each compactor is based on expert opinions and assumed to be €13.500.

4. The capacity of both the RVMs and compactors vary uniformly between X and Y. The capacity of RVMs inside supermarkets is smaller due to space allocation, compared to RVMs outside which typically are less constrained in their space occupation. The capacity of the RVMs is based on the current top 10% capacities of RVMs for returning large PET bottles. The capacity is not only based on the physical capacity but on the processing and therefore waiting time for customers as well. The capacity of a single RVM is assumed to be 400.000 units per year. However, these capacities vary among the different scenarios as well. Based on expert opinions the compactors increase the capacity of recycling locations by a factor two to three. This two- to threefold increase is achieved by the fact that less space occupation is needed for a bigger amount of returned UBCs. The presence of a compactor only increases the physical capacity.

Taking all the variable input for these parameters into account, we can create several scenarios. In total four scenarios will be evaluated.

4.2.3 Two-phase Solving Approach

As mentioned before, it is clear that it is difficult to solve the problem for a reasonable size. Therefore, the metaheuristic SA as described in the previous subsection is used to solve this problem. SA can be used to escape from local optima and find better solutions. The better solutions are always accepted, whereas inferior solutions are accepted based on the Boltzmann probability distribution. Figure 4.3 displays the solving approach for our problem and consists of two phases. The initial solution which is required for the SA algorithm is created at random. However this is a feasible solution, since the SA needs a feasible solution to start with. The random starting solution is feasible since we assume to have unlimited capacity, however when a distribution centre exceeds the capacity this location incurs penalty cost. Therefore, the random solution is most likely to be a worse solution. Next, the initial random solution is improved using the SA in Python.

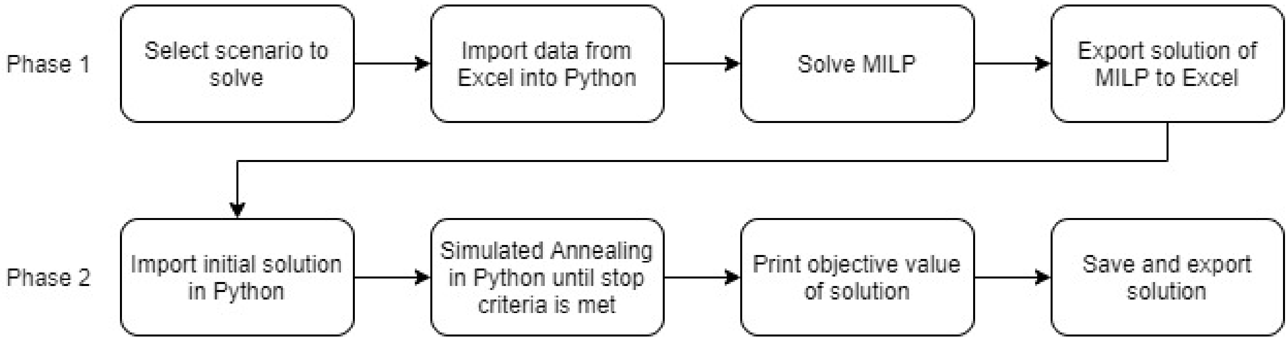


Figure 4.3: Two-Phase Solving Approach Flowchart

First in phase 1 a scenario is selected in order to optimize. Next, the scenario specific data is imported from an Excel-file into Python after which the MILP is solved. As stated before, the locations are randomly assigned to any of the distribution centres. This MILP and randomly assignments result in a feasible initial solution. It furthermore decides on the technologies to install at each of the locations, such that the capacity is sufficient and costs are minimized. However, due to the difficultly to solve the problem with the suggested MILP, we solved a reduced mathematical model. Constraints (4.3) and (4.4), which assure the flow balance from collection centres towards distribution centres, are neglected in solving the MILP in phase 1 of our solution. After the MILP is finished, it is saved and exported into Excel after which it is again imported into Python where phase 2 starts. In this phase, we use SA which does not neglect both constraints (4.3) and (4.4). The SA is done until the stop criterion is met after which we obtain a objective value. Finally, the solution and its result is saved and exported for later use in the Simheuristic (explained in Section 5.2). In Figure 4.4, the distinction between both phases is illustrated. As can be seen, in phase 1 we solve the capacity problem which we face at each of the locations. In phase 2, we solve the facility-location problem regarding distribution from locations towards DCs.

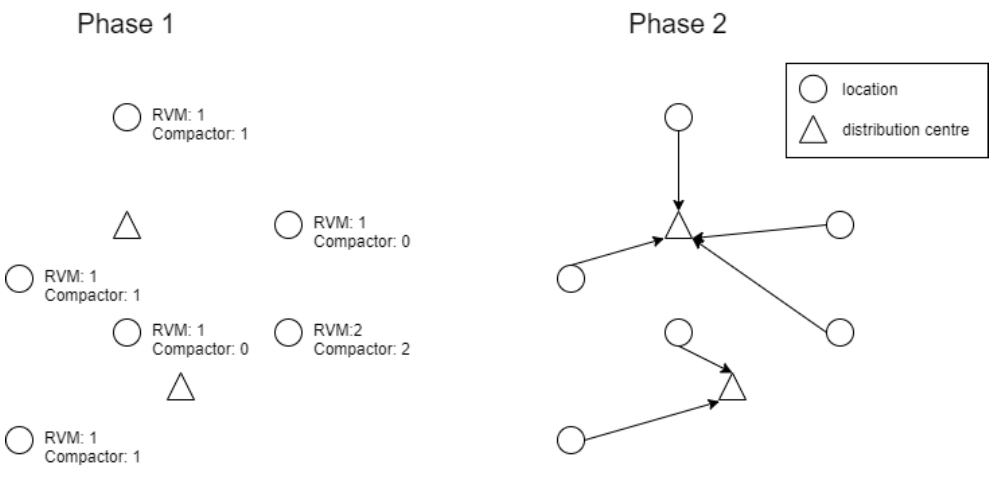


Figure 4.4: Example of phase 1 and phase 2

Our solving approach is based on the paper of Pishvaee, Kianfar and Karimi and Lalla-Ruiz, Heilig and Voβ (Pishvaee et al., 2009; Lalla-Ruiz, Heilig, & Voβ, 2020). They both provide a method of generation of neighbour solutions. Our approach is based on a part of their approach, but then slightly adjusted to better fit our problem. We generate a neighbour solution using the location-distribution centre combination. The swap operator is than used in order to swap the distribution centre with another for a certain amount of locations, depending on the stage of the SA. Figure 4.5 illustrates a possible 2-swap. We randomly select two locations L1 and L2 such that L1 $\neq$ L2, we then randomly select a new distribution centre for this location such that this distribution centre is not the same as in the current situation. It can happen that both locations L1 and L2 get assigned to the same new distribution centre, but it can not happen that their original distribution centre remains the same. We therefore swap their current distribution centre and evaluate the solution. A complete overview of our proposed algorithm is provided in the next section.

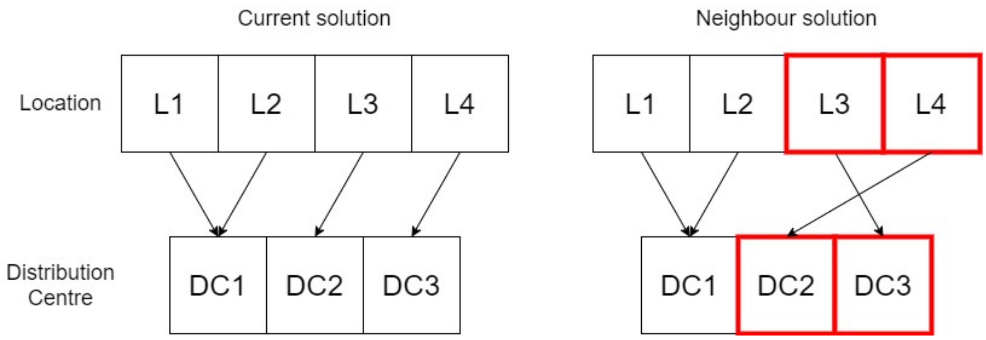


Figure 4.5: k-swap operator, with k=2

4.2.4 Algorithm Design

Simulated Annealing (SA) is among the most popular iterative methods that have been applied in research to many combinatorial optimization problems. The SA method is based on random local search techniques inspired by principles of physics. The use of SA in the design of reverse logistics network is scares in current day literature. However, due to its simplicity and speed of SA over other methods this approached is favoured.

The SA method is a probabilistic technique for approximating the global optimum. More specifically, it is a metaheuristic which approximates the global optimum in a large solution space for an optimization problem (Kirkpatrick, Gelatt, & Vecchi, 1983). It can be used for problems in which finding an appropriate solution in a reasonable amount of time, is more important than finding the precise optimum. The SA algorithm is used to escape from local optima and find better solutions. The name and idea behind the algorithm stem from annealing in metallurgy in which heating and controlled cooling of a metal is conducted in order to get a stronger structure. The SA algorithm starts with an initial solution, which can be generated completely at random. Furthermore it needs a starting temperature (T) and a cooling factor (α). A new solution (N) is generated by making slight adjustments in the current solution (C). The new solution is accepted if it is better than the current solution. If it is worse, it still has a probability to be accepted as a region to explore. The acceptance of a worse solution is based on the Boltzmann probability distribution ($e^{\frac{N-C}{T}}$) and this is used to escape local optima.

The idea behind the Boltzmann probability distribution is that in the beginning of the SA algorithm, when the temperature is high, many (worse) solutions are accepted in order to explore the solution space. When the temperature gradually decreases, the chance for a worse solution to be accepted decreases as well. These processes are called diversification and intensification respectively. As stated before, SA as a local-search based meta-heuristic for stochastic SCND is discussed by some authors in different settings, but stochastic models for SCND remain scarce in the related literature.

In SA algorithms, neighbourhood searches are used in order to evaluate the solution space of the problem. These neighbours are used as a way to explore this solution space. Although better neighbours are preferred, metaheuristics such as SA also accept worse neighbours in order to avoid getting stuck in local optima. In order to visit these neighbours, some swaps or moves in a current solutions have to be made. Inspired by the work of Pishvaee, Kianfar and Karimi, we suggest a SA algorithm which uses three neighbourhood search methods, consisting of three stages (Pishvaee et al., 2009). In the first stage, each element of the solution vector is randomly selected with equal chance to be changed using a 4-opt neighbourhood swap in which four locations are subject to change. In the second stage at lower temperatures, three locations are subject to change in a 3-opt neighbourhood swap. At the third and last stage, we focus more on intensification by selecting two locations that are subject to a change using a 2-opt neighbourhood swap. The swap consists of switching from a certain location-distribution centre combination, to the same location but different distribution centre combination. So in our approach at high temperatures in the SA we use a 4-opt neighbourhood search to achieve more diversification and to take bigger steps towards better solutions. At lower temperatures, the 2-opt neighbourhood search is used to achieve more intensification and search more carefully around the found solution. Experimenting with this suggested SA leaded to good results in the term of low cost. However the downside of this approach was very long run times.

Due to the poor run time performance of this SA algorithm when used for the 700 location instance, we considered variable neighborhoods (SA-VN)(VNS) as proposed by the works of Lalla-Ruiz, Heilig and Voβ (Lalla-Ruiz et al., 2020). They performed a Simulated Annealing with Variable Neighborhoods (SA-VNS). In order to evaluate the contribution of variable neighbourhoods within SA, we used the same locations, demand and settings for solving the problem. The SA was extended in which a parameter k was introduced for regulating the change of the neighbourhood structure, as can be seen in the pseudo-code of Algorithm 1 below. We apply the k-swap neighbourhood structure. That is, given a solution, the swap neighbourhood performs the transposition by swapping a location-distribution centre combination as described before. In order to compare these results to the initial SA algorithm based on the works of Pishvaee, Kianfar and Karimi, the same instances were used. Both algorithms are coded in Python 3.8 and Spyder software is used to optimize and compare the results. All the problems are solved on Intel core i7 8th gen computer.

Algorithm 1: SA with variable neighbourhood

Require: $Temp_{min}, \alpha, it_{max}$

$S \leftarrow$ get randomly generated solution;
initialization;
while ($Temp_{min} \leq Temp$ `and` $it \leq it_{max}$) **do**
  Generate a solution $S' \in \mathcal{N}^k(\phi)S$;
  Calculate $\Delta_{S,S'} = f_{obj}(S') - f_{obj}(S)$;
  if ($\Delta_{S,S'} \leq 0$) **then**
    $S \leftarrow S'$;
    $k \leftarrow 1$;
    Update best solution S_{best} if applicable;
  else
    $S \leftarrow S'$ with probability $e^{-\Delta/Temp}$;
    $k{+}{+}$
  end
  $Temp = Temp \times \alpha$;
  $it{+}{+}$;
end

The above shown algorithm applies the swap neighborhood structure. That is, given a solution $\phi \in S_n$, the swap neighbourhood, $\mathcal{N}^1(\phi) = \{\phi \circ (i,j) : 1 \leq i,j \leq n, j \neq i\}$, preforms the transposition of the arc (i,j) by swapping the distribution centre i assigned to a location j. We define $\mathcal{N}^k(\phi)$ as the application of k-swaps consecutively. In the next chapter, the results and analysis of the solution design are evaluated.

5 Solution Test

This chapter starts with the results of the solution design and an analysis on these results. In this chapter we will explain the experimental settings, summarize how the scenarios were generated and finally the outcome of these results. After that in the next section, we start with the description of uncertainty in our solution design and why this uncertainty should be dealt with. This section is followed by in Section 5.2 which explains the scenario description and stochastic analysis of our approach. The outcomes of this section is evaluated in Section 5.3. This chapter will provide an evaluation on the performance of the proposed designs under different stochastic conditions and thereby provide an answer to the following research question:

- **What results can be expected from the proposed solution designs?**

In order to answer this question, several experiments will be done as already explained in the introduction. In order to get a clear overview of the experiments, Table 5.1 below provides information in the form of an overview of the experiments carried out along this section, including a description of the goal of these experiments.

Table 5.1: Overview of experiments with an explanation of the goal of each experiment.

Experiment	**Goal**
1	Explanation of experimental settings and scenario generation
2	Deterministic analysis of the mathematical model
3a	Analysing the performance of proposed solution under stochastic amounts of returned UBCs
3b	Analysing the performance of proposed solution under stochastic capacity of the installed RVMs and compactors

5.1 Results and Analysis

This section describes the computational results obtained for the different scenarios and provides a short analysis on these results. All scenarios are coded in Python 3.8 and Spyder software is used to optimize and compare the results. All the problems are solved on Intel core i7 8th gen computer. As displayed in the previous chapter, we used the SA and SA-VN algorithm. The SA-VN algorithm will be used to solve each of the four scenarios described in Section 4.2.2. Further in this section, we will explain why this algorithm is used.

As stated in Table 5.1, experiment 1 is conducted in order to explain experimental settings and scenario generation. In order to illustrate this problem, we provided a small problem with a solution consisting of the amount of RMVs and compactors to install at certain locations and to which distribution centre these locations to assign. In order to make this work, we took 35 random locations to assign to 3 DCs. This is displayed in Figure 4.2 in the previous Chapter 4. This experiment is used to solve the test experiment, using the mathematical model. As stated in Chapter 4, we used Python to solve the mathematical model. More specifically, we tried using multiple libraries (PuLP, MIP and Gurobi), however, all of these packages could not cope with the non-linear constraint of dividing the returned UBCs over the DCs while minimizing for both transportation cost and penalty cost. In order to overcome this problem, we relaxed this constraint and solved the model. That is, for each location the amount of RVMs and compactors to install were determined, as well as which DC to allocate its returned UBCs to. However, this solution is optimal if we leave out the weighted penalty for each location and DC. The model is not able to solve to optimality in reasonable time if we include the weighted penalty constraints. We therefore introduced the SA-VN, as discussed in the previous chapter, since we wanted to include the weighted penalty which comes from allocating extra space and allocating extra work among others.

The results of the mathematical model solved with relaxed constraints can be found in Table 5.2 below. Notice that the optimality gap is very small, this however is due to the fact that we left out the most binding constraint of capacity. It is worth noticing that, even without this very limiting constraint the model is not able to be solved to optimality. This finding justifies our two-phase solving approach. This approach has been extensively discussed in the previous Chapter.

Table 5.2: Overview mathematical model performance when solved with Gurobi package in Python.

Instance	Objective	Gap
50	240514	0,0059%
100	2727677	0,0065%
150	4252365	0,0086%
200	5751040	0,0094%
250	7248906	0,0056%

The returned amount of UBCs for each of the scenarios were generated according to the process described in the previous chapter. Since we did not have access to existing data, because there is currently no legislation on beverages sold in cans, we extrapolated the return of beverages sold in PET-bottles on the expected return of beverages sold in cans. Note that we had to use PET-bottles larger than 1 liter, since at the time of gathering this data, there was no legislation on smaller PET-bottles in place as well. Since a few months, legislation on smaller PET-bottles is also in place. However, using this data could provide a distorted view of reality since we can not use sufficient amount of data. Therefore, we believe the use of data from beverages sold in larger PET-bottles is justified. A side note is that the data generation according to this method, can deviate from actual data on the return of UBCs since the point of consumption is different for large PET-bottles compared to beverages sold in cans. However, according to expert opinions we assume that the overall pattern will be similar. Therefore, the distribution used for the generation of returned UBCs per location, is showed in Figure 5.1 below.

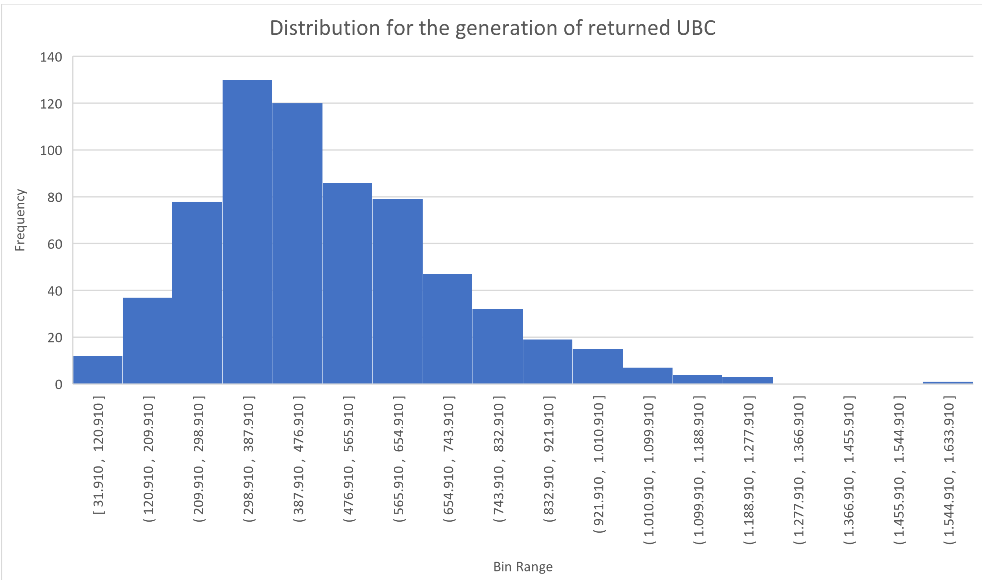


Figure 5.1: The used distribution to generate returned UBCs per location.

After the experimental settings and scenario generation, we concluded that we need to solve the model including penalties. Therefore, we designed the SA-VN as described in the previous chapter. The second experiment, as can be seen in Table 5.1, is done in order to do a deterministic analysis of the mathematical model using the SA-VN algorithm. In order to choose the best algorithm, we first started with a comparison of both the SA and SA-VN algorithm. Table 5.3 shows the comparison between the regular SA algorithm and the SA-VN algorithm, in which we use a k-swap operator to increase the neighborhood in search for better solutions. For each problem instance, the performances of the algorithms are given in terms of an average objective value, best objective value, worst objective value and the computational time. The bold printed results are the best achieved minimum for that problem instance.

Table 5.3: Overview algorithm performance

SA_{1-swap}					$SA-VN_{k=1}$				
Size	Min	Avg	Max	Time (s)	Size	Min	Avg	Max	Time (s)
50	3162070	3163573	3166210	27,96837	50	3162070	3163573	3166210	27,96837
100	6216230	6217180	6219150	52,84121	100	6216230	6217180	6219150	52,84121
150	9709860	9712348	9715700	78,08354	150	9709860	9712348	9715700	78,08354
200	12984800	12987130	12991200	106,052	200	12984800	12987130	12991200	106,052
250	16346700	16351540	16357800	130,511	250	16346700	16351540	16357800	130,511
350	23570700	23575340	23580800	182,4133	350	23570700	23575340	23580800	182,4133
SA_{2-swap}					$SA-VN_{k=2}$				
Size	Min	Avg	Max	Time (s)	Size	Min	Avg	Max	Time (s)
50	3161800	3163637	3166310	30,24834	50	**3161800**	3162552	3164160	**28,11944**
100	6216890	6219588	6225140	55,34162	100	**6215190**	6216296	6217100	**53,37941**
150	9714660	9716985	9718930	80,52135	150	**9709190**	9711173	9714160	**79,24694**
200	12990300	12997090	13004700	106,6928	200	**12984100**	12986550	12989900	**105,8185**
250	16356200	16362150	16368100	**131,6875**	250	**16348100**	16352020	16354000	135,6934
350	23588300	23598510	23611000	**184,6184**	350	**23569600**	23574110	23579100	188,6062
SA_{3-swap}					$SA-VN_{k=3}$				
Size	Min	Avg	Max	Time (s)	Size	Min	Avg	Max	Time (s)
50	3162420	3166975	3172140	31,19315	50	**3161800**	3162534	3165400	**28,37471**
100	6224640	6231278	6236310	56,77654	100	**6215190**	6216863	6219620	**53,61025**
150	9735830	9743382	9749420	81,83081	150	**9709190**	9711862	9715280	**78,65484**
200	13013100	13034450	13055900	107,9344	200	**12984700**	12987960	12994200	**103,9003**
250	16404200	16423720	16441000	133,0552	250	**16348400**	16350780	16356900	**130,704**
350	23673400	23709620	23750000	186,8802	350	**23569600**	23573340	23578200	**182,6382**
SA_{4-swap}					$SA-VN_{k=4}$				
Size	Min	Avg	Max	Time (s)	Size	Min	Avg	Max	Time (s)
50	3168320	3176482	3186060	32,59415	50	**3161800**	3162776	3164800	**28,10579**
100	6237310	6254255	6270530	58,20101	100	**6215810**	6217279	6219100	**54,00118**
150	9765630	9784729	9811010	82,81087	150	**9709410**	9711487	9715520	**78,72806**
200	13082200	13103510	13115400	109,1805	200	**12984500**	12988070	12991900	**105,4809**
250	16454200	16499290	16535200	135,1491	250	**16347800**	16350960	16354600	**132,8579**
350	23817300	23854650	23891600	188,3979	350	**23570700**	23573990	23578200	**184,3666**
SA_{5-swap}					$SA-VN_{k=5}$				
Size	Min	Avg	Max	Time (s)	Size	Min	Avg	Max	Time (s)
50	3175280	3189511	3197460	33,85183	50	**3161800**	3163196	3166530	**32,61601**
100	6270520	6282038	6294990	58,89895	100	**6216340**	6218327	6220980	**58,04761**
150	9814900	9835980	9865030	84,49617	150	**9709420**	9714554	9722390	**83,88143**
200	13140100	13173960	13210300	110,5784	200	**12984500**	12994060	13004900	**109,2294**
250	16561900	16592050	16624100	**136,4941**	250	**16350900**	16360840	16366300	137,1259
350	23958600	24003880	24075400	189,4739	350	**23584200**	23604430	23618900	**188,1068**

From these results, it can be seen that the SA-VN algorithm obtains similar or in most cases even better results as the standard SA. The best found objective value and computational time for each instance is printed in bold in the table. In terms of difference between the increasing amounts of k-swaps VN, we can conclude that a larger neighbourhood does not necessarily lead to better solutions. Surprisingly, even the opposite seems to be true. The smaller neighbourhood seems to achieve marginally better results. One explanation for slightly worse results in the SA-VN with k-swap = 5 could be that making 5 swaps at once results in a too high probability of at least one very worse swap, which increases the total costs. Especially in the beginning these can be accepted by a fairly high probability, which do not necessarily get selected for another swap in the next iterations. In order for fair comparison, we used a maximum of 100 iterations for each of the instances. All instances were solved for scenario 1 and had the same deterministic amount of returned UBC.

Recall from Section 4.1 that we divided the problem into four scenarios, which we refer to as scenario 1 through 4. For the complete scenarios, instances of 700 (scenario 1 and scenario 2) and 1000 (scenario 3 and scenario 4) are used. With the increase in instances for the SA and SA-VN to solve, the computational time increases as well. However, the SA-VN was able to find a reasonably good solution for each of the scenarios.

The results of these solution fix the layout of the SCND, which will be evaluated further in the next sections. The results look like the small scale problem as displayed in Figure 4.2, but than with much larger instances.

After experimenting with the first scenario, we conclude that we cannot obtain a reasonable solution with the mathematical model, as described before. Using Python we experimented with multiple solvers, but this did not yield a reasonable initial solution. The initial solution we got from the mathematical model by relaxing the constraint that assigns the location to a distribution centre, yielded a feasible initial solution by assigning the location to a random distribution centre. This did not take the optimal assignment of locations towards distribution centres into account. However, the model solved the amount of RVMs and compactors to assign to each location.

Whenever a neighbour solution is created using the SA or SA-VN algorithm, it is checked for feasibility based on the constraints of the mathematical model. In contrast to the first phase of the solving approach, the SA and SA-VN do not relax any of the constraints. Instead to make the constraints feasible, a penalty is included when one of the constraints is not respected. So in order to clarify, the constraint is altered compared to the original, in which a variable penalty is added. That is, a variable penalty cost is incurred if the model breaks any of the constraints such as the maximum capacity. The variable penalty consists of a fixed part which is always incurred if the capacity is exceeded plus a variable amount which increases when the limit is further exceeded. The constraint of course still holds if no penalty is incurred. As described previously, after some trial and error we found that the k=5 swap operator improves the solution the most often. The SA-VN algorithm improves the solution as expected by selecting better combinations between locations and distribution centres. The results for the four scenarios can be found in Table 5.4 below.

Table 5.4: Overview of the improvement using the SA and SA-VN algorithm, with the average amount of installed technologies at the locations.

Scenario	**Start**	**End**	**Improvement (%)**	**Avg RVMs**	**Avg Compactors**	**Time (s)**
1	80622353	57675269	28%	1,11	0,54	931
2	77978789	77347414	1%	1,69	0	936
3	123447936	94148872	24%	1,10	0,55	1332
4	161083799	123275037	23%	1,69	0	1352

In scenario 1 the model is allowed to use both RVMs and compactors, taking only supermarket locations into account. The first assignment to the DCs is at random, therefore this solution obtains a very high cost. The SA-VN improves on this cost during several iterations. What is interesting to see is that in most locations the model chooses to install 1 or 3 RVMs and in the case of 3 RVMs, the model does not choose to install any compactors. On the other hand, this can be explained by means of the cost and capacity that both technologies have. An overview of the total amount of installed RVMs and compactors in all scenarios can be seen in Table 5.5. Note the asterisk in the table. As stated in the model description, the maximum amount of RVMs was set to 3. However, due to the fact that scenario 4 was not able to use compactors, the model was not able to be solved since the demand for UBCs exceeded the capacity. Since no penalty could be incurred in this model, this temporary feature was added to solve the model.

Table 5.5: Overview of the amount of installed RVMs and compactors per scenario

	RVMs				**Compactors**			
	1	2	3	4*	0	1	2	3
Scenario 1	660	3	37	0	324	373	3	0
Scenario 2	287	345	65	0	0	0	0	0
Scenario 3	947	3	50	0	453	544	3	0
Scenario 4	403	506	88	3	0	0	0	0

As can be concluded from the table above, the model was not allowed to use compactors in scenario 2. We therefore see an increase in the amount of RVMs used in this scenario. This is in line with expectations, since the demand should be met. The same accounts for scenario 4, in which the model is not allowed to use compactors. As explained above, it was necessary to install four RVMs in three locations in this scenario as can be concluded from the table. In scenario 3, the model is allowed to make use of compactors. From the table we can conclude that scenario 3 uses more single RVMs in comparison with scenario 1. This can be explained due to the fact that scenario 3 represents outside locations nearby supermarkets, plus out of home locations such as train stations and petrol stations. It is assumed that the later ones are relatively small and therefore could possible meet demand with fewer RVMs.

This section provided an overview of the experimental settings as well as scenario generation and the deterministic analysis of the model, described as experiment 1 and 2 in Table 5.1. In this section we have seen that the found literature can be applied to a wider range of scenarios to be solved. The proposed solution approach using the SA-VN algorithm provides not only feasible but also reasonably good results compared to its computational time. In order to solve this problem, its solution approach was divided into two phases. The first phase consisted of the mathematical model which was solved by relaxing one of the constraints. The second phase used SA. In order to find a suitable way of solving the second phase of the problem, different kind of solving methods were examined. Both SA and SA-VN were examined with increasing k-swap of 1 up to 5. The SA-VN expands its search neighbourhood if it cannot find a better solution with the current k for the k-swap.

In order to test for the best solving approach in the second phase, the SA and SA-VN were compared, as described before. The comparison between the SA with a fixed amount of k for the k-swap and the SA-VN with increasing k for the k-swap yielded interesting insights. For instance, the SA did not outperform the SA-VN, which was expected. However, it did not even outperform the SA-VN on computational time which is hard to declare how this is possible. We used an increasing problem instance to compare and test the results of both the model in phase one and the algorithm of choice in phase two, before proceeding to the actual full-size scenarios.

Only the swap operator was considered in the SA and SA-VN algorithm, since we wanted to swap the location distribution centre combination and not move the demand of a certain location to elsewhere. What again is interesting to see, is that the increase towards k=5 in the SA-VN does not necessarily lead to improved solution compared to the k=3 and k=4. This however, can be clarified by the fact that the testing instances were relatively small compared to the actual problems. Swapping 5 combinations on as less as 50 to a maximum of 350 possible locations could of course result in far worse swaps. However, due to the nature of accepting worse solutions with a smaller probability if the number of iterations increases, this is not always the case. The two phase solving approach provided some interesting insights. In order to test for the robustness of the fixed layout provided by the model and algorithm, we are going to test the solutions in the next sections.

5.2 Scenario Description and Stochastic Analysis

Considering an environment with (multiple) sources of uncertainty, it is necessary to implement mechanisms to minimize the negative impact of possible events that might modify the outcome of the solution. Maximizing the robustness of a design enables it to maximize productivity. Regarding this study, we can think of multiple ways which could introduce uncertainty into the process. As has been stated in the literature review in Chapter 3, RL comes with more uncertainty than regular logistics mainly in the form of unknown demand. That is one of the biggest uncertainty factors regarding this design. It can be possible to have more returned UBCs at a certain location, than expected. At the same time, the opposite can be true at other locations. An important question in that case would be, if the proposed solution is still feasible. Furthermore, the actual capacity of a location can be less than anticipated. Since there are a lot of parameters involved in this process, uncertainty is a great factor of influence.

In this sense, simheuristic based algorithms are often proposed in literature as a general framework to address real world problems under uncertain conditions. The simulation process allows to model and recreate complex stochastic scenarios. In this way, by analyzing the obtained information provided by the simulation, it is possible to estimate the feasibility of the solutions in the scenarios. Based on this, we are able to select solutions that maximize robustness. That is, select solutions that are not minimizing the objective value of the deterministic problem, but the one that meets certain criteria and therefore maximizes the robustness.

In order to evaluate the solutions as proposed in the previous section, we use a simulation model. The problem we are facing is partially characterized by input parameters that are subject to stochasticity, in other words not known beforehand. The realization of these random variables is only revealed at the moment itself, after the strategic design of the network is already in place. The stochastic parameters included in our study are the number of returned UBCs per year and the actual capacity of the RVMs and compactors. The static parameters include the number of locations, DCs and the travel distance between these facilities. The goal of our simulation model is to evaluate the effect of stochasticity on the performance of our design. The method we are using to investigate the effect of stochasticity is Monte-Carlo simulation. This is an useful technique as we want to evaluate design performance under different scenario settings. This technique is proven to be efficient and gives reliable results, as for instance provided by Lalla and colleagues (Lalla-Ruiz et al., 2020).

Our approach is based on their work.

Using Monte-Carlo simulation we are able to evaluate and analyse different scenarios quickly. The randomness of the parameters is used to evaluate the robustness of the proposed network designs. In Figure 5.2 we illustrate the Monte-Carlo process per scenario. We start by defining the domain of possible inputs. Next, based on these inputs, we generate instances of the random parameters after which a deterministic computation of the objective value is performed for this one problem instance. This result is stored and a new instance is generated, evaluated and stored. This process is repeated until a certain stop criteria, in our case the amount of runs, is met.

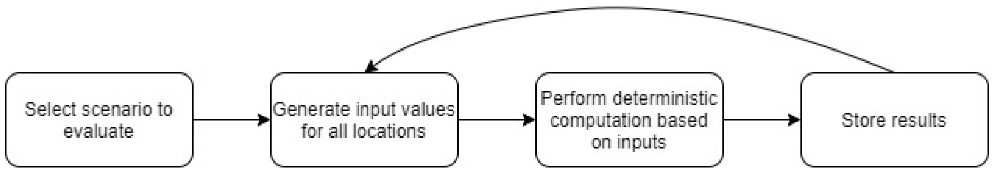


Figure 5.2: Monte-Carlo Simulation process

Different settings for the scenarios which we evaluate are used. We evaluate for each of the scenarios a higher than currently expected return rate of UBCs. This is done in order to evaluate the possibility of the system to cope with increasing demands. We furthermore evaluate a scenario in which the capacity is lower than expected, in order to determine which of the two parameters are more important in generating a robust system.The simulation process consists of an interactive process that is responsible for recreating stochastic or unexpected events and thereby evaluating the behaviour of the found solution. The outcome of this simulation can be quantified relative to the risk, for instance penalty cost for exceeding a certain capacity.

The simheuristic process is as follows. First, a solution which is generated by the SA-VN as described in Chapter 4 is provided as the input parameter for the simulation process. Then, for each iteration $j < MaxIteration$, each stochastic component is converted using a probability distribution that defines the uncertainty of the component. This creates new conditions for the scenario, but does not interfere with the deterministic layout of the network design since this is fixed after the SA-VN algorithm. For each solution the total cost and other parameters of interest such as penalty cost are determined and stored. In Algorithm 5.2, the generic procedure of our defined simheuristic is provided. The simheuristic receives input in the form of parameters. Each stochastic input for each scenario is transformed into a deterministic problem, for which the total cost are calculated. This process is repeated for each iteration $j < MaxIteration$ after which box-plots are generated to evaluate the robustness of the solution.

Algorithm 2: Simheuristic process

Require: Deterministic solution S_{Det} from SA-VN output
for $(i = 1; i \leq n; i++)$ **do**
  $s[i] = Metaheuristic(S_{Det})$;
  for $(j = 1; j \leq 100; j++)$ **do**
    $values[j] = Evaluate(s[i], Stochastic_{Problem})$;
  end
  $statisticMeasure[i] = calculateStatistic(values)$;
end
$eliteSolutions$ = select the best 4 solutions according to their $statisticMeasure$;
for $(s \in eliteSolutions)$ **do**
  for $j = 1; j \leq 1000; j++$ **do**
    $finalValues[s][j] = Evaluate(s, Stochastic_{Problem})$;
  end
end
Analysis($finalValues$)

5.3 Solution Evaluation and Comparison

This section presents the computational results obtained for the different scenarios using the Monte-Carlo simulation described in Algorithm 5.2 in the section above. All the problems are solved on Intel core i7 8th gen computer. As described above, the goal of this study is to analyze how stochastic return of UBCs and stochastic capacity affect the design after the initial solution is generated. Per scenario, we first do 15 runs of the SA-VN and thereby we generate 15 possible deterministic solutions. For each of these 15 solutions we apply a short Monte Carlo Simulation, in which we recalculate for this solution the objective value that is obtained in this stochastic case. When this process is repeated for each of the 15 runs, we take the best 4 solutions with the lowest interquartile difference and use these 4 best solutions to do the long executions of the runs. For each of thee 4 best solutions, we do generate 10.000 instances and evaluate the objective value of this instances. With this information, we obtain the input for the figures and tables presented below. Figure 5.3 up to Figure 5.10 illustrate the total cost of the scenarios. The results are showed in a box and whisker plot. Furthermore, we display for each scenario the average and standard deviation of both the objective value and the penalty cost in Table 5.6 up to Table 5.13. We start with evaluation of the stochasticity of UBCs for scenario 1, after which we evaluate this as well for scenarios 2, 3 and 4. Next, we evaluate the stochasticity of the capacity in the same order.

5.3.1 Experiment 3A

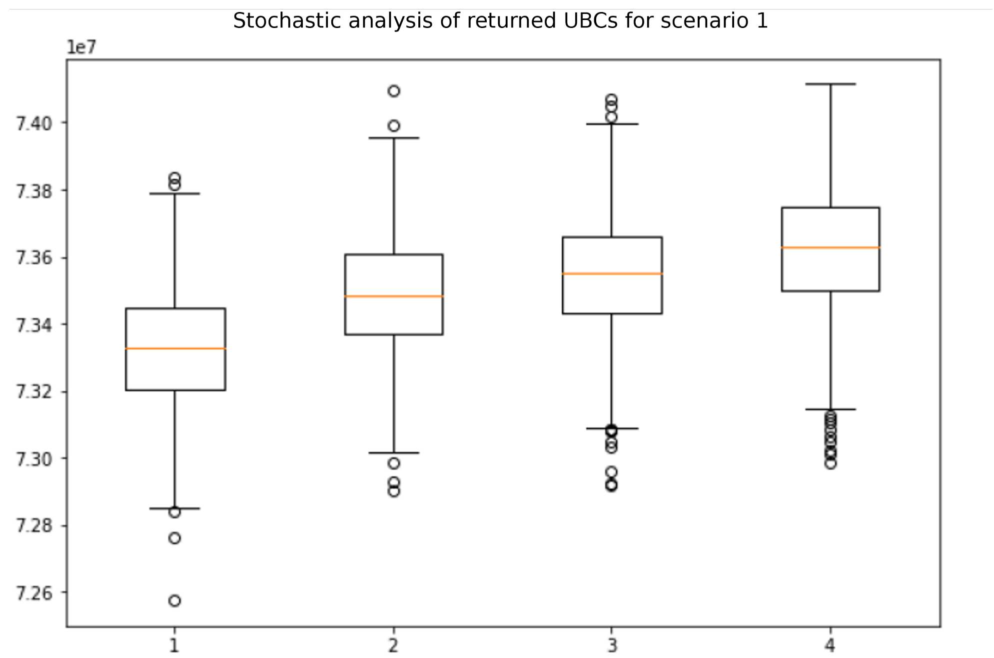


Figure 5.3: Boxplots of the four elite solutions for the Simheuristic for scenario 1 with stochastic returns of UBCs.

Table 5.6: Statistics of the uncertainty analysis for stochastic return of UBC in scenario 1.

Experiment	**Statistics**					**Penalty**
	Min	**Q1**	**Median**	**Q3**	**Max**	
1	72576732	73205036	73326077	73445893	73838708	15,87%
2	72902656	73368756	73485469	73607228	74094265	16,03%
3	72919164	73431273	73549467	73661403	74071233	16,01%
4	72984896	73499179	73627786	73745792	74113752	16,74%

Starting with the stochasticity of the actual amount of returned UBCs for scenario 1, we can clearly see various outliers at the downside of experiment 3 and 4. The scatter is fairly large for this scenario. With the exception of experiment 1, the minimum and maximum value for each of the scenarios are rather equal. In general, it can be concluded that the further both the maximum and minimum move away from 0, the more risk there is in such a scenario. We should point out that after having performed such an intensive Monte Carlos simulation of 10.000 iterations, the possibility that the results shown in both the boxplots and table depend on the randomness of the simulation.

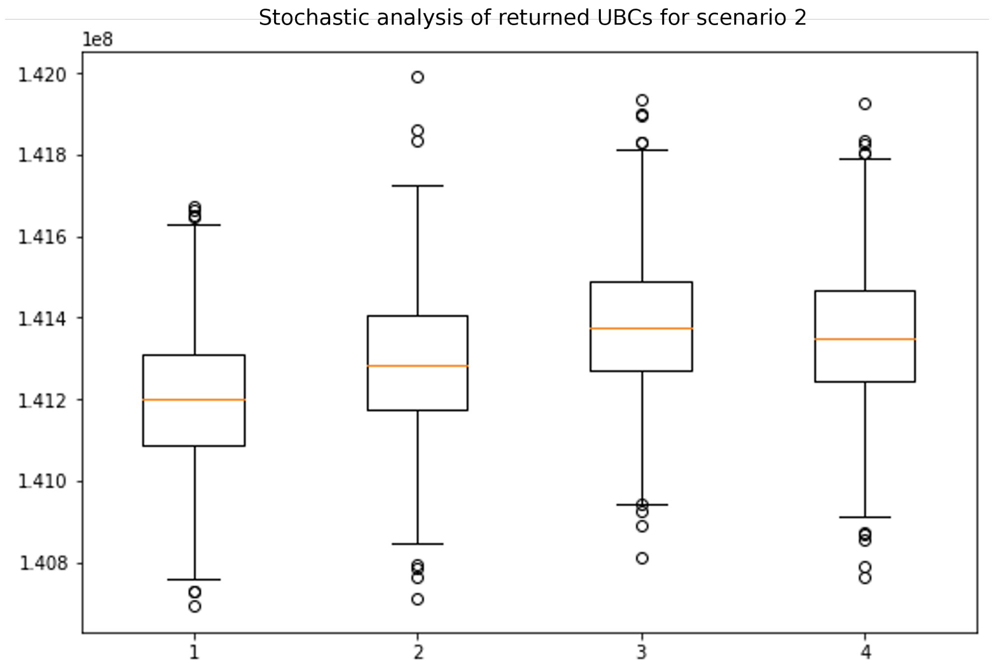


Figure 5.4: Boxplots of the four elite solutions for the Simheuristic for scenario 2 with stochastic returns of UBCs.

Table 5.7: Statistics of the uncertainty analysis for stochastic return of UBC in scenario 2.

Experiment	**Statistics**					**Penalty**
	Min	**Q1**	**Median**	**Q3**	**Max**	
1	140693672	141087242	141202276	141308110	141673008	9,94%
2	140710820	141174998	141283811	141405236	141989813	10,03%
3	140813397	141270211	141373996	141489088	141936999	9,97%
4	140763782	141243089	141349638	141465165	141927711	9,95%

It can be immediately concluded from the boxplots and table that the scatter is bigger in scenario 2, compared to scenario 1. This can be partly explained due to the fact that scenario 2 is only allowed to use RVMs. When the deterministic scenario used to solve the SCND had a demand at a certain location just not big enough for another RVM, the model chooses for instance only 1. If then in the case of stochasticity, the demand is greater than its capacity this location incurs a penalty which contributes vastly to the cost. This conclusion is supported by the bigger portion of penalty cost of the total cost as stated in the table.

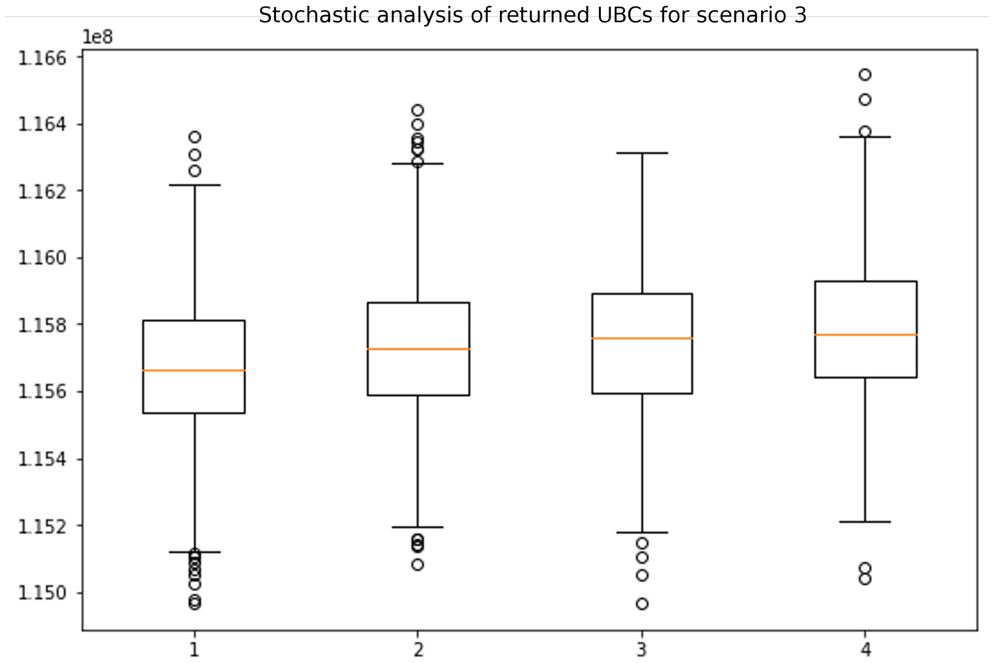


Figure 5.5: Boxplots of the four elite solutions for the Simheuristic for scenario 3 with stochastic returns of UBCs.

Table 5.8: Statistics of the uncertainty analysis for stochastic return of UBC in scenario 3.

Experiment	**Statistics**					**Penalty**
	Min	**Q1**	**Median**	**Q3**	**Max**	
1	114966335	115534679	115665254	115814019	116358800	24,33%
2	115084268	115589846	115727763	115867584	116441983	24,56%
3	114968636	115594441	115757422	115891809	116315229	24,11%
4	115043334	115641802	115769683	115929576	116544660	25,09%

The overall spread of objective values seems to be smaller in scenario 3, compared to both previous scenarios. However, the penatly cost slightly increase compared to both previous scenarios. This can mainly be declared by the fact that in all four scenarios we have the same amount of DCs, while we have more locations in scenario 3 and 4. The chance of allocating more UBCs to a certain DC is in these scenarios higher, which results in more penalty cost and thereby a higher total cost expressed as the objective value.

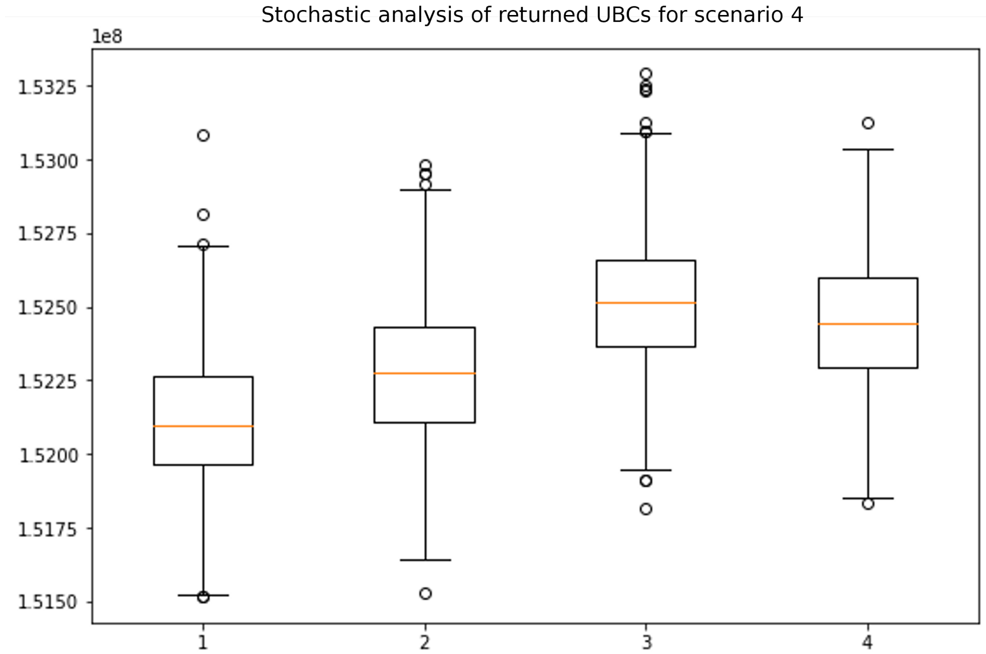


Figure 5.6: Boxplots of the four elite solutions for the Simheuristic for scenario 4 with stochastic returns of UBCs.

Table 5.9: Statistics of the uncertainty analysis for stochastic return of UBC in scenario 4.

Experiment	**Statistics**					**Penalty**
	Min	**Q1**	**Median**	**Q3**	**Max**	
1	151517506	151968093	152098499	152265323	153083701	17,07%
2	151529710	152111327	152276702	152429166	152984516	16,71%
3	151817016	152365428	152517539	152656815	153290150	17,39%
4	151833594	152297031	152441720	152601092	153126272	17,11%

We have now seen all experiments for all four scenarios. In this fourth scenario we can see the most variance in the total cost represented in the objective value. However, this is not due to the fact that this scenario incurs the highest penalty cost. This is scenario 3, in which percentage-wise the most penatly costs are incurred. A reasonable explanation for the high total cost in scenario 4, is the cost of a RVM. The cost of a RVM is relatively high and this scenario is not allowed to use compactors. This also, together with scenario 2, the scenario with the highest average amount of RVMs per location resulting in higher cost. As explaind before, only using a RVM can result in more vulnerability towards stochasticity of returned UBC.

5.3.2 Experiment 3B

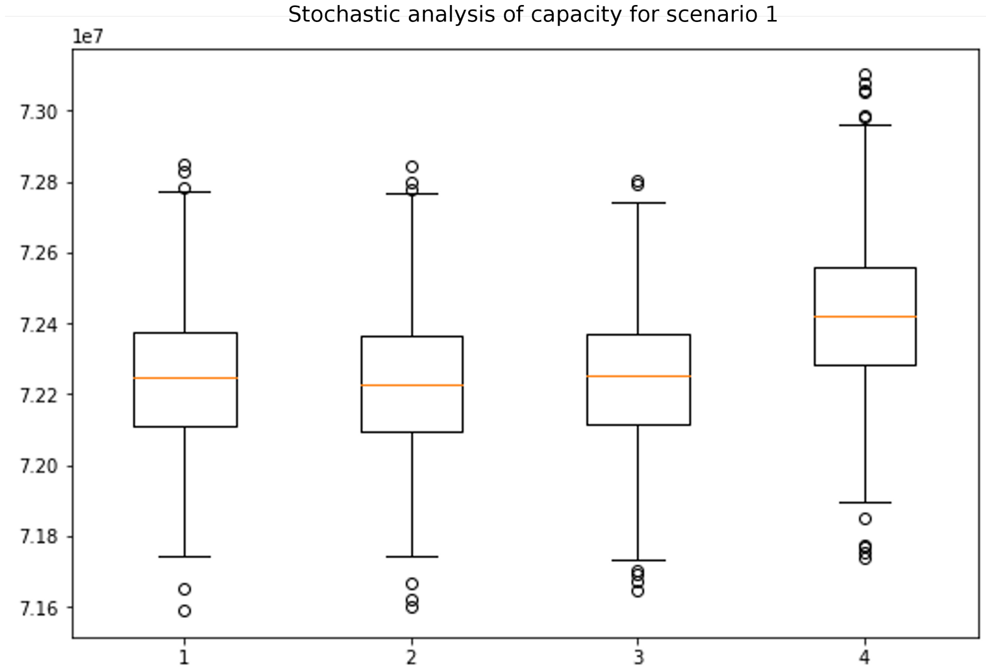


Figure 5.7: Boxplots of the four elite solutions for the Simheuristic for scenario 1 with stochastic returns of UBCs.

Table 5.10: Statistics of the uncertainty analysis for stochastic capacity of RVMs and compactors in scenario 1.

Experiment	**Statistics**					**Penalty**
	Min	**Q1**	**Median**	**Q3**	**Max**	
1	71590929	72109748	72247717	72377731	72848265	10,81%
2	71598783	72094421	72227948	72366297	72843570	10,77%
3	71646969	72113086	72250549	72371067	72801193	10,59%
4	71737803	72282328	72421593	72559432	73101308	11,54%

If we compare the results of stochasticity on capacity to the results of stochasticity on the return of UBCs for scenario 1, we can see that the total cost are lower when the capacity is stochasitc. However, the penalty cost as portion of the total cost is higher in this case. This can be explained by the fact that more locations will have shortage of capacity in these settings. However, the effect on the DCs is less and therefore this DCs incur not as much penalty cost as expected. The overall spread across the four experiments seems to be smaller than compared to the four experiment for the same scenario in the UBC case.

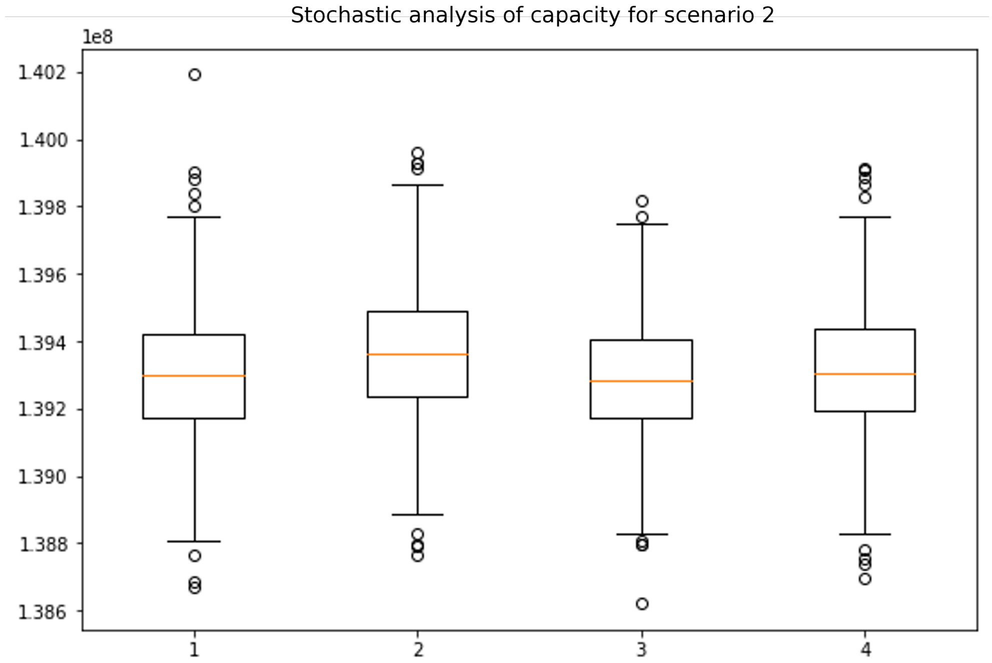


Figure 5.8: Boxplots of the four elite solutions for the Simheuristic for scenario 2 with stochastic capacity.

Table 5.11: Statistics of the uncertainty analysis for stochastic capacity of RVMs and compactors in scenario 2.

Experiment	**Statistics**					**Penalty**
	Min	**Q1**	**Median**	**Q3**	**Max**	
1	138669241	139174352	139299089	139421406	140190701	9,48%
2	138764323	139236100	139362524	139490181	139959435	9,02%
3	138622702	139172334	139282980	139407864	139815412	9,07%
4	138698864	139191340	139304405	139437952	139915105	8,96%

In the case where the scenario is only allowed to use RVMs and no compactors, we see the same happening. We can conclude lower cost, even with one exeptionally high outlier in the first experiment. The median of these experiments seems to be more in line with each other than any other experiment before. A good reason for this can be the fact that only RVMs are allowed to be used in this case. Therefore, there is a possibility that in the deterministic case we already have over capacity and therefore a reduction in capacity does not influence the overall performance of this scenario as much as the others.

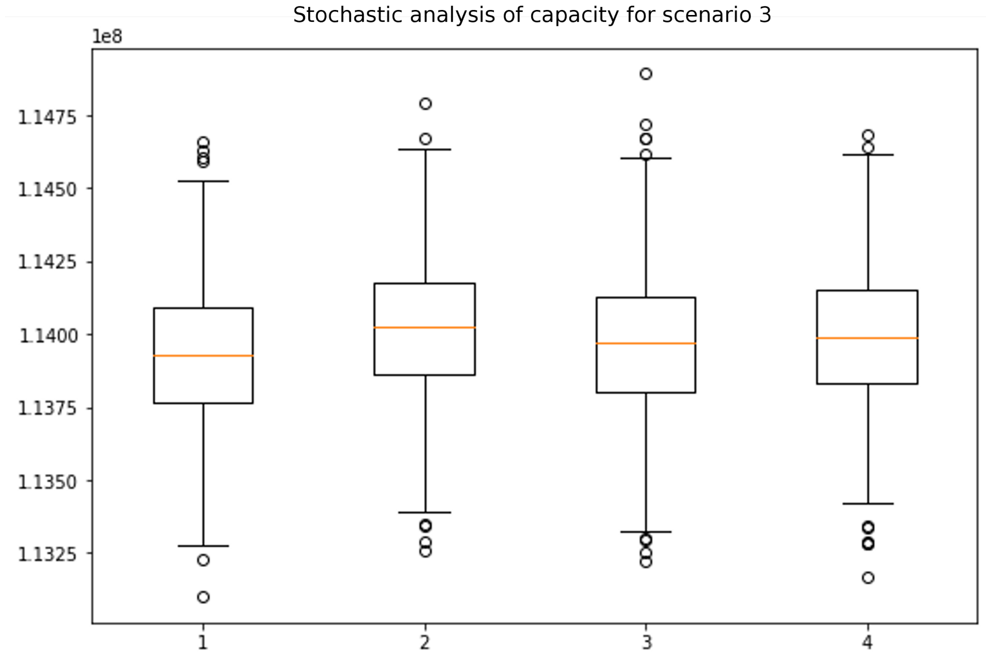


Figure 5.9: Boxplots of the four elite solutions for the Simheuristic for scenario 3 with stochastic capacity.

Table 5.12: Statistics of the uncertainty analysis for stochastic capacity of RVMs and compactors in scenario 3.

Experiment	**Statistics**					**Penalty**
	Min	**Q1**	**Median**	**Q3**	**Max**	
1	113101597	113765756	113930113	114094785	114659369	22,14%
2	113261278	113860599	114025594	114179397	114793013	22,89%
3	113222755	113801679	113969722	114127012	114892781	23,22%
4	113167725	113835371	113991578	114155402	114685744	22,31%

The same as in the previous scenarios applies for this scenario, namely that we incur lower overall cost for the scenario in which only the capacity is stochastic. However, we again see high penalty cost for scenario 3. Even higher than in the stochastic UBCs case, which is the case for all scenarios up till now.

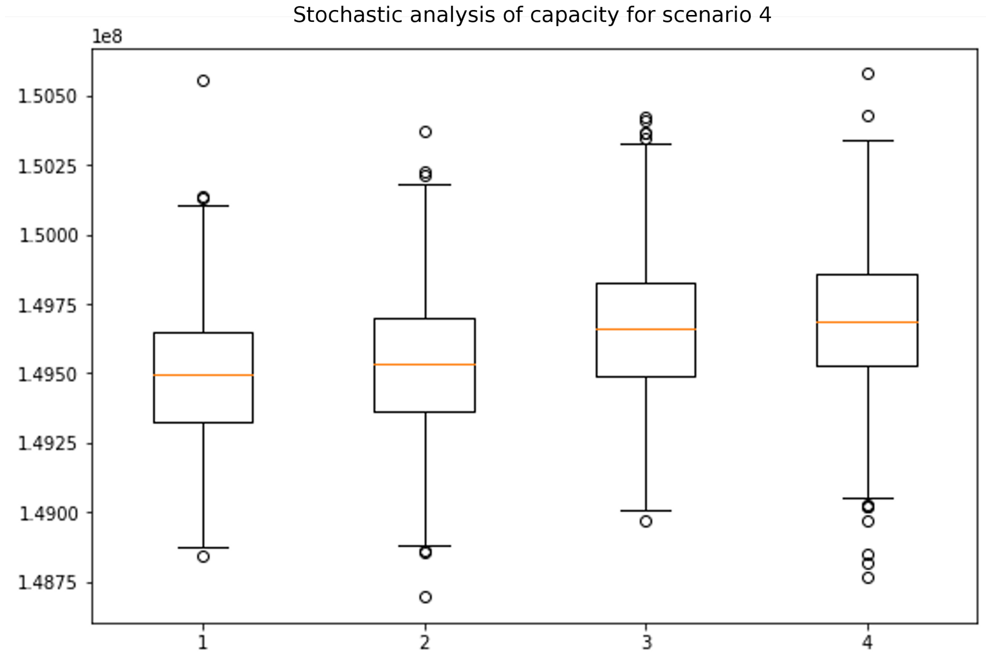


Figure 5.10: Boxplots of the four elite solutions for the Simheuristic for scenario 4 with stochastic capacity.

Table 5.13: Statistics of the uncertainty analysis for stochastic capacity of RVMs and compactors in scenario 4.

Experiment	**Statistics**					**Penalty**
	Min	**Q1**	**Median**	**Q3**	**Max**	
1	148845925	149327576	149496381	149645425	150554530	18,66%
2	148698472	149365086	149535270	149697021	150369368	18,42%
3	148971237	149488178	149661042	149825727	150421009	18,57%
4	148769148	149526457	149684798	149854700	150576701	18,51%

When we compare the results of stochastic capacity for scenario 4 to stochastic demand for scenario 4, we again see somewhat the same pattern emerging. That is, a greater spread in the observed total cost expressed as the objective value compared to the experiments in other scenarios.

If we take all experiments for each of the scenarios into consideration, stochasticity of the capacity does not seem to influence the total objective value very much. The penalty cost slightly increases in these experiments, but it appears that this does not seem to be of too much influence. This can mainly be declared by the fact that in most locations we have a certain overcapacity. Furthermore, in this cases the demand is not stochastic and therefore the capacity does not deviate severely from the actual demand. What can be noticed from both the boxplots and tables is that the penalty cost as a portion of the total cost is lower in both scenarios 2 and 4, the scenarios without compactors. This can be remarked by the fact that a location with a compactor already has a fairly large capacity, which is in some cases reduced but since the demand is not stochastic it still does not deviate much from the actual demand in a worst-case scenario. The penalty cost were defined as cost incurred if the capacity at locations or DCs is exceeded. This penalty cost can be seen as cost that have to be made when the capacity is not sufficient and extra capacity has to be arranged.

6 Conclusions and Recommendations

In this chapter, conclusions are drawn in the first section. Next, recommendations are given based on the results stemming both from the research and literature review. These recommendations are relevant for the implemantation of a nationwide system for the return of UBCs. The chapter is finalized with suggestions for further research. Topics for further research may be used for future researchers in both the green logistics research and at the companies trying to implement such a supply network.

6.1 Conclusions

This section draws the conclusions based on the research carried out. The research started with a research motivation, and by use of a problem cluster, the core and central problems are found. The perceived central problem in this research is the risk of supermarkets that they will become waste centres in the future. This central problem was formed due to the absence of an unambiguous recycling system which resulted in a no low-threshold method for the return of packaging material. To be more specific, this research focuses on the design of a supply chain network for the return of UBCs. In order to find an answer to this problem, a research objective was formulated in Section 1.4 as follows:

Designing and implementing the reverse logistics of empty beverage cans in a closed-loop cycle with the aim of minimizing the handling and operating costs while taking the requirements of the stakeholders into account

The increasing consumption of goods comes with an increase in the use of packaging material. The ever growing concern on both the processing of this packaging material and the use of virgin materials for the packaging, raises the awareness of ways to deal with these issues. Therefore, the circular economy is gaining more interest, by re-using raw materials efficiently in order to reduce the use of new raw materials. Furthermore, Governments in (developed) countries want to tackle the problem of littering since it causes serious environmental harm. Litter mainly stems from apathic behaviour of people, lack of knowledge and the absence of waste collection. As stated in the research motivation in Section 1.2, efficient collection systems are needed since the consumption of beverages takes place far from their point of origin. This clearly fits with the absence of waste collection in the proximity of the point of consumption. This gave rise to the need for this research, since the Dutch Government accepted a proposal for amendment of the law and thereby introducing legislation and deposit-refund on UBCs as of the 31th of December 2022. However, it is yet unclear how this should regulated how the system should be designed.

The stakeholders involved in this process all agree upon the fact that the accessibility for consumers should be high in order to succeed, as can be seen in the stakeholder analysis in Section 2.2. Several researchers have shown that the initial success of recycling programs will depend on the integration into the existing waste management, while its ultimate success will depend on the participation of consumers. Furthermore, the success of the recycling process depends on the ability to turn the discarded waste into high-quality new materials in a cost-effective manner. Therefore, quality control is essential because contaminants should be avoided.

The recovery options in a waste reverse supply chain determine what types of waste can be dealt with in the system. Therefore, when designing the reverse network, the waste streams should be taken into consideration. Since we are dealing with UBCs, besides recycling not many options are left on the table. When deciding on what technologies to install at certain locations at the strategic level, this sets constraints for decision variables on the tactical level. Simultaneously optimizing strategic and tactical decisions in a supply chain network design is sparse in current literature, especially when taking the upscaling into account. Optimizing for multiple objective functions has been done in literature. However, the biggest factor in supply chain network design is uncertainty. As stated in the literature review in Chapter 3, uncertainty in reverse logistics is a key factor which is more unpredictable than in forward logistics.

Both the (uncertain) return flow and costs are two relevant parameters which are often described in relevant literature. Our mathematical model covers these parameters amongst others as well. The constraints of the model relate to the capacity of the locations. Besides that, each returned UBC must be taken back at any location that it is presented to.

Due to NP-hardness of the model, we are not able to solve the problem within reasonable time. We therefore splitted the solving approach into two phases. The first phase used a mathematical model to determine the amount of RVMs and compactors to be installed at a location. Thereafter in the second phase, we proceeded using a simulated annealing approach in order to solve for the combination between location and distribution centre, in a supply chain network design problem. The SA is tested, together with a SA-VN. In order to find the right balance between computational time and results of the algorithm, we did intensive comparison while designing the algorithm. Using a swap operator in both the SA and SA-VN, we tried to solve a small scale problem. These experiments with the amount of locations were also used to test for scalability of the approach. After intensive testing, we found that the SA-VN performed better than the SA.

The problem is characterized as a static and stochastic problem, as input is known beforehand and some parameters are stochastic. Monte-Carlo simulation is used to simulate realizations of the random parameters. This is a suitable technique as it efficient and gives reliable results. The following scenarios were evaluated: low, medium and high return volumes, capacity and penalty cost. It is interesting to see that not all parameters had the same influence on the outcome of the model.

6.2 Contribution to Theory and Practice

This research has several contributions to both the theory and to practice, which will shortly be evaluated in this section. First of all when looking at the theory, this research entered an untrodden field of research since the combination of both recycling systems and supply chain network design are rarely investigated in current literature. We furthermore showed that introducing a variable neighborhood search into a Simheuristic can reveal interesting insights for scenario selection under uncertainty. The introduction of SA-VN in Simheuristics has been done before such as in the paper of Panadero et. al (Panadero, Doering, Kizys, Juan, & Fito, 2020) for project portfolio selection, but not in the field of supply chain network design.

In terms of usage for practice this report has shown that, even when facing with bigger problems, there are possibilities to find feasible and reasonable solutions. The case that this research has covered, is not nearly as large as the total case for the whole of the Netherlands. If we would apply this problem to the whole of Netherlands, there would be over 10000 locations, since there are already 6300 supermarkets in the Netherlands. However, since we use a two-phase solving approach, our methods provides promising results to solve this problem. It is hard to say what the exact benefits of this approach are, compared to not implementing our way of working. However, if we do not align all locations in the Netherlands, we will create stand-alone solutions which are far from optimal. Our approach has shown that it is possible to obtain near optimal results, even for large instances.

This study contributes not only to knowledge pertaining to recycling and supply chain network design, but also suggests various practical insights for managers of both public and private organizations such as supermarkets, Councils and other practitioners engaged in recycling of consumer materials, such as waste contractors and sub-contractors. This study considers the technologies to install at for instance supermarkets, but the location of these recycling facilities and its distribution centres, fleet size of vehicles, vehicle allocation and route planning would help decision makers to plan for the most efficient assignation of these locations. This study provides insight in the possibilities for waste management, which is also beneficial for the environment in several ways. For instance by using a closed-loop approach in which recycling strategies are established in order to provide for a reduction in greenhouse gas emissions, global warming, and environmental pollution. Results of this study help decision makers, for instance policy makers in the government, to ensure that the process of consumer waste recycling approaches its optimum. Furthermore, waste minimization throughout the complete value chain leads to an outstanding savings on cost. Thus, economic advantages that are achieved by incorporating correct waste management are vital. By using the outcomes of this study, decision makers are enabled to undoubtedly maximizes cost efficiency.

6.3 Recommendations for future research and limitations

In order to utilize the results from this research, the kerbside collection method of scenario 3 should be implemented, in which the model is allowed to use divers locations and both RVMs and compactors. This implementation comes with serious cost. However, as stated by the several stakeholders in Section 2.3, there are certain factors which can not be expressed in costs but that are important to these stakeholders. One of these being hygiene aspects. Furthermore, as stated by several stakeholders and in literature, the point of consumption is far from the point of purchase. In order to succeed with a high recycling rate, this option suits best since a lot of locations have the potential to become a return location.

However, one of the limitations of this study is the assumption of the return flows. A good recommendation for further research could be to get better insight in the probability distributions of the parameters. It could even be possible to work out prediction models in which parameters can be tuned specifically for a certain location according to seasonality, weather predictions, previous sales and upcoming events to name a few. On top of that simultaneously optimizing strategic and tactical decisions in a supply chain network design is sparse in current literature but could prove to be helpful for future research. Especially when taking the upscaling and use of a third party logistics into account. Besides that, this research did not take the advantages and disadvantages of source separation with direct or indirect flows into account, which could be valuable before the phase out of this solution.

Another recommendation for future research could be to investigate a possible merging of PET and UBCs into one reverse logistic system. Since a lot is yet unclear about how the system will be set up, it could be an interesting research to find out if a merging of PET bottles and UBCs is possible, feasible, wanted by consumers and what this would cost for retailers, producers and other stakeholders involved.

An important issue to mention is that the mathematical model only focuses on physical capacity of the location. We therefore see that the model often chooses to use 1 RVM with 1 compactor or 3 RVMs without any compactor. It could be possible that waiting times for customers increase in the scenario that only 1 RVM with 1 compactor is chosen, while the three RVMs in the other scenario reach relatively poor utilization scores. It therefore would be interesting to force the model into the option of selecting 2 RVMs with 2 compactors. In order to get more insights on waiting times when installing a certain amount of RVMs and compactors, it would be interesting to dive deeper into queuing theory, arrival and service rates of the locations, especially during low and peak hours.

We have showed that the SA-VN algorithm works well to solve these problems. However, in order to improve the algorithm we could think some corrections to the algorithm. For instance keeping a Tabu list of the location distribution centre combinations that are swaped and therefore are not allowed to be chosen in the next few iterations. Furthermore we could think of improvements such as selection the combinations with the highest priority. This priority can be based on several things, such as the most expensive combinations, a combination that is assigned to the DC with the highest penalty cost or a combination that has not been swaped for a certain amount of iterations. The priority can also be based on the swap, for instance swap towards the DC with the most capacity left. Even hybrid solution approaches could work, so for instance start a certain amount of iterations with a priority rule and later on switch to another priority rule.

Besides promising adaptations to the SA-VN algorithm, several interesting questions for further research remain. For instance, is it possible that the system will be financially self-sufficient or would it even be possible to take a profit out of this system. Furthermore, how much compensation should consumers get for the return per UBC and who remains or becomes the owner of the material. Even the option of collaborative logistics could be interesting. For instance installing RVMs on busy transit locations and by the use of collaborative logistics take back the UBCs. The broad perspective of research fields makes this problem suitable for many research directions.

All things considered, this research has been pioneering on the frontier of both literature regarding recycling systems and supply chain network designs for such systems. This research has presented a modification to existing solving methods for an extended facility location problem. Specifically, we presented a mathematical two phase solving approach that can be extended to implement such systems on a larger scale. It is clear that a lot of research still can be done and even has to be done in order to formulate a design for a working system for the return of UBCs. Adding UBCs to the current system could definitely work, but investigating its impact or other options and their impact are certainly worth mentioning.

References

Alshamsi, A., & Diabat, A. (2015). A reverse logistics network design. *Journal of Manufacturing Systems*.

Baeyens, J., Brems, A., & Dewil, R. (2010). Recovery and recycling of post-consumer waste materials. part 1. generalities and target wastes (paper, cardboard and aluminium cans). *International Journal of Sustainable Engineering*.

Bernon, M., Tjahjono, B., & Ripanti, E. F. (2018). Aligning retail reverse logistics practice with circular economy values: An exploratory framework. *Production Planning & Control*.

Chilton, T., Burnley, S., & Nesaratnam, S. (2010). A life cycle assessment of the closed-loop recycling and thermal recovery of post-consumer pet. *Resources, Conservation and Recycling*.

Co, H. C., & Barro, F. (2009). Stakeholder theory and dynamics in supply chain collaboration. *International Journal of Operations & Production Management*.

Detzel, A., & Mönckert, J. (2009). Environmental evaluation of aluminium cans for beverages in the german context. *International Journal of Life Cycle Assessment*.

EMF. (2013). Towards the circular economy.

England, J. V., Beliën, J., Boeck, L. D., & Jager, S. D. (2020). Literature review: Strategic network optimization models in waste reverse supply chains. *Omega*.

Fattahi, M., & Govindan, K. (2016). Integrated forward/reverse logistics network design under uncertainty with pricing for collection of used products. *International Journal of Operations Research*.

Ferguson, N., & Browne, J. (2001). Issues in end-of-life product recovery and reverse logistics. *Production Planning & Control*.

Forbes, G. (2009). Reducing litter on roadsides, a synthesis of highway practice,. *Transportation Research Board of The National Academies*.

Foundation, P. S. (n.d.). *No plastic in our water or our bodies - plastic soup foundation.* Retrieved from `https://www.plasticsoupfoundation.org/`

Freeman, R. E. (1984). *Strategic management: A stakeholder approach.* Cambridge University Press.

Geissdoerfer, M., Savaget, P., Bocken, N. M., & Hultink, E. J. (2017). The circular economy – a new sustainability paradigm? *Journal of Cleaner Production*.

Geng, Y., & Doberstein, B. (2008). Developing the circular economy in china: Challenges and opportunities for achieving 'leapfrog development'. *International Journal of Sustainable Development & World Ecology*.

Geyer, R., & van Wassenhove, L. N. (2005). The impact of constraints in closed-loop supply chains: The case of reusing components in product manufacturing. *Distribution Logistics*.

Govindan, K., Fattahi, M., & Keyvanshokooh, E. (2017). Supply chain network design under uncertainty: A comprehensive review and future research directions. *European Journal of Operations Research*.

Heerkens, H., & van Winden, A. (2017). *Solving managerial problems systematically.* Noordhoff Uitgevers.

Hoppe, T., Bressers, H., de Bruijn, T., & Franco Garcia, L. (2013). Street litter reduction programs in the netherlands: Reflections on the implementation of the dutch litter reduction program for 2007 – 2009. lessons from a public private partnership in environmental policy. *Environmental Engineering and Management Journal*.

Kirkpatrick, S., Gelatt, C. D., & Vecchi, M. P. (1983). Optimization by simulated annealing. *Science*.

Lalla-Ruiz, E., Heilig, L., & Voβ, S. (2020). Assessing simulated annealing with variable neigborhoods. *Springer*.

Linderhof, V., Oosterhuis, F. H., van Beukering, P. J., & Bartelings, H. (2019). Effectiveness of deposit-refund systems for household waste in the netherlands: Applying a partial equilibrium model. *Journal of Environmental Management*.

Meade, Sarkis, & Presley. (2007). The theory and practice of reverse logistics. *International Journal of Logistics System Management*.

Melo, M., Nickel, S., & da Gama, F. S. (2008). Facility location and supply chain management – a review. *European Journal of Operations Research*.

Meylan, G., Seidl, R., & Spoerri, A. (2013). Transitions of municipal solid waste management. part i: Scenarios of swiss waste glass-packaging disposal. *Resources, Conservation and Recycling*.

Mitchell, R. K., Agle, B. R., & Wood, D. J. (1997). Toward a theory of stakeholder identification and salience: Defining the principle of who and what really counts. *Academy of Management Review*.

Muchová, L., & Eder, P. (2010). *End-of-waste criteria for aluminium and aluminium alloy scrap: Technical proposals* (Tech. Rep.). European Commission.

Niero, M., Negrelli, A. J., Hoffmeyer, S. B., Olsen, S. I., & Birkved, M. (2016). Closing the loop for aluminum cans: Life cycle assessment of progression in cradle-to-cradle certification levels. *Journal of Cleaner Production*.

Niero, M., & Olsen, S. I. (2016). Circular economy: To be or not to be in a closed product loop? a life cycle assessment of aluminium cans with inclusion of alloying elements. *Resources, Conservation and Recycling*.

Panadero, J., Doering, J., Kizys, R., Juan, A. A., & Fito, A. (2020). A variable neighborhood search simheuristic for project portfolio selection under uncertainty. *Journal of Heuristics*.

Pishvaee, M. S., Kianfar, K., & Karimi, B. (2009). Reverse logistics network design using simulated annealing. *International Journal of Advanced Manufacturing Technology*.

Rashid, A., Asif, F. M., Krajnik, P., & Nicolescu, C. M. (2011). Resource conservative manufacturing: an essential change in business and technology paradigm for sustainable manufacturing. *Journal of Cleaner Production*.

Sehnem, S., Jabbour, C. J. C., Pereira, S. C. F., & de Sousa Jabbour, A. B. L. (2019). Improving sustainable supply chains performance through operational excellence: circular economy approach. *Resources, Conservation & Recycling*.

Simon, B., Amor, M. B., & Földényi, R. (2016). Life cycle impact assessment of beverage packaging systems: focus on the collection of post-consumer bottles. *Journal of Cleaner Production*.

Stewart, R., Niero, M., Murdock, K., & Olsen, S. I. (2018). Exploring the implementation of a circular economy strategy: the case of a closed-loop supply of aluminum beverage cans. *Procedia CIRP - 25th CIRP Life Cycle Engineering (LCE) Conference [Special Issue]*.

Stichling, J., & Nguyen-Ngoc, D. (2009). Life cycle inventory and impact analysis for beverage cans final report. *PE International*.

Suárez-Eiroa, B., Fernández, E., Méndez-Martínez, G., & Soto-Oñate, D. (2019). Operational principles of circular economy for sustainable development: Linking theory and practice. *Journal of Cleaner Production*.

van der Bles, R. (2018). *Als blikken konden doden.* (Unpublished master's thesis). Wageningen University.

Varvasovszky, Z., & Brugha, R. (2000). A stakeholder analysis. *Health policy and planning*.

Warringa, G., Boeren, M., van de Water, S., Bergsma, G., & Rozema, J. (2018). *Monitoren van de effecten van zwerfafval* (Tech. Rep.). CE Delft.

Watkins, E., ten Brink, P., Withana, S., Mutafoglu, K., Schweizer, J.-P., Russi, D., & Kettunen, M. (2015). Marine litter: socio-economic study. *Institue for European Environmental Policy*.

Wright, R. E., Richey, R. G., Tokman, M., & Palmer, J. C. (2011). Recycling and reverse logistics. *Journal of Applied Business and Economics*.