Master thesis, optimizing the reverse process of PostNL pakketten

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Summary

This research is conducted at the PostNL parcels headquarters in Hoofddorp. The parcel market in the Netherlands is growing fast (17.2% in 2017 (PostNL, 2018)), the market of reverse parcels is growing even faster. The rapidly growing number of reverse parcels and the concerns at PostNL if the current processes are the most efficient processes are the motivation for this research. Together with PostNL, the following research question is developed:

To what extent is the reverse chain of PostNL robust and sustainable and how should it be organized and designed to be robust and sustainable for the next 5 years considering the expected growth?

We separated this research question in two parts, the assignment of customers to processes, which can be seen as a multiple knapsack problem, and process improvement, which can be seen as a shortest path problem. The process improvement is embedded in the hub and spoke network of PostNL, the goal of the process improvement is to come with a new, robust and sustainable process.

The research question is answered in the five sections of this research. First the current situation is analyzed by getting clarity over the current processes and involved stakeholders. At this moment, PostNL distinguishes three different processes: “Verzend” process, “Ritsortering” process and the “Hengelo/Nieuwegein” process. Around 60% of the reverse parcels is handled via the “Verzend” process, 30% via the “Hengelo/Nieuwegein” process and 10% via the “Ritsortering” process. The internal stakeholders involved in this research are the different logistics designers, depot’ management and the control room. The external stakeholder considered is the customer of PostNL.

After the analysis of the current situation we studied literature. The main goal of the literature study is to get to know how problems related to the problem at PostNL are solved in literature. The first part of the literature study was aimed at reverse logistics optimization. We focused on reverse logistics in the hub and spoke network and on reverse logistics in ecommerce. We found that models to optimize the hub and spoke networks are most of the time modeled as MILP models. A powerful method to solve those problems is the CPLEX algorithm. The second part of the literature study is aimed at a literature study to assign customers to processes. In this part of the literature study we found that it might add value to apply chance constraints. Chance constraints are constraints that should be met with a certain probability. A method to solve a chance constrained model is the method of Ben-Tal and den Hertog (2011) in combination with the CPLEX 12.6 algorithm as described by Bliek, Bonami, & Lodi (2014).

The next step in the research was to study what ideas to improve the process are present within PostNL and what ideas can be generated by a brainstorm and mind mapping. This resulted in four feasible process designs that are incorporated in the research. The ideas are: a central reverse depot, depot transcending truck routes, a central reverse depot with hubs and decentral reverse depots. The idea of a central reverse depot is that nearly all customers are served via one central location, the parcels will no longer disturb the regular process. In the depot transcending truck route process, a truck drives via different customers to deliver the parcels in roll containers. In a central reverse depot with hubs the parcels are sorted at a central reverse depot and distributed via multiple hubs. In the decentral reverse depot, the process as is in Nieuwegein and Hengelo is extended with more depots and customers assigned to one of these depots.

Accordingly, we created a model to assign customers to processes and decide on which process should be “open”. When a process is considered open, customers can be assigned to the process. This model is based on the knapsack model of Dawande, Kalagnanam, Keskinocak, Ravi, & Salman (2000) and the hub and spoke model of Zhou, Pan, Chen, Yang, & Li (2012). We combined both models in our

implementation in AIMMS. Different experiments are developed to test the impact of customer specific data for the delivery costs and parcel size. Additional experiments are conducted to determine what the cheapest processes are. We developed a Monte Carlo simulation to test the outcome of the cost optimization on robustness.

Before we conducted the experiments, we validated the model by conducting a Monte Carlo simulation of the current situation. The problem owner at PostNL stated that the output of this simulation was close to reality and thereby that the model was valid. Besides we compared the outcome with our analysis of the current situation and we note that the outcome of the Monte Carlo simulation is similar to reality.

In the conducted experiments, we found that the customer specific delivery costs and parcel's size have a small impact on the assignment of customers to processes. Therefore, the customer specific information is used in the optimizations to determine what PostNL should do at this moment and in five years from now. In both, situations the central reverse depot turned out to be the cheapest solution for most of the customers regarding the operational costs. In the situation in five years, the depot transcending truck tours are a cost efficient process as well.

We tested the different new processes that we designed on the costs, impact on the stakeholders, scalability and robustness. Based on pairwise comparison by the problem owners we came with weights for the different criteria. From these weights it turned out that the costs, is the most important criterium, followed by the scalability/robustness and the impact on the customer.

New process/ Impact on	**Central reverse depot**	**Decentral reverse depots**	**Depot transcending truck tours**	**Central reverse depot with hubs**
Costs	++	+-	+	-
Scalability/ robustness	+/-	+-/+	+/+-	+/-
Customer	+-	+	+	+-

Table 1 Compare new processes

As can be seen in the table above, the depot transcending truck routes and central reverse depot both score well on the two most important criteria. Besides, the impact on the customer is positive for the depot transcending truck routes.

When we do not change the processes of PostNL, we can, in an ideal situation, reduce the operational costs of the reverse process of PostNL with 6.7%. In this situation we for example assume that the depots do not have appointments with transporters about the biggest reverse customers in their "Ritsortering" process. Therefore, this costs reduction of 6.7% is not likely to be reachable in practice. When we can introduce new processes at PostNL we can reduce the operational costs by 21%. To be able to do so, significant investments should be made, and further research should be conducted.

To conclude, we recommend PostNL to

- **Implement the depot transcending truck routes process on the short term**
  When multiple customers can be combined in efficient routes this process can be implemented. Experiments have shown that when combinations of customers become more beneficial the process can be applied to even more customers.

- **Study the possibilities for a central reverse depot**
  For the longer term PostNL should study the possibilities of a central reverse depot. It should be studied with which other processes this dedicated reverse depot can be combined to create a high utilization of the depot.
- **Question if all reverse parcels should be delivered in one day**
  When this is no longer a constraint, new possibilities for processes occur that might be cost efficient and scalable.
- **Study the possibilities of separation at collection**
  When reverse parcels are separated at the collection points from the other parcels, the reverse parcels can be handled separately from the start. This can have positive impact on the costs structure of for example the central reverse depot. A transportation and sorting stage can be excluded from the process

Preface

Dear reader,

At this moment you are reading the master thesis I have conducted at PostNL pakketten. This master thesis is the last product I have created as Industrial Engineering and Management student at the University of Twente and marks the end of my study time.

I would like to thank everyone from the StafOps department at PostNL for the interest they have shown in my graduation project and input they gave me. I want to thank the "Ketenbeheer & Ontwerp" team for answering all my questions regarding all kinds of processes, methods and habits at PostNL. In special I would like to thank Francine Tol for all her input and critical review on my writings.

To conclude I would like to thank Martijn Mes and Leo van der Wegen for their feedback and supervision on behalf of the University of Twente.

I wish you a lot of pleasure in reading my master thesis,

Kind regards,
Bram Pijnappel

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Definitions and abbreviations

Customer	The customers of PostNL are defined as the web shops that provide the parcels
Consumer	The person who orders and receives the parcel
PNP	PostNL Pakketten
Regular parcel flow	Parcel flow from the customer to the consumer
Reverse parcel flow	Parcel flow from the consumer to the customer
Shift	Cluster of distribution tours that departs at the same time

Table 2 Definitions and abbreviations

Overview of figures

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1 Introduction

In this chapter the master thesis is introduced. First in Section 1.1 the company PostNL is introduced. Section 1.2 describes the problem context and identifies the problem. Section 1.3 introduces the research questions and explains how those questions are answered. Section 1.4 explains the structure of this report.

1.1 Company introduction

This research is conducted at the PostNL pakketten (PNP) headquarters in Hoofddorp. PostNL in its current state is founded in 2011. It was formerly a part of PTT that was government owned and founded in 1928. In 2017 PostNL delivered 207 million parcels and 1,994 million letters (PostNL, 2018). The daily number of parcels is around 660,000 and the daily number of reverse parcels is around 70,000. In 2017, the postal department of PostNL employed 33,305 people and generated a revenue of 1,783 million euro. The parcel department employed 4,136 people and generated a revenue of 1,110 million euro. In 2017 the growth in parcel volume was 17.2% (PostNL, 2018).

In this research the customers of PostNL are defined as the companies that send the parcels to the consumers. Those customers are defined in three distinct classes: a small web shop that sends a few parcels per day, a medium size web shop that sends up to a few hundred parcels per day, and the big size that sends thousands of parcels per day. There are no exact limits on those classes. A customer can be moved between classes when this is required.

The problem owner is the responsible person for the reverse process of the department "Ketenbeheer en ontwerp (KBO)" (chain management). This department consists of logistics designers who are all responsible for a certain part of the process.

1.2 Problem introduction

In this section the problem is introduced. First, we describe the context, the knowledge about the context is used to identify the problem.

1.2.1 Problem context

To understand the challenges in this thesis the context should be clear. This context is now described.

The demand for reverse parcels is increasing substantially, the capacity available at PostNL might not be sufficient for the foreseeable growth. The growth in parcel volume of PostNL in recent years is given in Figure 1. PostNL notices that the number of reverse parcels is increasing as well. In this research, we distinguish between the regular parcel flow, from the customer to the consumer, and the reverse parcel flow, from the consumer to the customer. At this moment PostNL can handle all (reverse) parcels in a satisfying way. In the future that might not be possible without changes in the current processes of PostNL. PostNL wants to know how they should optimize the reverse flows, to serve all reverse customers in the future in an appropriate way and how the reverse process can be improved.

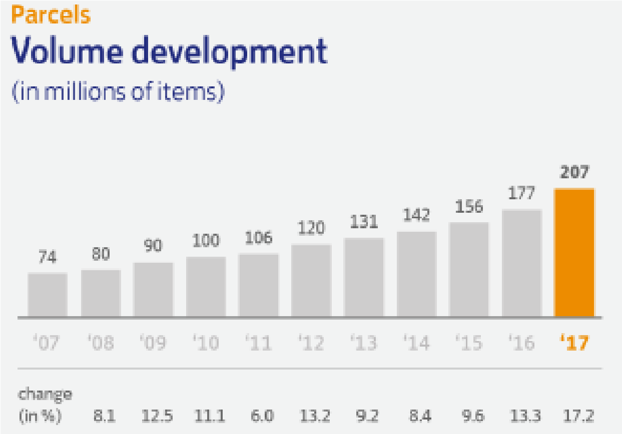

Figure 1 Volume PostNL parcels (PostNL, 2018)

The network of PostNL that handles the parcels is a so-called hub and spoke network. A pure hub and spoke system is a system that is characterized by an organizational structure in which the single depots cover areas with specific collection and delivery points (Zäpfel & Wasner, 2002). The depots of PostNL are connected with each other via Depots+. A hub in the model of Zäpfel & Wasner (2002) is called a Depot+ at PostNL where the terminals are called depots. The difference between a depot and a depot+ is the addition of a cross dock next to the standard depot facilities. The cross dock is used to combine containers of multiple trucks with the same destination to full truckload trucks. In the Netherlands there are four Depots+, fifteen Depots and one extra cross dock location. At this last one, the cross dock location in Dordrecht no other relevant activity is conducted than transshipping. The Depots and Depots+ are given in Figure 2. The colors used for the Depots' location refer to the corresponding Depot+. A depot is marked with a dot in the location point and depot+ is marked with a plus in the location point. From each depot trucks drive towards every cross dock. But each depot is only delivered via one cross dock. For example, from Hengelo (HGL) trucks drive towards AMF, NWG, HT, WVN, DDT, but trucks only go from AMF towards Hengelo. If a parcel needs to go from Hengelo towards Sassenheim (SSH), then a truck goes from Hengelo towards WVN where the container in which the parcel is in, is transshipped to a truck that goes to Sassenheim. Between some depots so called Inter3 routes are driven. An Inter3 does not go via a cross dock but drives between two depots directly.

Figure 2 Map of depots

The depots described before are part of a bigger PostNL network. A visualization of the entire PostNL network is given in Figure 3. A distinction is made between different process stages at PostNL. At the left of the figure the collection methods are visualized. In the middle section the first sorting, transshipment and transport are visualized. In the right part the distribution processes are given. A distinction is made between house distribution and company distribution. The house distribution is delivered via the delivery vans, where the company distribution is delivered by trucks and vans. In this research we focus on the sorting, transshipment and distribution phase. At the depots and depots+ the parcels are sorted with a machine called the Sorter. This sorter sorts the parcels in gutters, at the bottom of the gutter a person puts the parcel in a roll container. At each gutter there are six slots for roll containers with different destinations.

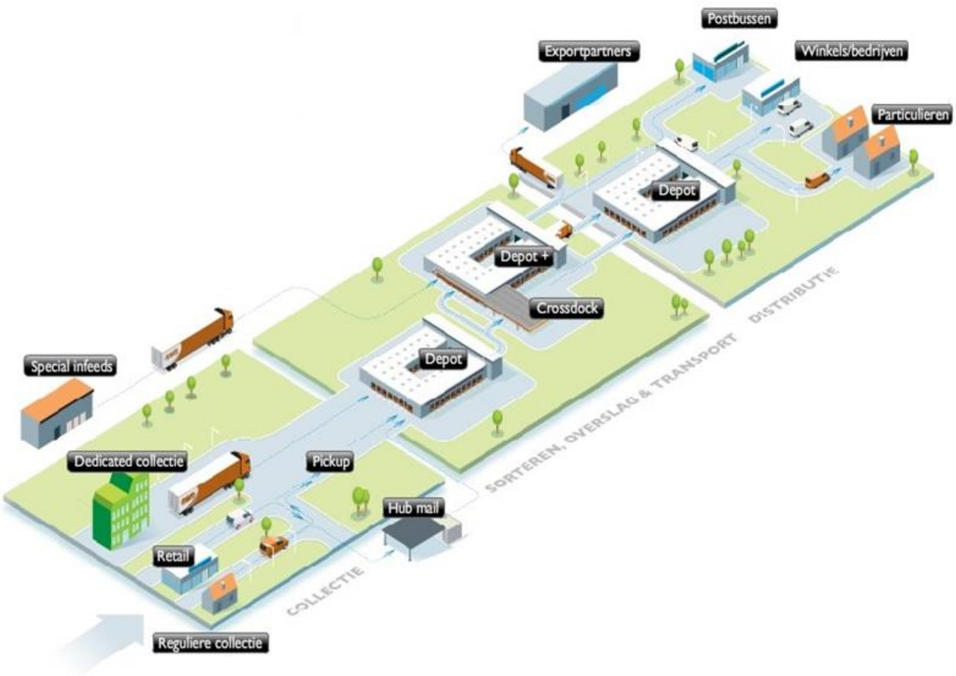

Figure 3 Overview supply chain PostNL pakketten

The reverse parcels PostNL handles are divided over different market segments. The major part of the turnover is in the Fashion segment, 59% of the turnover in reverse parcels is in the fashion segment. From the total turnover generated in the fashion segment 26% is generated via the reverse parcels. In mature market segments it can be assumed that the customer base of PostNL in the future is structured in the same way as the customer base at this moment. Based upon the forecasting analyst of PostNL, the total market expands, but the ratio of small, medium and big web shops stays approximately the same. For immature markets it is not possible to predict the customer base. If a market is mature or immature depends on multiple factors, for example the percentage online sales of total sales in the market. The classification is given by a market intelligence manager of PostNL.

For all markets defined by PostNL in Table 3, an overview is given of the segment reverse turnover in % of total reverse turnover, segment reverse turnover in % of total turnover segment and the categorization of the market segments.

Market segment	Segment reverse turnover in % of total reverse turnover	Segment reverse turnover in % of total turnover segment	Categorization market segment
Electronics	20%	12%	Mature
Fashion	59%	26%	Mature
FMCG	3%	2%	Immature
Home & Garden	3%	4%	Immature
Media & Entertainment	2%	5%	Mature
Sport and game	1%	4%	Mature
Remaining	12%	4%	Immature

Table 3 Overview market segments PostNL

To serve the customers in those different market segments, PostNL distinguishes three different reverse processes. For now, it is sufficient to understand that there are three different processes and each customer is served by one of these processes. We come back on these processes in Section 2.1. Different processes are created since there is a variety of customers and customer wishes for packaging. The number of reverse parcels for one customer varies from a few parcels a week for a small customer till thousands of parcels per day for a large customer. Some customers want to receive the reverse parcels on a pallet, loosely loaded or in a corlet where the PostNL roll container is the standard packaging. To be able to fulfill those wishes in an efficient way, the three different processes are designed.

1.2.2 Problem identification

As mentioned before, the demand for the delivery of parcels is increasing substantially. This leads to pressure on the systems and processes of PostNL. PostNL opened in 2017 one new depot. This resulted in an increase of capacity of roughly 5.5%, an increase from 18 to 19 depots, but the total volume of parcels increased with 17.2%. This resulted in an increase of the volume per depot. The forecasting analysts of PostNL think that the volume of reverse parcels will double in the next five years. The number of parcels handled by PostNL is expected to grow in the future with approximately the same speed as at it does at this moment. PostNL is not able to build depots in the same speed as the volume is increasing. This means that the utilization of the current processes increases, and the processes should become more efficient.

The problem that PostNL wants to be solved is that the reverse process might not be robust and sustainable for the next five years. Robustness is defined by Vlajic, Vorst, & Haijema (2012) as: "*the degree to which a supply chain shows an acceptable performance in (each of) its Key Performance Indicators (KPIs) during and after an unexpected event that caused disturbances in one or more logistics processes".* Different causes have been identified for this problem: there are many parcels in the house distribution and parcels are more often on the sorter than necessary. This can be caused by a non-optimal distribution of the customers to the different processes. The non-optimal distribution is caused by a potential sub optimal design of the processes and lack of information at the decision maker to decide upon the reverse process for a customer. In this research we focus on potential improvements in the reverse process design and the assignment of customers to the reverse processes. An overview of the problems encountered by PostNL is given in the problem mind map in Figure 4. In this mind map we map the relation between different problems and symptoms that are related to the problem we solve in this research.

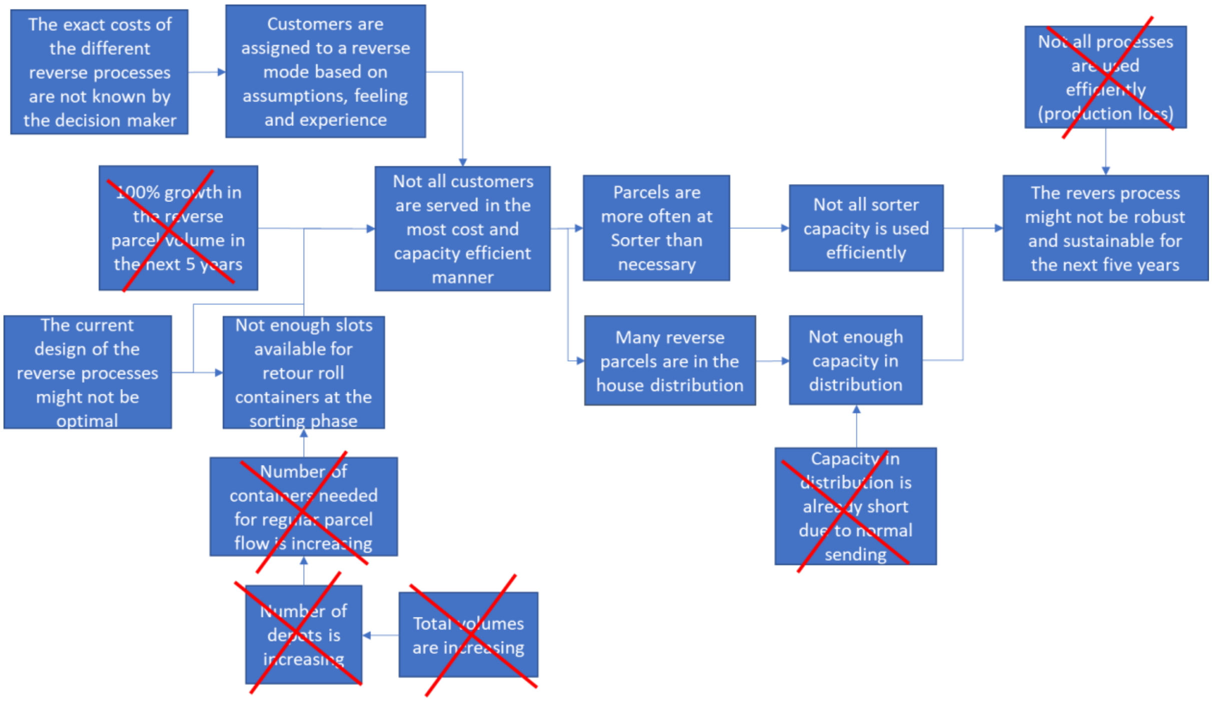

Figure 4 Problem mind map

1.2.3 Problem without the context

When we look at the problem studied at PostNL, we can distinguish two different problems: assignment of customers to processes and reverse process design. We now separate the problems from the context and present the theoretical framework for the problem. First, we discuss the determination of the reverse process for the customer. Secondly, the process design problem is discussed. We end this section with a short conclusion.

If we go to the basis of the assignment of customers to processes, the problem can be stated as: all customers should be served by a process, each process has limited resources, the overall costs should be minimized. This looks like a knapsack problem, which was first defined by Dantzig (1957). An informal definition is: maximize the profit with the given budget. In other words, the best result with given resources should be reached. In the PostNL case, the budget is the capacity and the profit is maximized by minimization of costs. There are multiple processes that have capacity available. In other words, there are multiple knapsacks. The multiple knapsack problem is defined as a problem that consists of m knapsacks with different capacities, objects should be divided over the knapsacks to generate profit (Khuri, Bäck, & Heitkötter, 1994). The three different processes with the capacity related can be considered as multiple knapsacks. Some customers can only be assigned to specific reverse processes, due to specific wishes of the customer. According to Dawande, Kalagnanam, Keskinocak, Ravi, & Salman (2000) the difference between a multiple knapsack problem and a multiple knapsack problem with assignment restriction is that, for each item j a set Aj of knapsacks that can hold item j is specified. Applied to the PostNL case, some customers can only be hold by certain processes. The multiple knapsack problem is therefore changed to a multiple knapsack problem with assignment restriction.

In the basis the goal of the process design improvement is to get reverse parcels from the collection depots to the customer within 24 hours against the lowest cost. During the process some processing actions might be required. In the shortest path problem, the goal is to find the shortest path from a source node to a target node among all paths that satisfy the criteria (Lorenz & Raz, 2001). Since there are 19 depots in the Netherlands where a parcel can enter the system, there are multiple sources. So, we have a shortest path problem with multiple sources, Klein (2005) named this problem as a multiple source shortest path problem.

To conclude, the assignment of customers to processes can be seen as multiple knapsack problem with assignment restriction and the process design as a multiple source shortest path problem.

1.3 Research introduction

The research is introduced in this section. First the scope of the research is set, secondly the objectives are formulated and then the research questions are stated. In stating the research questions, the research approach is described directly.

1.3.1 Research scope

This thesis is focused at the system of PostNL that is involved in the reverse process from the moment that the parcels arrive at the first depot until the moment that the parcels are delivered at the customer. The regular parcel flow is outside the scope of the research but is considered a constraint. For example, process changes that reduce the capacity available for the regular parcels are impossible. The reverse process design is within the scope of the research. The allocation of customers to a depot and a reverse process is variable. Route and location optimization of and between depots are not within the scope of this research.

The parcels that are considered are the parcels that are classified as machine enabled. These are parcels that are smaller than 58*70*100 cm and have a weight between 0.1 kg and 31.5 kg. This scope is set since nearly all reverse parcels fit in this category and the data collected by the sorting machine is the basis to determine the number of reverse parcels per customer and per process. Reverse customers that are too small to detect in the data as reverse customer are not considered in this research. PostNL does not know if a parcel in that low volume is a reverse or a regular parcel.

Based on the wishes of PostNL in the cost optimization only the operational costs are considered.

1.3.2 Research objective

The objective of this research is to get to know to what extent the current reverse process of PostNL is robust and sustainable and to come up with improvements to the reverse process in terms of robustness and sustainability. This can be by designing new processes additional to the current processes, instead of the current processes or by improving the current processes. It is required that the reverse parcels are delivered in time 98.4% of the days, this results in five days per year that parcels are not delivered in time.

1.3.3 Research questions and methodology

In this section the research questions are defined and the methodology to answer them is explained. The main question in this research is developed with PostNL and is:

To what extent is the reverse chain of PostNL robust and sustainable and how should it be organized and designed to be robust and sustainable for the next 5 years considering the expected growth?

To answer this main question multiple sub questions are formulated. Those sub questions are defined in a logical sequence of activities conducted in this research. The activities are: analysis of the current situation, literature study, solution generation, model design and validation, and evaluation of solutions.

In Figure 5 those activities are mapped in a chronological sequence. The arrows on the left and right of the activities are used to show dependencies between the activities. For example, outcomes of the literature study are required to be able to conduct the model design and validation.

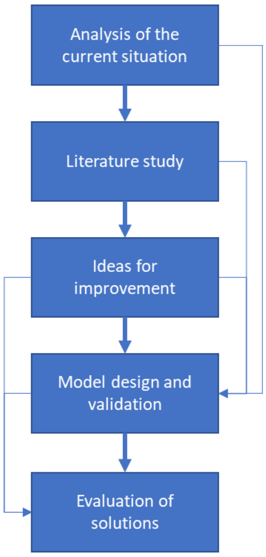

Figure 5 Steps in research

1.3.3.1 Analysis current situation

It is important to understand the current situation at PostNL before examining if the situation is future proof. As described in the reverse process specific context, there are multiple reverse processes with all specific characteristics. It is important to know how those processes are organized and what the processes can handle.

1. How much parcels are handled via the different reverse processes?
2. How much reverse parcels can be handled in the current situation of PostNL?
3. In what way are reverse processes currently assigned to the customers?
4. What are important stakeholders in the reverse process and what are their interests?

The information needed to answer the questions above will be gathered by interviews with the concerned logistics designers and by data analysis. The data can be collected with the track and trace system of PostNL that is used to store all data concerning the scan events of parcels. Data that is collected in the track and trace system are scan notifications. Scan notifications are generated when a parcel is on the sorter or scanned by the hand device of the parcel deliverer.

1.3.3.2 Literature study

In the literature study we study how comparable problems as the problem at PostNL are solved and modeled. Besides we investigate how the customers of PostNL can be classified since we have the idea that the current classification of customers is not ideal. To test solutions a model is needed, how this model should be developed is studied in literature as well. The literature study will be focused on mathematical models and not on process improvements.

5. What can we learn from literature about reverse logistics optimization?
6. What can we learn from literature about the assignment of customers to processes?

The literature study for research questions 5 and 6 is started with a search for literature reviews and overview articles. Based on those articles the snowballing technique is used to find new additional sources. If we do not find enough information, we will focus on research papers.

1.3.3.3 Ideas for improvement

Ideas to improve the problems found in the analysis of the current situation will be gathered by two research questions. We think that radical innovations cannot be excluded upfront. Research questions that are used to find ideas for improvement are:

7. What are existing solutions for the problems encountered that are already present within PostNL?
8. What radical innovations can we think of for the solution of the process design improvement?

Research question 7 is answered by interviews with different involved stakeholders within PostNL. To answer research question 8, a small literature study will be conducted, based on this literature study methods are selected that are used as tools to come to radical innovations.

1.3.3.4 Model design and validation

To test the solutions that are created a model is needed. The model shall be developed and validated in this stage of the research.

9. How can we design a model to be helpful in evaluating solutions for the problems encountered at PostNL?

Research question 9 shall be answered based on research questions 5 and 6. The results of those research questions shall be used to develop a model. This model is created after answering research question 9, the model will be proposed at this research question.

1.3.3.5 Evaluation of solutions

Solutions found in research questions 7 and 8 are evaluated by the next two research questions:

10. What are the pros and cons of the solutions for the stakeholders, and which solutions are feasible?
11. What is the best solution found?

Research question 10 will be answered by interviews with several stakeholders and by reasoning of the researchers. To answer research question 11, the solutions that are feasible will be modeled and the results of the solutions will be computed. To decide what the best solution is, a combination of the computed results of the solutions and the pros and cons for the stakeholders will be used.

1.4 Structure of the report

The remaining part of this thesis is structured such that each chapter provides answers to the research questions in one of the subjects. In Chapter 2 the analysis of the current situation will be conducted. In Chapter 3 the literature study is described. In Chapter 4 solutions for the problems will be created that will be modeled in Chapter 5. In Chapter 6 all solutions will be evaluated and discussed. In Chapter 7 conclusion and recommendations are given. We end with discussing the assumptions made and giving implications for further research in Chapter 8.

2 Analysis of the current situation

In this chapter the current situation at PostNL is analyzed. This is done by answering the research questions stated in Chapter 1. First the reverse processes at PostNL are studied in detail. This chapter is structured as follows:

- 2.1 Description of the reverse processes

In Sections 2.2 till 2.5 the next research questions are answered:

- 2.2 How much parcels are handled via the different reverse processes?
- 2.3 How much reverse parcels can be handled in the current situation of PostNL?
- 2.4 In what way are reverse processes currently assigned to the customers?
- 2.5 What are important stakeholders in the reverse process and what are their interests?

2.1 Description of the reverse processes

The customers of PostNL can receive the reverse parcels via three different processes. The three processes are first described. After the processes are described, cost structures for the different processes are described. At the end of this section, data about the seasonality at PostNL is analyzed.

2.1.1 Three different reverse processes

In this section the three different reverse processes are explained in detail. For all reverse processes we describe the route of the reverse parcel. In the figures that visualize the processes, the big arrows visualize a transport action between depots by a truck. The thin arrows visualize an internal transport within a depot. First, we dive into the "Ritsortering" process, second the "Verzend" process, and the last process is the "Hengelo/Nieuwegein" process.

2.1.1.1 "Ritsortering" process

When a customer receives the parcel via the "Ritsortering" process, the parcel is delivered with a PostNL delivery van. This reverse process is only used for small customers. Unfortunately, there is no clear definition of a small customer. In theory the parcels handled via this process should be delivered in a normal distribution tour. That is the same as delivering parcels to consumers. In practice this is not always the way the process is used. When a customer receives too many reverse parcels, it gets a dedicated tour. In a dedicated tour, a delivery van goes dedicated towards one or several customers. This dedicated tour is more expensive per parcel than a regular tour. The turning point between a normal tour and dedicated tour is not fixed and each depot handles this in its own way. An overview of the "Ritsortering" process is given in Figure 6. To create more feeling with the process an example of the flow of such a parcel is given. In the flow of the parcel the term shift is introduced. A shift is a cluster of delivery van tours that departs at the same time to deliver the parcels to the small web shops and consumers.

Suppose someone from Enschede has ordered something at smallwebshop.nl that does not satisfy his/her demands. The parcel is delivered to a PostNL service point in Enschede. From the PostNL service point the parcel is transported to a depot close by, in this case depot Hengelo. At depot Hengelo the parcel is sorted on destination depot and shift. The parcel is placed in a roll container at depot Hengelo together with other parcels with the same destination and shift. Suppose that the warehouse of smallwebshop.nl is close to depot Halfweg. Then the container is transported by truck from depot Hengelo, maybe via cross dock Nieuwegein, to depot Halfweg. At depot Halfweg the parcel is sorted based on tour and placed in a delivery van. The delivery man of PostNL delivers the parcel to the warehouse.

Between some depots daily full truckloads are transported. In that case the parcel does not visit a cross dock but directly goes to the depot close to the customer.

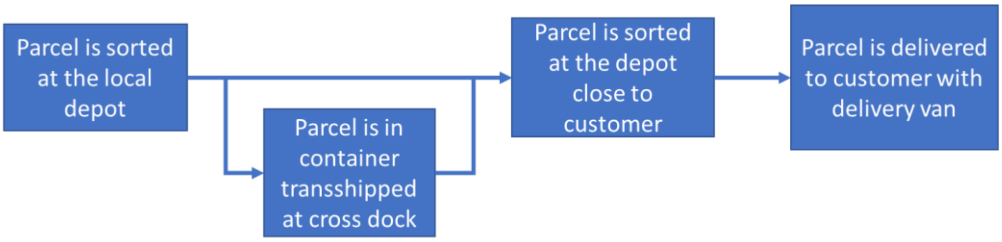

Figure 6 Reverse process via "Ritsortering"

2.1.1.2 "Verzend" process

When a customer is in the "Verzend", the customer gets its own roll container place at all depots in the Netherlands in the first sorting phase. At all depots the layout during this sorting stage is the same. This is the sorting phase conducted at the local depot. This reverse process is only used for the biggest customers of PostNL, the process is given in Figure 7. There is only a limited number of roll container slots available. This sorting phase is used by the regular parcel flow as well, which is the same process as the "Ritsortering" process described above. To create more feeling with the "Verzend" process an example of the flow of such a parcel is given.

Suppose someone from Enschede has ordered something at giantwebshop.nl that does not satisfy his/her demands. The parcel is delivered to a PostNL service point in Enschede. From the PostNL service point the parcel is transported to a depot close by in this case depot Hengelo. At depot Hengelo the parcel is sorted based on the customer of PostNL, in this case giantwebshop.nl. The parcel is placed in a roll container at depot Hengelo dedicated to giantwebshop.nl with all other parcels for giantwebshop.nl. Suppose that the warehouse of giantwebshop.nl is close to depot Halfweg. Then the container is transported by truck from depot Hengelo, maybe via cross dock Nieuwegein, to depot Halfweg. In practice, most giant web shops are close to the depot+ in Den Bosch. For simplicity PostNL decided to handle most giant customers via Den Bosch. At depot Halfweg all containers for giantwebshop.nl from the Netherlands are collected and transported by truck to the warehouse of giantwebshop.nl.

For some customers, additional steps in the process are requested before the containers can be loaded in the truck. This does not influence the process choice since those additional handlings are the same in each process.

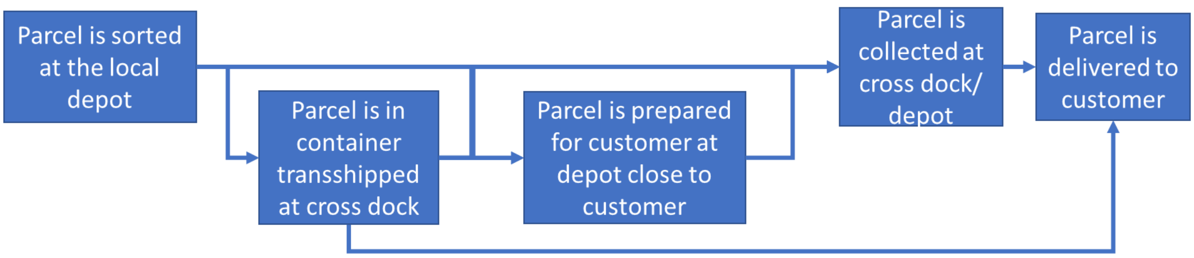

Figure 7 Reverse process via "Verzend"

2.1.1.3 "Hengelo/Nieuwegein" process

When a customer is in the "Hengelo/Nieuwegein" process, the customer receives the reverse parcels by truck. In the sorting phase at the local depot the parcels are sorted based on reverse Hengelo or reverse Nieuwegein. This reverse process is used for customers that are too big to be in the

"Ritsortering" process, too small to be in the "Verzend" or have special requirements like reverse parcels on a pallet. The reverse process via Hengelo/Nieuwegein is given in Figure 8, to create more feeling with the process an example of the flow of such a parcel is given.

Suppose someone from Haarlem has ordered something at mediumwebshop.nl that does not satisfy his/her demands. The parcel is delivered to a PostNL service point in Haarlem. From the PostNL service point the parcel is transported to a depot close by in this case depot Halfweg. At depot Halfweg the parcel is sorted based on the customer of PostNL, in this case medium customers. A distinction is being made between the customers that are served via Hengelo and via Nieuwegein. The parcel is placed in a roll container at depot Halfweg, together with the parcels for the other customers that are sorted via Hengelo or Nieuwegein. The parcels for depot Hengelo are temporarily stored in Utrecht. These parcels are sorted the next afternoon and not during night like in Nieuwegein. The distance to Hengelo is too far to get all parcels at depot Hengelo on time for sorting during the night. At depot Hengelo or Nieuwegein the parcels are sorted on customer level, in this case mediumwebshop.nl. All reverse parcels from the Netherlands for mediumwebshop.nl are sorted and placed in containers. Those containers are transported to the warehouse of mediumwebshop.nl.

For some customers, additional steps in the process are requested before the parcels can be loaded in the truck. This does not influence the process choice since those additional handlings are the same in each process.

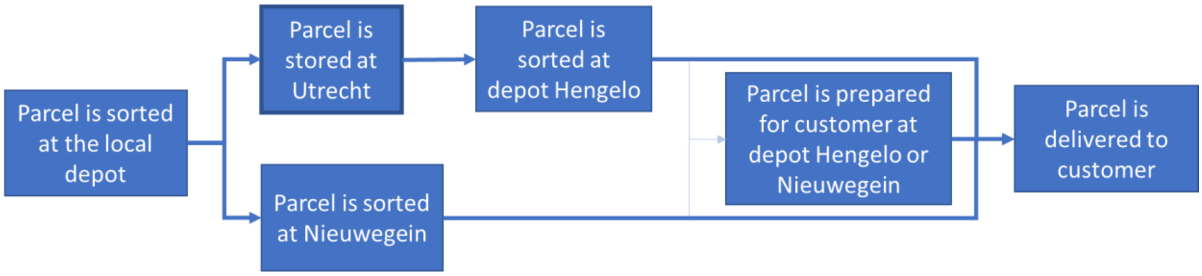

Figure 8 Reverse process Via Hengelo/Nieuwegein

2.1.2 Cost structure

For confidentiality reasons it is not possible to state the exact costs of the process steps. Instead of giving the exact costs, the costs of transport of a roll container is set at 100 and all other costs are valued based on this 100. The three different reverse processes have different cost structures. First the building blocks of the costs are given. Secondly, the costs per reverse process are explained. At the end of this section figures are given of the total reverse costs per transport mode. The costs are computed based on the standard handling times and costs that PostNL uses.

On average 65% of the transported parcels are transshipped at a cross dock. For the "Hengelo/Nieuwegein" process this does not hold. Due to some differences in the costs structure at Hengelo and Nieuwegein, we look at Hengelo and Nieuwegein separately. Transport to Nieuwegein is always direct, since Nieuwegein is a cross dock, and therefore, directly connected with each depot. Reverse parcels in the process of Hengelo always go via Utrecht in a process comparable to the cross dock process, therefore there are two transport movements needed. As mentioned, the second sorting step in Hengelo is conducted the next day, therefore a new team of employees is needed and the process should be started again. The efficiencies are lower, for example caused by some turnover activities. Due to those inefficiencies the costs per parcel are higher. In Nieuwegein the same team is used as in the first sorting phase and continues in approximately the same process speed.

The number of roll containers needed in the transport is estimated based on the average parcel size per customer. Some costs are per parcel and some costs are per roll container, therefore the number of parcels and the average size per parcel is relevant. When costs are per roll container the average parcel size of a customer is used to determine the costs per parcel. If a roll container is dedicated to a specific customer it is not possible to fill the container with other parcels, so the entire container price is attributed to the specific customer.

For transport between depots an average cost per roll container is used. This cost is independent of the fill rate of the roll container since the truck has only limited number of container slots available. In this average cost per roll container the fill rate of trucks is accounted. This cost is set at 100. In the "Hengelo/Nieuwegein" and "Ritsortering" process, parcels for multiple customers are combined to fill roll containers, therefore a fraction of the transport costs of the roll container is used. In the "Verzend" process containers are assigned to customers. Therefore, the number of containers needed for a customer is always rounded up to entire containers for all depots in the Netherlands. Since almost all large reverse customers in this process are in the area of Den Bosch. The average costs of a roll container send to Den Bosch is used instead of the national average of 100. The Den Bosch average is 109.

The sorting costs in the sorting phases are computed per parcel since the time required to handle the parcel is independent of its size since we consider machine enabled parcels. Those costs are based on the average time required to handle a parcel by an employee, those costs are 2.32.

After the sorting is conducted the parcel is placed in a roll container, this roll container is moved to the collection buffer and placed in the trailer. The costs for this handling is 16.33.

If the container is transshipped at a cross dock, the trucks are unloaded, roll containers are placed in a buffer and loaded to another truck. The costs for this transshipment is 16.5.

When the truck arrives at a depot it is unloaded and the roll containers are placed in a buffer. The costs related to these actions are 8.

For customers that are delivered via the "Ritsortering" process, the average costs of the delivery of the parcel are 17.57 when a parcel is delivered via a dedicated tour. This number is based on the average at one depot. When a parcel is delivered via a regular tour than the costs are 42.16+ 4.32*number of parcels for the specific customer.

In Table 4 an overview of the costs building blocks is given. The grey shaded building blocks are processes that are accounted for per parcel. The other building blocks are accounted for per roll container.

Action + cost	Count in "Ritsortering"	Count in "Nieuwegein"	Count in "Hengelo"	Count in "Verzend"
Transport roll container- 100	1.65*(Number of containers needed in two digits)	1*(Number of containers needed in two digits)	1*(Number of containers needed in two digits)	1.09*(Number of containers needed rounded up)
Sorting -2.32	2	2	2.63	1
Roll container handling within depot after sorting-16.33	1	1	1	1
Transshipment handling - 16.5	.65	0	1	.65
Unloading truck- 8	1	1	1	1
Delivery "Ritsortering" dedicated tour 17.57	1*Number of parcels	0	0	0
Delivery "Ritsortering" normal process 42.16 + 4.32*number of parcels	1	0	0	0
Delivery by truck- 100	0	1	1	1

Table 4 Costs building blocks in process

In the figures below the total costs for 25 and 125 parcels per roll container are given, given a number of parcels for a customer. The blue graphs refer to the "Verzend" process, the red graphs to the Nieuwegein process, green is used for the Hengelo process and in purple the "ritsortering" process is described. A few remarkable characteristics in the graphs are now discussed.

The stairs structure in the "Verzend" process can be explained by the fact that the number of roll containers required is always rounded up. The assumption is made that the parcels are collected equally distributed over all depots and depots+ in the Netherlands.

The jump in the "Ritsortering" process total costs is caused by the switch between a normal distribution route and a dedicated tour, this is assumed to be at 20 parcels. Before the turning point, the costs of delivery are relatively low, since the delivery van is already in the street to deliver parcels. A delivery van driver gets paid per stop with a small additional fee per parcel delivered. A stop at a reverse customer with multiple parcels is therefore relatively cheap for PostNL. When a reverse customer is delivered via a dedicated tour, a delivery van drives from a depot to one or a few reverse customers. In this case the delivery van driver only has a few stops and therefore not agrees with a fee per stop plus a small fee per parcel. Therefore, the delivery van driver gets paid via other agreements. The average costs per parcel are used in this graph since we were not able to get more detailed data.

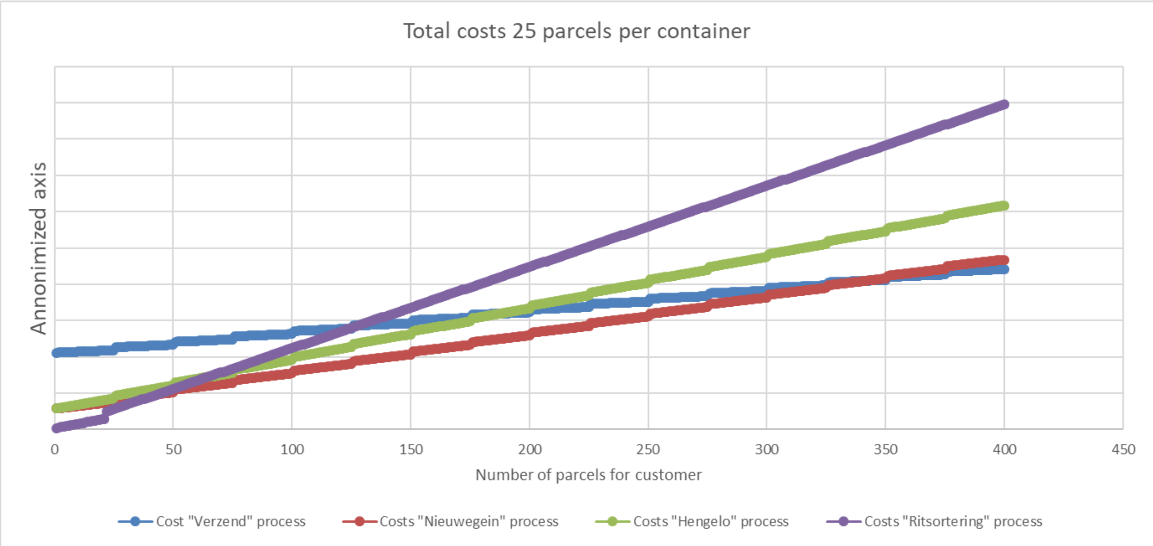

Figure 9 Total costs 25 parcels per container

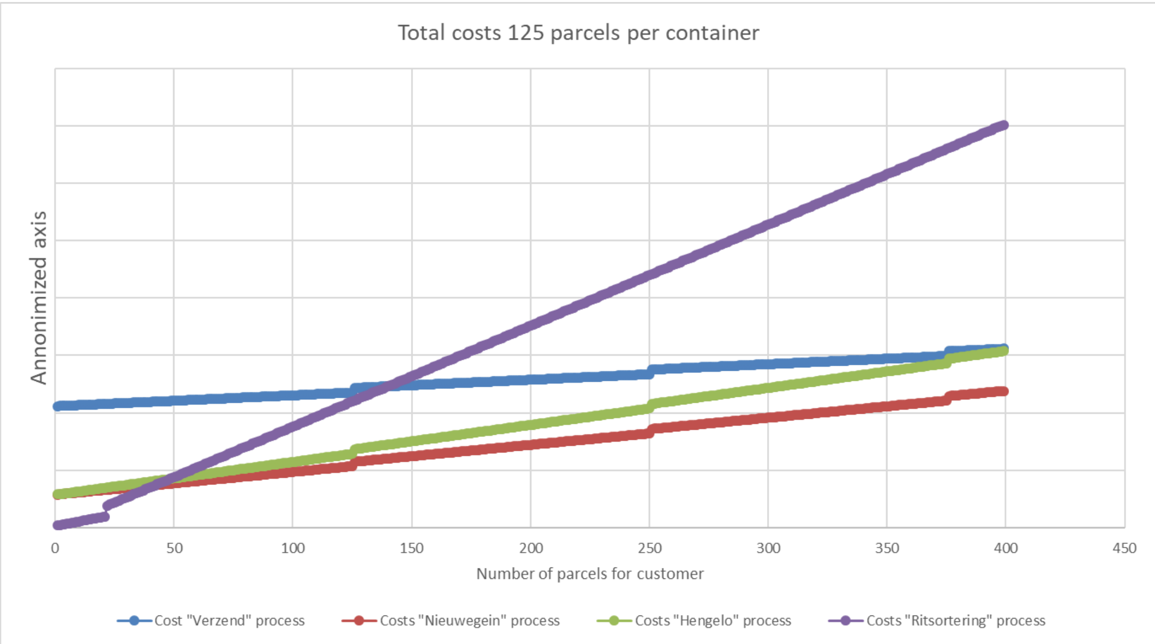

Figure 10 Total costs 125 parcels per container

When studying Figure 9 and Figure 10 we can conclude that the “Ritsortering” process has no initial costs, but the marginal costs are high. The “Verzend” process has high initial costs with low marginal costs and the “Nieuwegein” and “Hengelo” process has intermediate initial costs and marginal costs. So, for big customers the “Verzend” process is cost efficient, for small customers the “Ritsortering” process and for the medium sized customers the “Hengelo” and “Nieuwegein” process.

2.1.3 Data analysis

In this section we first study data about the seasonality over a year at PostNL. Secondly, we study seasonality within the week and we conduct a statistical test to study if we can describe the daily demand. This study on week level is conducted for two large customers, denoted by Customer x and Customer y, and for the Hengelo and Nieuwegein process. We conclude this section with a heatmap of the reverse customers of PostNL in which we show were the reverse parcels are delivered to.

In Figure 11 the number of parcels per week are given for the period week 26-2016 until week 36-2017. In the overlapping weeks 26 until 36 the growth in weekly volume is the gap between both graphs. The peak around week 18 can be explained by the payment of first part of the holiday fee in the Netherlands, all employees in the Netherlands have more money to spend. Besides there is Easter, this results in more time for online shopping. Around week 22 the remaining employees in the Netherlands receive the holiday fee. In week 35 the schools start after the holidays, all students order the study books before this moment resulting in a peak in demand. From week 44 on, the beginning of November people in the Netherlands start ordering the Sinterklaas and Christmas presents. Therefore, the number of parcels grow from that moment on towards the real peak just before Sinterklaas and Christmas.

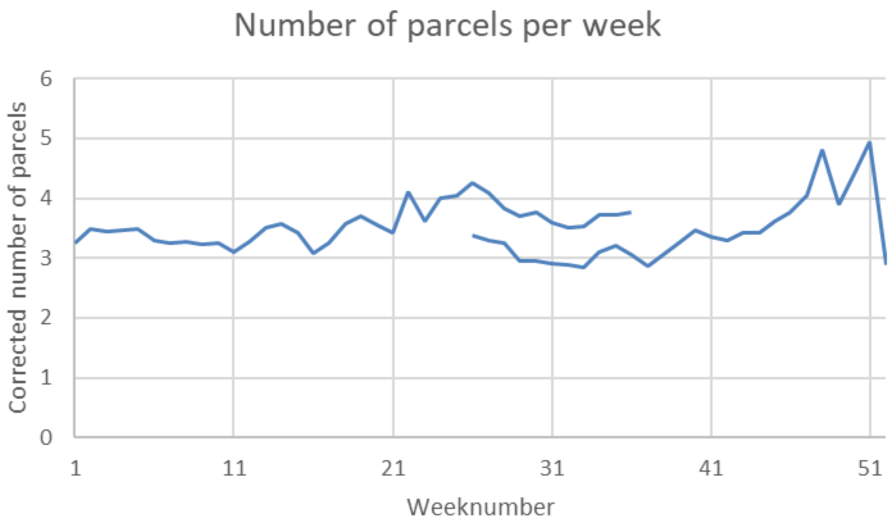

Figure 11 Number of parcels per week

In Figure 12 till Figure 16 data of the number of reverse parcels of two customers of PostNL is given. One is from the fashion segment and the other from the electronics segment. September and October of 2017 are used for the data collection since there are no holidays or other relevant peakdays that disturb the data. Study books are not in the fashion nor electronics segment, therefore the study book peak does not affect the data studied from Customer x and y. A longer time span is not possible since in November the first Sinterklaas shopping is in the data and in the summer months the holidays affect the data majorly. Combining with months earlier in the year might not be useful due to demand increases.

When studying Figure 12 and Figure 14, the box plots of the reverse parcels per day, it can be concluded that the number of reverse parcels at Monday is the highest for both clients. Reverse parcels delivered at a PostNL service point at Saturday, Sunday and Monday are sorted on Monday evening, this results in the peak at Monday evening. The number of parcels at the other days do not differ significantly when studying the box plot. We created histograms for the number of reverse parcels for each day of the week. A histogram is made for the demand at Tuesday to Friday, those histograms can be found in Appendix 1. In Figure 13, Figure 15 and Figure 16 histograms of the number of reverse parcels per day for the customers are given. The frequency that is given refers to the number of days that the demand for a customer was in the specified range, called a bin. Expected values are plotted in the diagram as well. Due to the differences between the number of parcels at Mondays and the remaining days of the week, we created a mixture of distributions to describe the number of parcels per bin in the histogram over a longer period. We do want to study the impact of customers divided over processes over the entire week. For some customers it can be possible that at a non Monday the demand is higher than at a Monday. We want to include this effect in our research. The mixed probability distribution we propose to describe the demand is:

$$P(A) = 0.2 * \phi\left(A \middle| \mu_{Monday}, {\sigma_{Monday}}^2\right) + 0.8 * \phi\left(A \middle| \mu_{Remaining\ days}, {\sigma_{Reamining\ days}}^2\right) \qquad \text{(i)}$$

This mixture of distributions is used to describe the customer demand in the entire week. In words this formula states that the probability of having value A is 0.2 times the probability of having value A, in the distribution at Mondays and 0.8 times the probability of having value A, in the distribution at other days.

For Customer y and Customer x we conducted a Chi-square test to test if we can describe the long-term histogram of demand by the proposed distribution (i). The test statistic of the Chi-square test is $\chi^2 = \sum \frac{(Observed - expected\ )^2}{expected}$. For Customer y we used 20 bins and therefore have 19 degrees of freedom. For Customer x we used 16 bins and therefore have 15 degrees of freedom.

For Customer y, the test statistic has a value of 44.98 and the 95% chi-square test value is 31.41; therefore, we have to reject the hypothesis that the distribution of the number of reverse parcels can be described by the proposed distribution. When studying Figure 13 we notice one bin with an outlier in the middle of the graph. If we exclude this outlier from the chi-square test, the test statistic has a value of 16.85, which is lower than 31.41. In that case we cannot reject that the distribution of demand for Customer y can be described by the proposed distribution. So, we can describe the histogram over the period of September and October by the proposed distribution for Customer y.

For Customer x, we tested the proposed distribution (i) as well, the test statistic has a value of 10.57, the 95% chi-square test value is 25.0. Therefore, we cannot reject the assumption that the number of reverse parcels for Customer x can be defined by the proposed distribution. Therefore, for Customer x we can use the propose distribution to describe the data as well. So, we can describe the histogram over the period of September and October by the proposed distribution for Customer x.

Besides the chi-square tests for the combination of distributions (i), we conducted the chi-square test to test if we can describe the histogram by a single normal distribution. In this single normal distribution, the mean and standard deviation are used as parameters of the distribution. The number of parcels for Customer y cannot be described by one normal distribution, even when the biggest outlier is excluded from the test.

For Customer x the test statistic resulted in 18.86 which is lower than the chi-square test value at 95% of 25.0. Therefore, for Customer x the histogram of the number of parcels can be described by a single normal distribution and the combination of distributions.

That we find this difference between Customer y and Customer x can be explained by the difference in the gap between the number of reverse parcels on Monday and the remaining days of the week. For Customer y this gap is bigger than for Customer x. In Appendix 1 histograms per day of the week of Customer x and Customer y are presented. A normal distribution in plotted in those histograms.

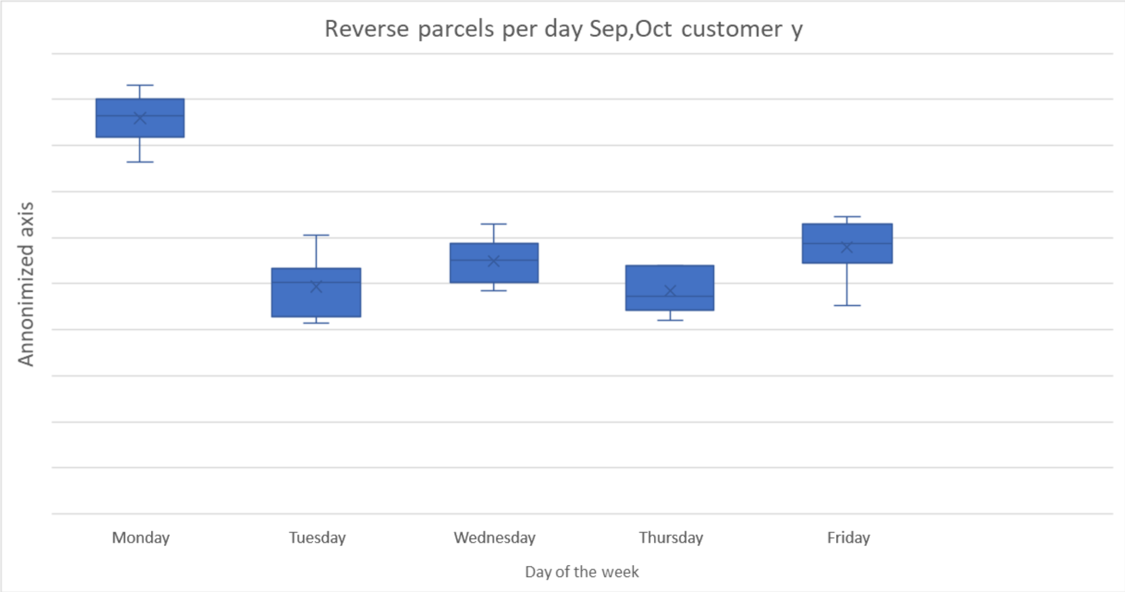

Figure 12 Boxplot reverse parcels Customer y

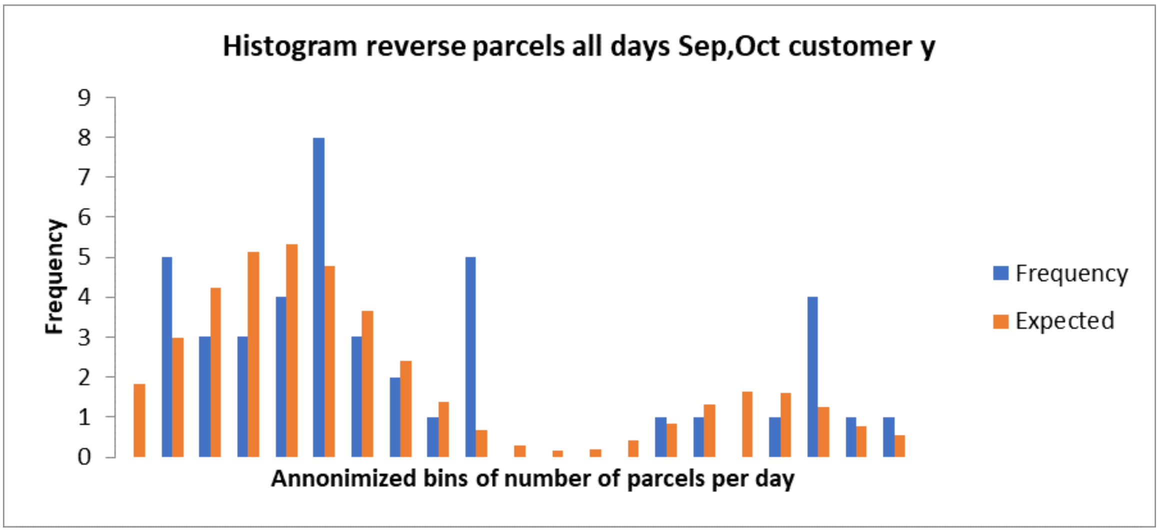

Figure 13 Histogram reverse parcels per day of the week Customer y

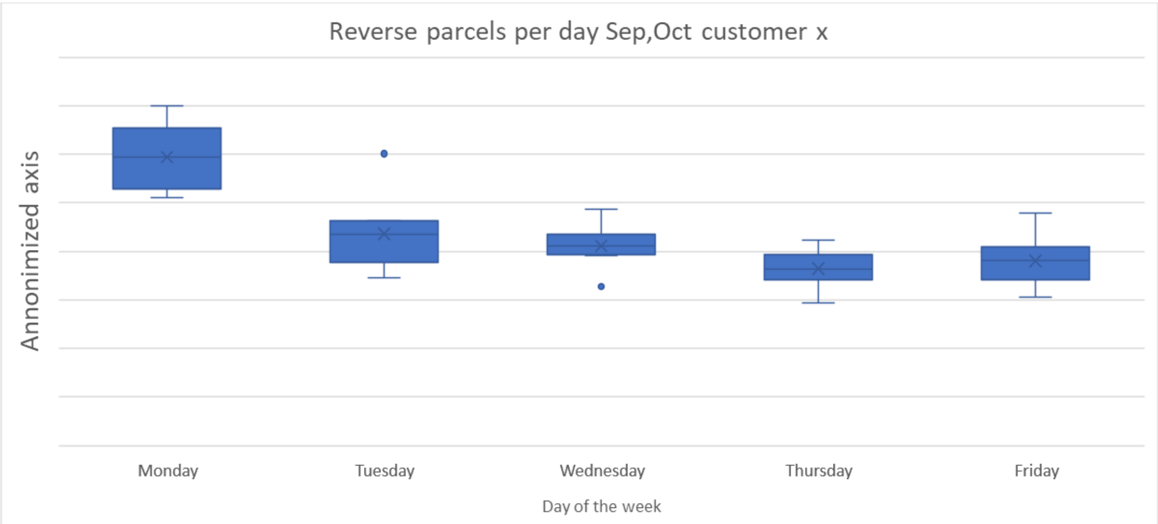

Figure 14 Boxplot reverse parcels Customer x

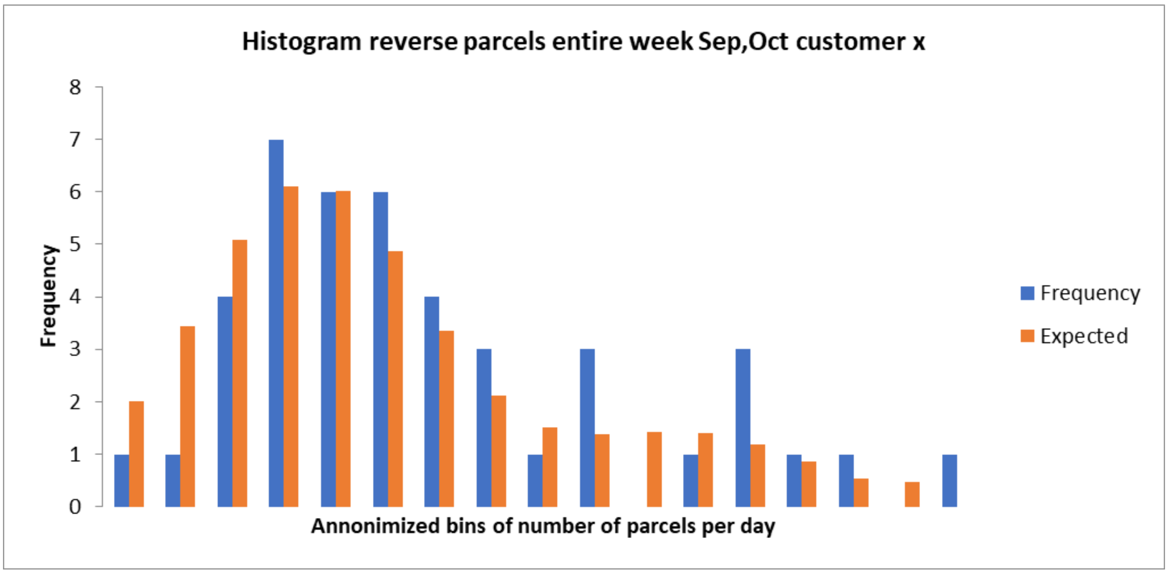

Figure 15 Histogram reverse parcels Customer x, combination of normal distributions plotted

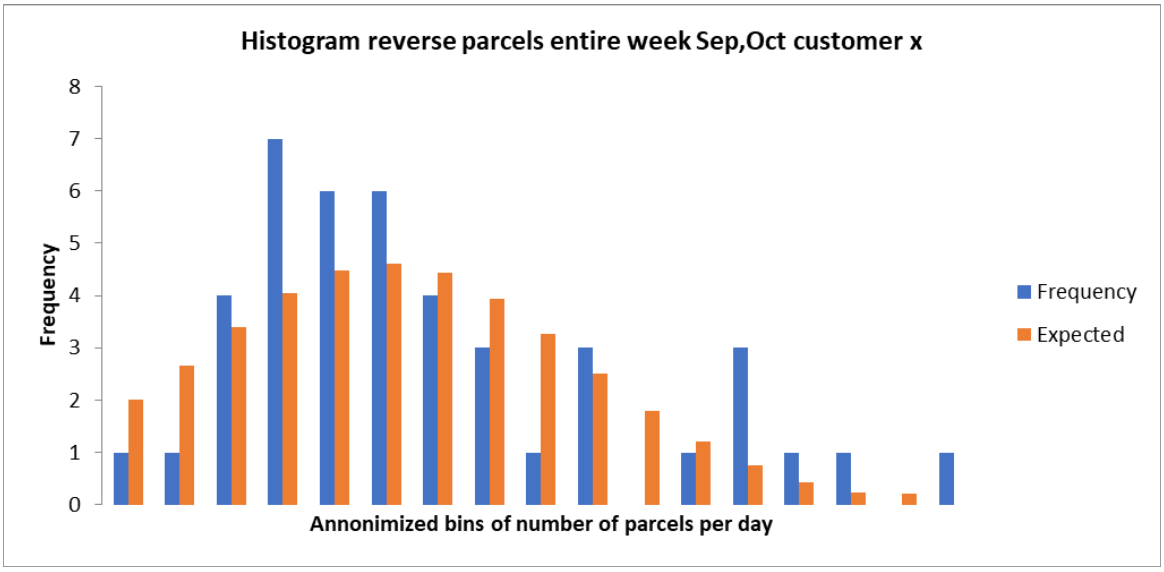

Figure 16 Histogram reverse parcels Customer x, single normal distribution plotted

The "Hengelo" process started mid September 2017. In the starting phase, the volume is managed to test the process and train the staff. Therefore, the data about September and October does not describe the reality at this moment. In February and March, the demand is relatively flat as well, as shown in Figure 11. Therefore, for the "Hengelo/Nieuwegein" process those months are studied. The proposed distribution to describe the histogram of the demand per day is the same distribution as the combination of distributions that is proposed for Customer x and Customer y. This distribution is used in the next sections of this research to determine the demand corresponding to a certain service level per customer.

$$P(A) = 0.2 * \Phi\left(A \middle| \mu_{Monday}, {\sigma_{Monday}}^2\right) + 0.8 * \Phi\left(A \middle| \mu_{Remaining\ days}, {\sigma_{Reamining\ days}}^2\right) \quad \text{(i)}$$

In Hengelo this resulted in a Chi-square value of 20.1 with a 95% boundary value of 23.7 with 14 degrees of freedom. So, we do not reject the hypothesis and can use the combination of distributions to describe the number of parcels handled in Hengelo per day. In Nieuwegein this resulted in a Chi-square value of 26.83 with a 95% boundary value of 23.7 with 14 degrees of freedom. So, we have to reject the hypothesis that we can describe the data by the proposed distribution. Therefore, we tested the normal distribution with a mean and variance of all days. This resulted in a Chi-square value of 20.044 and so we do not reject the hypothesis that we can describe the distribution with a normal distribution. To conclude we can describe the number of parcels per day in Hengelo by a combination of normal distributions. The number of parcels per day in Nieuwegein can be described by a single normal distribution. In Figure 17 until Figure 20 the boxplots and histograms of the reverse process "Hengelo/Nieuwegein" are given.

In the analysis of the distribution of the number of parcels, we see that, for individual customers and the reverse process "Hengelo/Nieuwegein", the number of parcels can be described by a single normal distribution, if the difference between the number of parcels at Monday and the number of parcels at the other days the remaining part of the week is small. When the number of parcels on Mondays is forty percent higher than at the other days, a mixture of distributions is better.

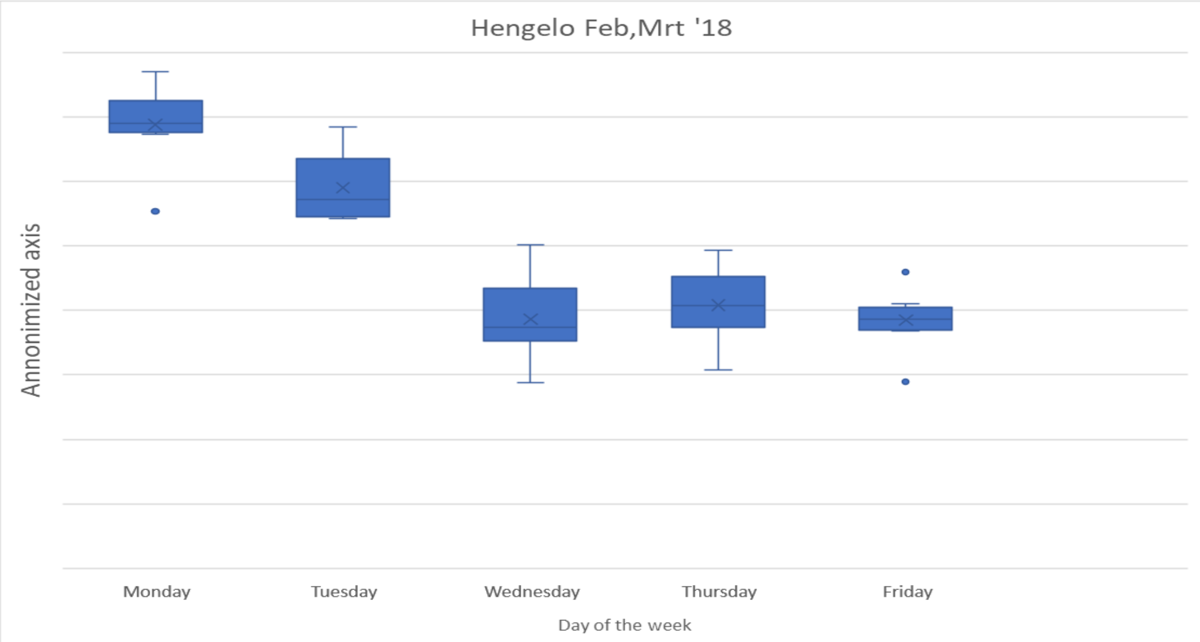

Figure 17 Boxplot Hengelo reverse parcels

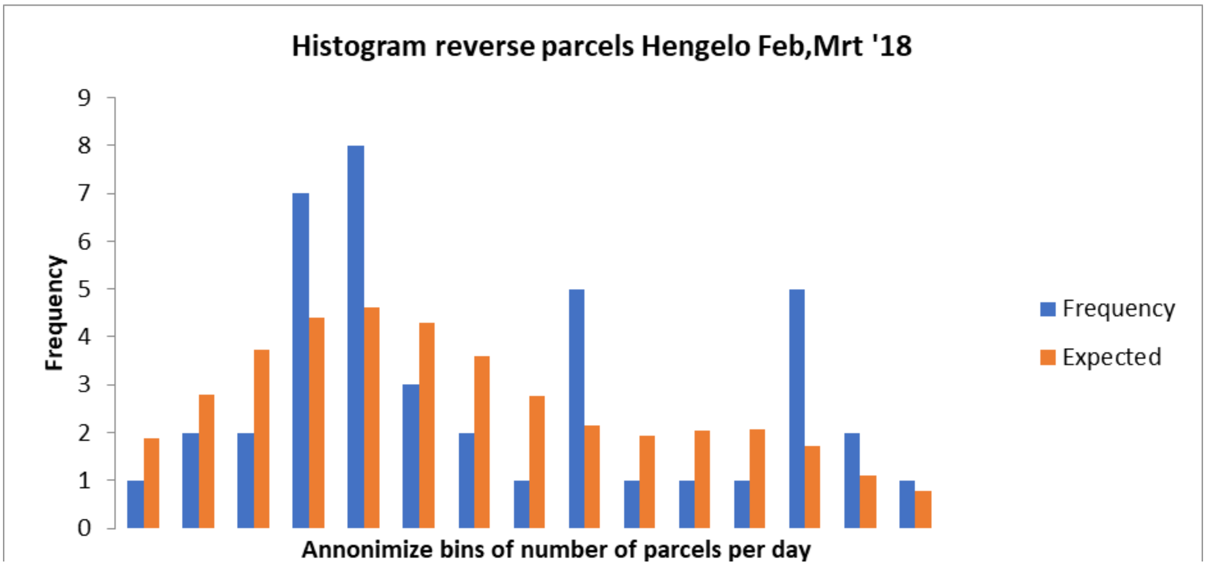

Figure 18 Histogram Hengelo reverse parcels

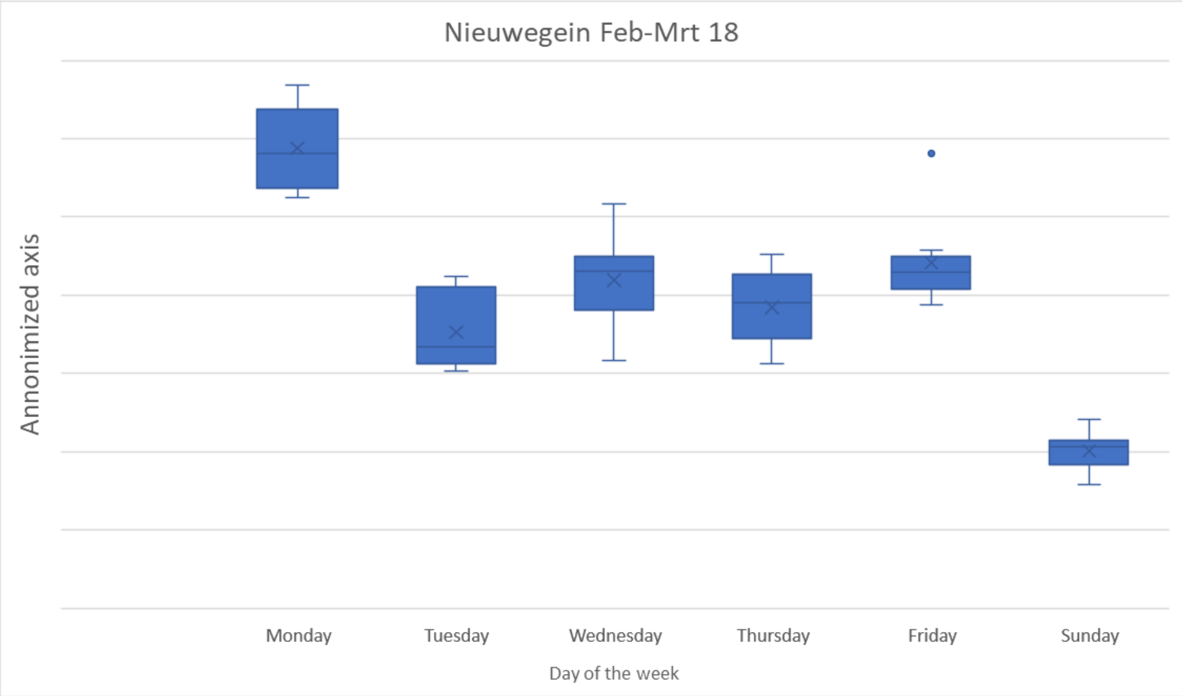

Figure 19 Boxplot Nieuwegein reverse parcels

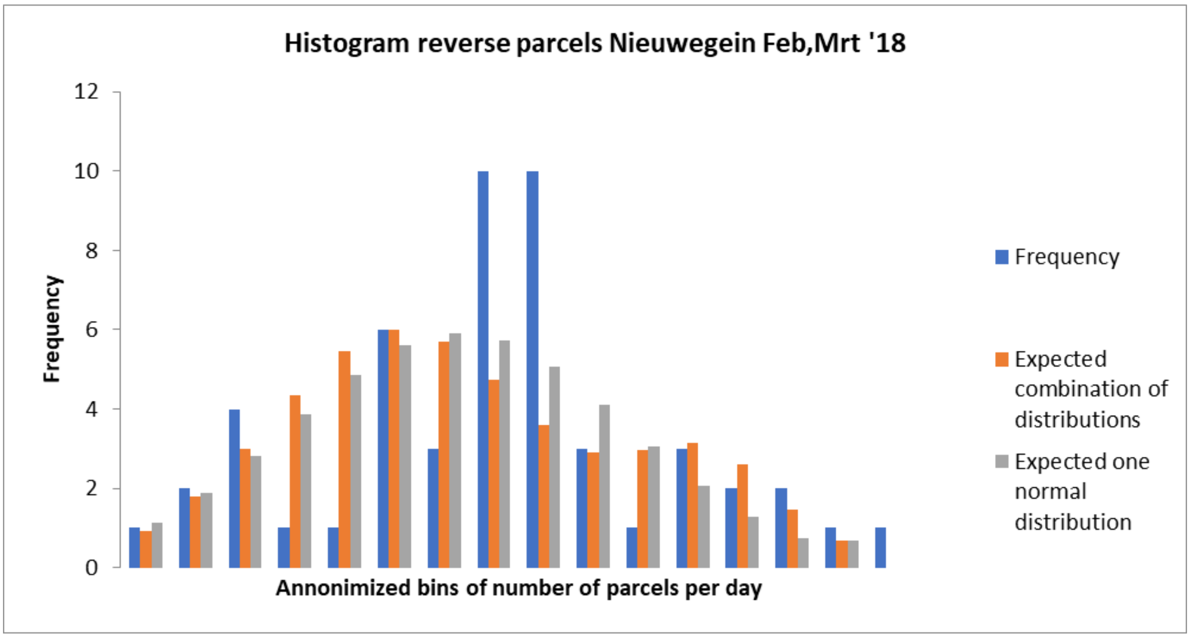

Figure 20 Histogram Nieuwegein reverse parcels

To gain an overall feeling of the different customers of PostNL we state some general remarks, we cannot give specifics about individual customers due to confidentially. In total 80 customers are considered in this research. Their daily number of reverse parcels differs between a few parcels per day (<10) to more than 10,000 parcels per day. To show the differences between the demand of the customers, we created Figure 21. In this figure each pie slice corresponds with one customer. Some customers are, compared with the other customers, too small to note them in this figure. The number of parcels per roll container fluctuates between 15 and 50 with most customers considered average at 35 parcels. The geographical location of a customer can be anywhere in the Netherlands as can be seen in the heat map in Figure 22. A bigger circle implies more reverse parcels for a customer in the specific zip code. The big circle around Hengelo is for the German customers that have distribution centers in the middle and north of Germany. The big circle around Born is for the customers that have their distribution centers in the south of Germany. If we ignore the German customers, we notice that the majority of the reverse parcels are to be delivered in the southern part of the Netherlands.

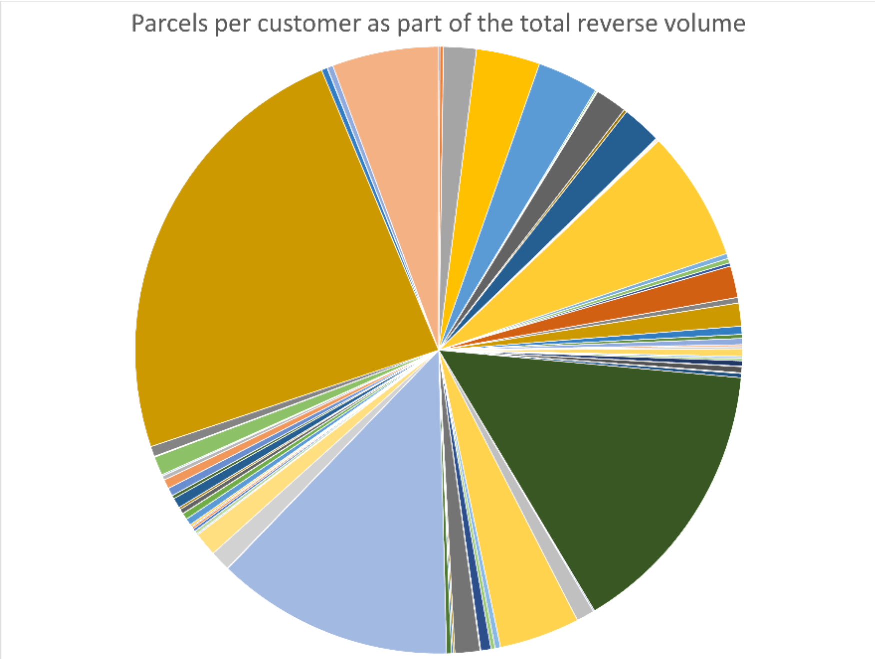

Figure 21 Diagram of size of customers

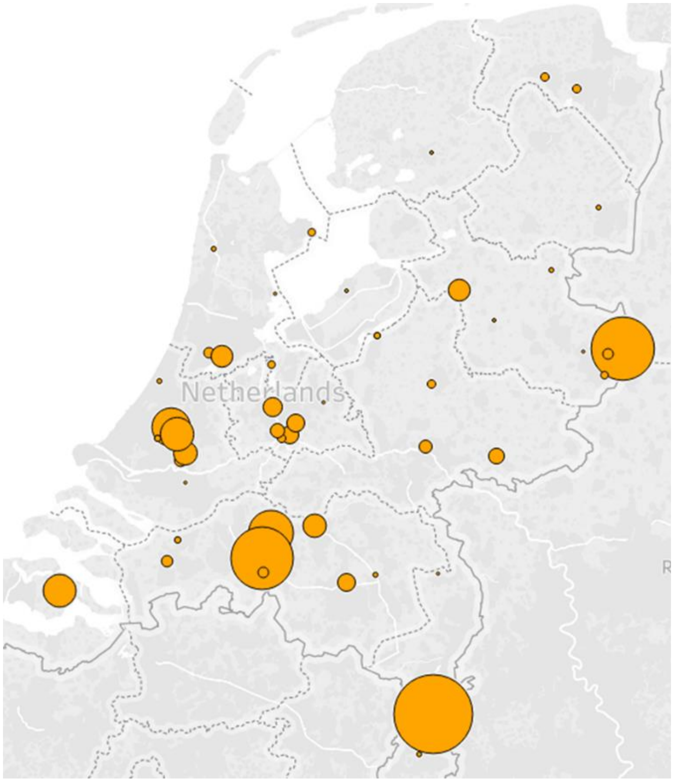

Figure 22 Heat map reverse customers PostNL

2.2 Number of parcels handled via the different reverse processes

In this section the current distribution of the reverse process is investigated. First by an interview with a logistics designer and second using two samples to validate the expert opinion.

The logistics designer of the reverse process of PostNL stated that: "*At this moment 60% of the reverse parcels is going via "Verzend", 30% of the reverse parcels is going via "Hengelo/Nieuwegein", and 10% of the reverse parcels is going via "Ritsortering". The current situation is mainly based on capacity restriction in the reverse process via "Verzend" and via "Ritsortering"."*

It cannot be determined how much reverse parcels are sent via "Ritsortering" based on the available data. Reverse parcels in the "Ritsortering" are sent to normal addresses; small web shops and retailers do not have an "antwoordnummer" and cannot be separated from consumers that order parcels often. To get the exact number of this reverse process for all the addresses of the 660,000 parcels sent, it should be checked if a company is registered at the address. This seems not worthwhile. The volume in "Ritsortering" is relatively low since a lot of the volume in the Netherlands is sold by and returned to the bigger web shops. To validate the opinion of the expert, the data of the first two weeks of February 2018 is analyzed, the results of this analysis are given in Table 5, the third and fourth column.

It is assumed that 10% of the reverse parcels is in the "Ritsortering", therefore 90% is in the "Verzend" and "Hengelo/Nieuwegein" process. The partial volumes found in the data samples are multiplied with the remaining 90% to come to a sample for all processes. To be able to determine the real situation under the assumption that 10% of the reverse parcels is in the "Ritsortering" process, we multiplied the percentages we found in the samples of February with 90%. These computations are used to create a sample under the assumption. The computations are as follows: 70%*90%=63% and 90%*(15%+16%)/2=13.5% and 90%*(15%+14%)/2=13.5%. Based on Table 5 we can state that the expert has made a good estimate. The distribution in the reverse process between the processes is given in Table 5.

Method/ process	Expert opinion	Sample week 1 February	Sample week 2 February	Sample under assumption	Absolute number of parcels in assumption situation
Via "Verzend"	60%	70% of data available	70% of data available	63%	44,100
Via Hengelo/ Nieuwegein	15%/15%	15% of data available/15% of data available	16% of data available/14% of data available	13.5%/ 13.5%	9,450/9,450
Via "Ritsortering"	10%	No data available	No data available	10%	7,000

Table 5 Distribution of reverse volume

2.3 Number of parcels that can be handled in the current situation of PostNL

The current reverse process of PostNL is divided into three different reverse processes. Those are explained in detail in Section 2.1. To compute the number of parcels that can be handled, per reverse process the capacity is calculated. How this capacity is calculated is explained in this section.

In the "Verzend", the capacity can be computed by multiplying the number of gutters available for the reverse process, with the norm of the number of parcels that the employee can handle per hour, with the hours that the "Verzend" is active. There are 4 gutters available for the reverse process, 425 parcels per hour and 4 hours of process time on average. So, the capacity per depot is 6,800 parcels. Multiplied with 19 depots this is 129,200 parcels. One should notice that there is a limited number of container locations available, in this process a customer has a dedicated roll container. All parcels in this process should be delivered to only a limited number of customers. So, the capacity can only be reached if all 129,200 reverse parcels are for a limited number of customers.

In the process via Hengelo/Nieuwegein the bottleneck is the sorting capacity in Hengelo/Nieuwegein. It is assumed that additional transport always can be hired. The storing capacity in Utrecht is way more than required and therefore this is not encountered in computing the capacity per day. The capacity in Hengelo is computed as follows: from 13:00 to 17:00 parcels can be sorted with 5,000 parcels per hour. This results in a total capacity per day of 20,000 parcels. In Nieuwegein the reverse parcels can be sorted from 3.00 AM until 6.00 AM with 8,000 parcels per hour. This results in a maximum capacity of 24,000 parcels per day.

Via "Ritsortering" the capacity in the process is high. The limitation is that there is a priority for the parcels send towards the consumer above the reverse parcels. We assume, based on requirements of PostNL, that at most 2.5% of the available capacity in the "Ritsortering" can be assigned to reverse parcels. The capacity is 700,000*2.5%=17,500

The capacities calculated are given in Table 6.

Process	**Capacity per day**
Via "Verzend"	129,200 parcels
Via Hengelo	20,000 parcels
Via Nieuwegein	24,000 parcels
Via "Ritsortering"	17,500 parcels

Table 6 Capacity in reverse processes

When studying Table 5 and Table 6, it might seem that there is no problem with the capacity yet. The capacity available per day is at least double the average daily volume, and the expected growth in the next 5 years is estimated at 100%. Nevertheless, there is a problem for PostNL. At peak season the demand is nearly 100% higher than during the normal season. In that situation the capacity available is slightly more than the capacity required. Besides the calculated capacity is the capacity that can be reached in the optimal situation. When the total parcel market is increasing as expected, more capacity is used by the regular process, thereby even less capacity is available for the reverse process. This mainly influences the capacity available in the Hengelo/Nieuwegein process.

2.4 Current way of assigning reverse processes to customers

Several steps are taken in the decision process to decide via which process a customer receives the reverse parcels. These decisions are executed monthly.

At this moment customers are assigned to a reverse process based on volume and the way the customer wants to receive its parcels reverse. In some situations, a customer wants to receive the parcel on for example a pallet. Depot Hengelo and depot Nieuwegein are specialized in the deviant transport modes, as for example transport on pallet. Therefore, all those parcels go via depot Hengelo or Nieuwegein. All German customers, in the Hengelo/Nieuwegein process, collect the parcels via depot Hengelo since they deliver parcels to Hengelo as well. If a customer is one of the biggest x% customers, the customer gets parcels via the "Verzend". For the remaining customers, it is decided if a customer receives the parcels via the "Ritsortering" or depot Nieuwegein based on the capacity available in the "Ritsortering" and at depot Nieuwegein. The form and size of a typical parcel for the customer is also a factor that is considered. Either way, there are no hard guidelines regarding the form and size, therefore, no decision parameters can be given. The decisions that are made are given in Figure 23.

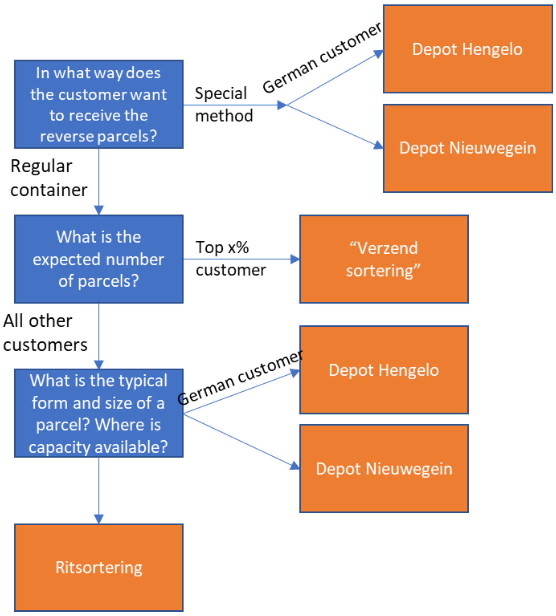

Figure 23 Decision tree reverse process

2.5 Stakeholder analysis

In this research it is desired that solutions found are acceptable to stakeholders. To be able to do so we need to know what stakeholders are important and what their interests are.

Important stakeholders in this research are the logistics designers of the reverse process, depots, the logistics designer of the regular parcel flow, the control room and customers. The stakeholders that are considered are internal and external stakeholders. Internal stakeholders in this research are logistics designers for the reverse and normal process, depots' management and the control room management. External stakeholders that are considered in this research are the customers of PostNL. The interests of the mentioned stakeholders are now described.

2.5.1 Logistics designers reverse process

The logistics designers of the reverse process are the problem owners. For them it is most important that the outcomes of this research give them the tools to improve the reverse process of PostNL. A solution that creates the highest additional capacity against the lowest additional costs will have the preference. For the problem owner it is also important that there is support in the organization for the solution. Otherwise it is hard to implement any outcomes.

2.5.2 Depot' management

For the management of the depots it is important that their job does not get more complicated. Besides, to create support at the depots for a solution it is important that they have the idea to be part of the project. The depot manager and his process managers are responsible for the processes and operations at the depot.

2.5.3 Logistics designers regular parcel flow

The regular parcel flow process cannot be disturbed by changes in the reverse process. The regular parcel flow currently has a higher priority than the reverse parcel flow. The logistics designers of the regular process are the stakeholders that represent the normal process in this research.

2.5.4 Control room management

The control room manages the entire process of PostNL, mainly in the evening and at night. For them it is important that solutions found do not make the overall process more complex. The “regisseur” is the responsible person for the overview of the operations at all depots in the Netherlands and the shared resources they make use of. The “regisseur” is supported by two operators during a work shift.

2.5.5 Customers

The customers of PostNL are not interested in how the process is organized internally. There main interest is to get the parcels back to their warehouses as soon as possible by their favored transport mode. Additional value can be offered to a customer when information about the number and type of reverse parcels is shared.

2.6 Conclusion analysis current situation

In this chapter the current situation has been analyzed, and a detailed description of the reverse processes has been provided. To answer the research questions of this chapter, we conclude that at this moment around 63% of the parcels is handled via the “Verzend” process, 10% via the “Ritsortering” process, 13.5% via the “Hengelo” process and 13.5% via the “Nieuwegein” process. In all current processes there is still capacity available to growth in volume, but not enough for the next five years. The customers are assigned to processes based on the total number of reverse parcels for a customer and the packaging method required. Besides the German customers are handled close to the border. The internal stakeholders of PostNL are all in favor of a non-complex process for the lowest costs possible. The external stakeholder, the customer, its only interest is to get the reverse parcels as soon as possible.

3 Literature study

In this chapter the relevant literature is evaluated. The main goal of the literature study is to learn how problems related to the problems at PostNL are solved in literature. The next research questions are used to structure the literature study. In this chapter those research questions are answered.

- 3.1 What can we learn from literature about reverse logistics optimization?
- 3.2 What can we learn from literature about the assignment of customers to processes?

3.1 Literature study reverse logistics

To study what we can learn about reverse logistics optimization, we first study optimization within the hub and spoke network. Thereafter, we look into reverse logistics in ecommerce, after which general reverse logistics models are studied. We conclude this section by answering the research question: What can we learn from literature about reverse logistics optimization?

3.1.1 Optimization in hub and spoke networks

In this section we first focus on research conducted in the hub-and-spoke system in general. Then we study literature regarding the intermodal hub-and-spoke system. We conclude with some statements about the application to the PostNL case.

Research conducted on hub-and-spoke networks mainly focusses on transport optimizations and hub location problems (O’Kelly, 1998) (Serper & Alumur, 2016) (Campbell & O'Kelly, 2012) (Alumur & Kara, 2008). Decisions made in a standard hub and spoke network problem can be divided into strategic and operational decisions. According to Zäpfel & Wasner (2002) strategic decisions in the hub-and-spoke models include: selection of suitable locations, assignment of customers to depots and determination of the routing. Operational decisions include: disposition of the number of trucks for line haul and planning of pick-up/delivery tours. In general, the goal function is to minimize costs.

The assignment of customers to depots is the only decision within the scope of this research, when considering the list of Zäpfel & Wasner (2002). Since the variables in this research are not the same as in the hub-and-spoke network, the hub-and-spoke models are not directly applicable. Nevertheless, it is useful to know how the hub and spoke models are built. The hub and spoke model can be formulated using a variety of mathematical models. Some examples are: path-based mixed-integer linear programming models with four-dimensional variables and origin-based mixed-integer linear programming models with three-dimensional variables (Meng & Wang, 2011).

Meng & Wang (2011) propose an intermodal hub-and-spoke network design for multi-type container transportation. They have extended the hub-and-spoke model with the possibility to have multiple containers during the transport. In the PostNL case, the containers can be defined as a parcel, roll container and truckload. Meng & Wang (2011) propose a mathematical program with equilibrium constraints. With big M constraints they make sure that all depots have transshipment of at least one container type. For each container type, capacity constraints are used to make sure that the capacity is not violated. Binary variables are used to decide if transshipment lines, and thereby container types are used. To solve the problem Meng & Wang (2011) developed a hybrid genetic algorithm.

He, Wu, Zhang, & Liang (2015) propose an improved MIP heuristic combining branch-and-bound, Lagrangian relaxation, and linear programming relaxation to solve the intermodal hub location problem. The goal function is a minimization of cost. Linear capacity constraints are used to restrict the capacity for the different container types. They found that the proposed heuristic achieves better results and optimality gaps achieved by the developed heuristic are comparatively more stable and have a smaller variation in comparison with other MIP heuristics. In the proposed heuristic by He, Wu, Zhang, & Liang (2015) a lower bound and upper bound are determined. A combination of branch and bound and Lagrangian relaxation leads to an upper bound of the goal function. A combination of both is applied to reduce the chance of the incumbent solution being infeasible. An LP relaxation is used to determine the lower bound. Given the upper and lower bound, the intuition behind the IMMIP heuristic is to find an efficient way to fix a subset of variables that leads to a restricted version of the problem that is easier to solve. Those sub problems are combined later to come to an end solution.

Zhou, Pan, Chen, Yang, & Li (2012) use binary variables in their MIP model to decide on changes. When a change is made the binary variable gets the value 1 and 0 otherwise. This binary variable is used in the goal function and constraints to evaluate the results of the decision to implement the change. A constraint is constructed to make sure that the required improvements are generated.

Based on the literature review a MIP model might be appropriate to model the intermodal hub-and-spoke network at PostNL. Since the decision variables at PostNL are different than those considered in literature, we need to combine or adapt existing models. A new model should be developed that decides about container types and if changes in the process of PostNL are needed. This model can be solved by a MIP heuristic.

3.1.2 Reverse logistics in ecommerce

Rajagopal, Sundram, & Naidu (2015) created an overview of definitions of reverse logistics. This overview is given in Figure 24. Rajagopal, Sundram, & Naidu (2015) conclude: "*Moreover with the emergence of ecommerce and the ever-increasing willingness of consumers to reverse goods, comes the need to rethink the significance of Reverse Logistics management.*"

In Figure 24 one can see that the input products in reverse processes that are found in literature, ecommerce reverse parcels are not present. The used products that are studied in this research are products that are used and should be revised or dismantled in some way. The reverse products in reverse parcels as we discuss, are products that can directly be resold. Other aspects of the reverse process of PostNL can be recognized in this figure, for example, transport activities and the transport direction from the consumer to the customer.

What is?	Inputs	Activities	Output	From	To
▪ Process ▪ Task ▪ Skills ▪ Activities	▪ Discarded products ▪ Used products ▪ Products/parts previously shipped ▪ Packages and products from hazardous and non - hazardous. ▪ Information ▪ Raw material ▪ In process inventory	▪ Management ▪ Collection ▪ Transportation ▪ Storage ▪ Processing ▪ Acceptance ▪ Recovering ▪ Packaging ▪ Shipping ▪ Reducing ▪ Disposing	▪ Products again reusable ▪ Recycling ▪ Remanufacturing ▪ Disposal ▪ Reducing ▪ Managing ▪ Recapturing value	▪ Point of consumption	▪ Point of origin ▪ Central collection point ▪ Manufacturer

Figure 24 Overview reverse logistics (Rajagopal, Sundram, & Naidu, 2015)

Wang, Chen, Rogers, Ellram, & Grawe (2017) state that handling ecommerce reverses can be more costly than regular retail reverses. The main causes for the higher costs are: shipping costs, unknown condition of items returned, and the need to transport returned items to be resold or otherwise disposed (Wang, Chen, Rogers, Ellram, & Grawe, 2017). Besides Wang, Chen, Rogers, Ellram, & Grawe (2017) imply that not much research is conducted into the field of ecommerce reverse logistics.

To conclude, in reverse logistics literature the reverse process in ecommerce is recognized as a promising field of research, nevertheless this research is not yet conducted. Based on the definitions found, the reverse process in ecommerce is partly like normal reverse processes and thereby research conducted in reverse logistics is worth studying.

3.1.3 Reverse logistics models

No literature about reverse logistics in ecommerce is found, but there are great similarities between reverse logistics in ecommerce and general reverse logistics. Therefore, we analyze regular reverse logistics models now.

Most reverse logistics models developed before 2001 are MILP models (Fleischmann, Beullens, Bloemhof-Ruwaard, & Wassenhove, 2001). After 2001 no overview study is conducted in this field of research, therefore we studied literature after 2001 ourselves. After 2001 most models developed to model reverse logistics are MILP models (Choudhary, Sarkar, Settur, & Tiwari, 2015), (Roghanian & Pazhoheshfar, 2014) and (Galvez, Rakotondraniaivo, Morel, Camargo, & Fick, 2015). Different methods are used to optimize the MILP models, Choudhary, Sarkar, Settur, & Tiwari (2015) implements a modified and efficient forest data structure to derive the optimal network configuration. Roghanian & Pazhoheshfar (2014) propose priority based genetic algorithm.

The model developed by Choudhary, Sarkar, Settur, & Tiwari (2015) decides about which facility to open, what number of returned products to ship from a certain collection area to a distribution facility, and what number of returned products to ship from a distribution facility to production facility. There is no distinction made between products. All products can be handled via all processes. The model of Roghanian & Pazhoheshfar (2014) decides on to open certain facilities and transport between the different facilities. Facilities implemented are recycle facilities, returning, disassembly and processing facilities.

Govindan, Soleimani, & Kannan (2015) state that: "*as real-world problems are always complex and complicated, problems cannot be modeled using simple linear programming approaches".* They mention different papers that come with alternative methods, for example Sun, Wu, & Hu (2013). Sun, Wu, & Hu (2013) formulate the problem into a three-stage stochastic programming problem. Each stage is solved separately with a proposition that is proven as an optimal decision rule for the specific stage. The decision that is made is how much to produce given expected demand and received reverse products. The optimized stages are combined afterwards.

According to Salema, Póvoa, & Novais (2005) MILP models are very hard to solve under consideration of uncertainty. Salema, Póvoa, & Novais (2005) came with a solution to cope with the uncertainty, a stochastic optimization model*. The uncertainty is modeled by a small number of discrete scenarios. Random variables assume deterministic values in each scenario. The objective is to find a solution that performs best under all scenarios, this is known as the recourse problem. In practice recourse problems are applied when a combination of tactical and operation decisions is conducted. Decision variables are classified as first stage or second stage variables, the first stage variables are proactive where the second stage variables are reactive (Sen & Higle, 1999). Recourse problems are widely applied, an example outside the reverse logistics field is a blueprint schedule as tactical decision and patient planning as operational decision (Leeftink, Vliegen, & Hans, 2017). Salema, Póvoa, & Novais (2005) implemented a recourse model in a reverse logistics situation to model a small number of discrete scenarios. Random variables assume deterministic values in each scenario. The objective is to find a solution that performs best under all scenarios.

In those recourse problems, decision variables are split in two groups, the first and second stage. The first stage decision variables are the decision variables regarding strategic decisions, defined as those decisions that cannot be reviewed when future outcomes are realized. The second stage decision

** Note: Stochastic optimization is divided in two different methods of optimizing when considering stochasticity. The recourse problem as described in this section and chance constrained optimization as described in Section 3.2.2.*

variables are the decision variables regarding tactical decisions, defined as decisions that can be reviewed after the scenario occurrence. Birge & Louveaux (2011) came with the idea for two stage modeling as first in 1997, they described the method in detail in their book. They define the first stage as, before the random experiment and the second stage as after the random experiment. In the goal function of the developed MILP model a factor π is introduced has represents the weight of a specific scenario.

3.1.4 Conclusion

We have divided the research question into three sub sections. First, we have studied optimization in the hub and spoke network. For the optimization of hub and spoke networks often MIP models are used, a variety of solving methods for these models is developed. Secondly, we have studied reverse logistics specified for ecommerce, unfortunately not enough research is conducted yet. Therefore, we studied reverse logistics in general thirdly. The reverse logistics models found in literature are merely MILP models. Those models are solved in multiple ways, algorithms and heuristics are developed and stochastic optimization is applied.

3.2 Literature study assigning customers to processes

As explained in Section 1.2.3, the assignment of customers to processes can be seen as a multiple knapsack problem with assignment restriction. Therefore, we study literature in that field of research. Due to the randomness in the reverse volume we also study stochastic programming as a solution method.

In the multiple knapsack problem with assignment restriction, a given set of items should be divided among multiple knapsacks. All items have a weight and all knapsacks have a capacity that cannot be exceeded. All items can be assigned to one knapsack, items can be assigned to a limited set of knapsacks (Dawande, Kalagnanam, Keskinocak, Ravi, & Salman, 2000).

First, we discuss solution methods for a deterministic variant of the multiple knapsack problem with assignment restrictions. Thereafter, we discuss solution methods for a stochastic equivalent.

3.2.1 Deterministic multiple knapsack problem with assignment restriction solution method

In literature, we found an algorithm that might solve the problem to optimality, besides we studied heuristics for the situation when the algorithm does not function properly. First, we discuss the method that potentially can solve the method to optimality, secondly the heuristic is discussed.

AIMMS is a software platform provider making the use of prescriptive analytics easier. AIMMS is claims to be developed to bring the benefits of prescriptive analytics to business and society. The software is capable of solving a lot of mathematical programming models, as for example MILP (AIMMS, 2018). AIMMS uses a presolver to reduce the problem size of a model before it is optimized (AIMMS, 2018). After the presolver, multiple different solvers can be applied dependent on the specific mathematical problem. For example, the CPLEX method.

CPLEX is a method that is widely used in literature as method to solve different versions of MIP. The CPLEX mixed integer optimizer solves MIP models using a general and robust algorithm based on branch & cut (IBM, 2018). CPLEX generates its cuts in such a way that they are valid for all subproblems, even when they are discovered during the analysis of a subproblem. If the solution to a subproblem violates one of the subsequent cuts, CPLEX may add a constraint to reflect this condition (IBM, 2018). Being integrated into branch & cut, the heuristic solutions gain the same advantages toward a proof of optimality as any solution produced by branching, and in many instances, they can speed the final proof of optimality, or they can provide a suboptimal but high-quality solution in a shorter time than by branching alone. With default parameter settings, CPLEX automatically invokes the heuristics when they seem likely to be beneficial (IBM, 2018).

In the literature, we found one heuristic dedicated to the multiple knapsack problem with assignment restriction that claims to perform well in a situation related to the PostNL case. Dahl & Foldnes (2006) solve the problem of assigning telephones to antennas. The decision to be made is if a person can be connected and, if this is the case, to which antenna the person should be connected. The heuristic is tested for instances with multiple persons who have a demand and multiple antennas available.

Dahl & Foldnes (2006) prove that the multiple knapsack problem with assignment restrictions is NP-hard. Therefore, this problem cannot be solved to optimality for larger problem sizes. Dahl & Foldnes (2006) propose a heuristic that is in fact, an iterative rounding scheme. In each iteration the heuristic uses information from previous steps. The heuristic is aimed to divide items over knapsacks such that the profit is maximized. All knapsacks have a capacity constraint and each item can only be placed in one knapsack. The heuristic consists of the following five steps:

1. Initialize
2. Find an optimal solution, x, for the LP relaxation
3. Based on x, assign some of the items. Add the assigned items to the fixed item set.
4. Update the set with non-fixed items
5. **If** the set with non fixed items is empty **then** stop **else** go back to 2

For the decision which items to fix, three decision rules are applied. The decision can be random, items that are in the LP relaxation completely assigned to one knapsack or a combination of those two. Fixing items based on the LP relaxation performs best if $\frac{Number\ of\ knapsacks}{Number\ of\ items}$ is small. In some situations, fixing items randomly gives the best result. For large problem instances all three methods perform well (Dahl & Foldnes, 2006).

3.2.2 Stochastic programming

In literature stochastic programming is used when one or more of the data elements are better described by a random variable than a deterministic variable. Stochastic programming is an extension of a deterministic model. Deterministic approximation of stochastic variables can result in unsolvable problems (Sen & Higle, 1999). In literature a distinction is made between recourse problems and restriction on the infeasibility. In recourse problems decision variables are classified according to whether they are implemented before or after an outcome of the random variable is observed as described in Section 3.1.3. The restriction on the infeasibility are modeled as chance constraints, a constraint should be met with a certain probability. In specific applications a combination of both methods can be applied (Sen & Higle, 1999). Since the recourse problem is described in Section 3.1.3 we do not discuss this further in this section, in this section we focus on the models regarding restrictions on the infeasibility.

Restrictions on the infeasibility are applied when there is an implicit acceptance of the inability to meet system requirements at all times. It is also known as chance constrained, which is defined by Cooper (1959) as: "*Select certain random variables as functions of random variables with known distributions in such a manner as (a) to maximize a functional of both classes of random variables subject to (b) constraints on these variables which must be maintained at prescribed levels of probability.*" This is often applied in situations where there are service level agreements. In that situation a constraint should be met with a probability equal to the service level (Sen & Higle, 1999). Stochastic constraints are in the form $P(A*x \geq b) \geq p$. This is a modification of a deterministic constraint $A*x \geq b$. In a stochastic variant, variable x and/or parameters A,b should be a random number. The distribution of the randomness is based on the distribution of the data set.

Interesting research is conducted by Beraldi, Bruni, & Conforti (2004). They address the problem of designing robust emergency medical services. A model is developed to get to know where service sites should be located, how many vehicles are needed at each service site and which level of reliability should be guaranteed in the area. The developed model uses the probabilistic paradigm. Chance constraints are used to model that areas should be served with a certain confidence level. In the model of Beraldi, Bruni, & Conforti (2004) a demand point can only be served by a server as a certain constraint is met. The developed model is a special facility location model described as a MILP. The MILP is improved by a stochastic formulation of some constraints, by describing those as probabilistic constraint. To solve the problem, the problem is reformulated into a unique integer problem.

There are no formulas to exactly compute probability functions in chance constraints. They can be estimated by simulation (Ta, L'Ecuyer, & Bastin, 2006). Ta, L'Ecuyer, & Bastin (2006) propose to simulate multiple independent days with random numbers. Accordingly, the random numbers can be estimated with an average over the different runs, this is also known as Monte Carlo simulation.

According to Hong, Yang, & Zhang (2011) Monte Carlo simulation is often used when the closed form of the chance constraint is not available. For multiple random generated scenarios, a model is optimized, this is called the scenario approach. The scenario approach is simple to understand and easy to implement (Hong, Yang, & Zhang, 2011). However, there are several drawbacks. When the approximation of the original problem is too conservative, for example the expected demand is too low, a feasible but suboptimal solution is found. Solutions found in the scenario approach need not to be stable, in different scenarios the outcome can be drastically different. More samples will not necessary lead to a better performance as in many other Monte Carlo applications (Hong, Yang, & Zhang, 2011). Nevertheless, the Monte Carlo approach is used often used in literature and shows good results.

Besides Monte Carlo simulation, relaxing a stochastic constraint is a widely used method. For example, Li, Wendt, Arellano-Garcia, & Wozny (2002) applied relaxations. If a stochastic model is linear it is relaxed to a convex problem and therefore easily solvable. A stochastic constraint can be relaxed to the form: $\Phi\left(\frac{Y_{max}-\mu_Y}{\sigma_Y}\right) \geq \rho$.

Ben-Tal and den Hertog (2011) prove that a linear optimization problem with parameter uncertainty can be reformulated as a quadratic programming problem. Ben-Tal and den Hertog (2011) do not use a reformulation as a semi-definite problem as was usual in literature until that moment. Therefore, they are not restricted to the Slater condition and do not need a interior point. Their method gives a more complete picture of when nonconvex quadratic problems are in fact equivalent to certain explicit convex problems (Ben-Tal & Hertog, 2011). An example of a nonconvex quadratic problem is given in Figure 25.

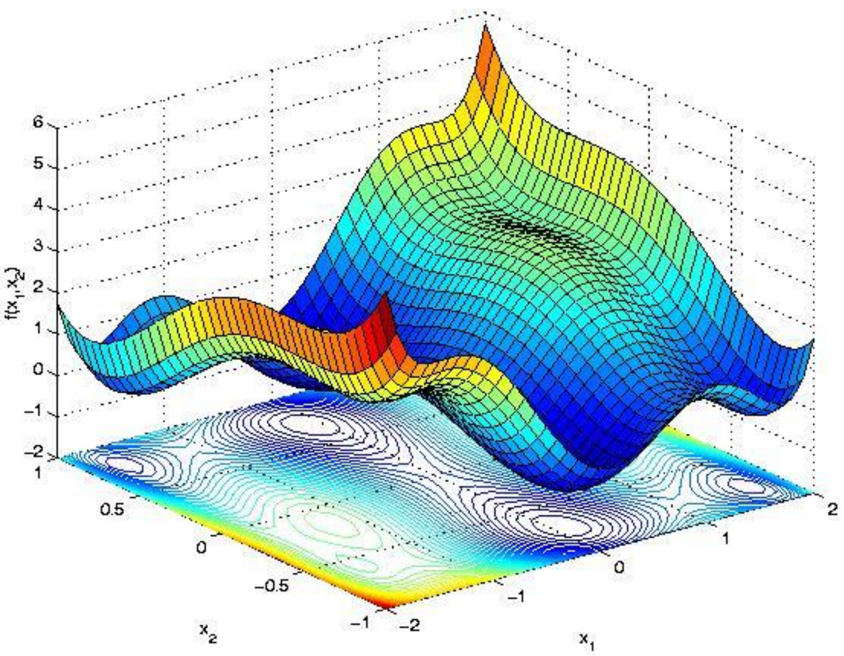

Figure 25 Example of a non convex quadratic problem, six hump camelback function (WaveOpt_Lab, 2018)

A nonconvex quadratic problem can be solved by for example CPLEX. Bliek, Bonami, & Lodi (2014) describe the CPLEX 12.6 method of solving mixed integer quadratic programming (MIQP) problems. In this method, first it is tried to transform the MIQP to a MILP. The most efficient way to make this change is by changing the quadratic terms to new constraints by adding new variables. This is only possible for convex MIQP problems. A problem is convex if it has to optimize a convex function in a certain space. When a problem is non-convex, the CPLEX 12.6 method uses the Spatial Branch and Bound algorithm. In the spatial branch and bound algorithm, a linear constraint is created to limit the search space and to improve the convex relaxation. After this first relaxation, CPLEX 12.6 applies two new ways of convex relaxation. The Q-space reformulation and relaxation and the Factorized Eigenvector space reformulation and relaxation. Both relaxations are aimed at getting a better convex relaxation. The bounds are changed by updating all Secant and McCormick approximations. In this way the convex relaxation is getting tighter, which means that it is better describing the real function (Bliek, Bonami, & Lodi, 2014). The convex relaxations are used together with heuristics to solve the problem in the same way as the CPLEX algorithm explained in the previous section.

In AIMMS the method of Ben-Tal and den Hertog (2011) and the CPLEX 12.6 method are implemented (AIMMS, 2018). Next to those two methods, AIMMS applies pre-solve methods to limit the problem what makes it easier to solve.

3.2.3 Conclusion

We found that the assignment of customers to processes can be compared with the knapsack problem. This problem can be modeled as a deterministic mixed integer linear programming model or stochastic model. According to Ben-Tal and den Hertog (2011), a stochastic model can be reformulated to a quadratic programming problem. Recent versions of the CPLEX algorithm can solve this problem. The CPLEX algorithm can solve mixed integer linear programming problems as well. Next to the CPLEX algorithm we found the heuristic of Dahl & Foldnes (2006). When the model is infeasible, in reasonable computation times, in AIMMS we can apply the heuristic. An alternative for applying CPLEX on the stochastic model, relaxation of Li, Wendt, Arellano-Garcia, & Wozny (2002) or a Monte Carlo simulation as proposed by Hong, Yang, & Zhang (2011) can be applied. The CPLEX algorithm and the reformulation of Ben-Tal and den Hertog (2011) are applied in AIMMS.

3.3 Conclusion literature study

In literature we have found interesting insights and models to apply at PostNL. We could answer the both research questions we stated in this chapter.

We found most interesting reverse logistics models in the general reverse logistics literature. No dedicated models for reverse logistics in ecommerce are found. The general reverse logistics models are MILP models.

For the assignment of customers to processes we have found relevant research and ideas. We found that chance constraints can be used to model the required service levels. Furthermore, we found a method to change the model with chance constraints to a quadratic programming model. The new versions of CPLEX can solve most of those problems in reasonable computation times.

4 Ideas for improvement

In this chapter we will generate ideas for the improvement of the reverse process. This is structured by the next two research questions.

- 4.1 What are existing solutions for the problems encountered that are already present within PostNL?
- 4.2 What radical innovations can we think of for the solution of the process design improvement?

The chapter is concluded with an overview of the relevant ideas that are investigated further.

4.1 Solutions existing at PostNL

At PostNL different ideas exist on how to cope with the growing number of parcels in the reverse process each year. The different options suggested are, Shift-0, adding a Slide and a Central reverse depot. The suggested options are discussed below.

4.1.1 Shift-0

The idea behind the Shift-0 solution is that reverse parcels are not in the regular processes. The reverse parcel sorting times are not bound by the delivery times for consumers. It is only possible to deliver parcels to a consumer between specific hours of the day. For the delivery of reverse parcels to customers this restriction is not always there, for lots of customers arrangements about the delivery times have been made. Therefore, the reverse parcels can be sorted and distributed before the regular parcels.

The idea of Shift-0 is to start the distribution process before the regular distribution process is started. For the details about the distribution process we refer to Figure 3. This change only affects reverse parcels that are already in a dedicated tour. Reverse parcels that are in the normal distribution routes cannot be separated since it is not known if it is a reverse or normal parcel. The main advantage of the Shift-0 solution is that the number of parcels that needs to be sorted in the peak hours is decreased. It does not affect the cost structure in the reverse process since all handling activities stay the same. The handling might be conducted at another moment, which can have effect on the costs that have to be made. Therefore, the Shift-0 idea will not be considered as a stand-alone solution. The ideas behind the Shift-0 solution can be implemented in other solutions.

4.1.2 Slide

The idea of the slide solution is that sachets with clothes require manual stacking. This is not necessary if the parcels directly flow into the roll container. Since the sachets with cloths are non-fragile it is not a problem if they fall into the roll container. If a slide is attached to the sorter, and the sachets of a customer can be separated from the regular parcels then this solution might work. This results in additional capacity of roll containers at a gutter and the sachets do not need to be handled by an employee.

This idea is not incorporated in the remainders of this research, since it requires a change on the machine and the processes stay merely the same. Nevertheless, when new sorting machines are developed it might be interesting to investigate the opportunities of such a slide for sachets.

4.1.3 Central reverse depot

The idea of the central reverse depot is that all reverse parcels at the first sorting stage are combined in one roll container. The parcels are transported to the central reverse depot where they are sorted on customer level. From the reverse depot on, the parcels are delivered in a roll container to the customer. This transport can be done in different manners, a truck can drive a tour along different customers or one customer and deliver the roll containers with parcels to the customer. In this method the number of containers needed in the first sorting stage is reduced to one per depot instead of the 10 roll containers that are used at this moment. The sorting of the parcels at the reverse depot can start in the early night when the first roll containers arrive. Due to the driving distances between depots and number of parcels, this sorting can take a major part of the day. To create a better understanding of this process we describe the way of the parcel and give a process flow chart in Figure 26.

Suppose someone from Enschede has ordered something at webshop.nl that does not satisfy his/her demands. The parcel is delivered to a PostNL service point in Enschede. From the PostNL service point the parcel is transported to a depot close by, in this case depot Hengelo. At depot Hengelo the parcel is sorted as reverse parcel. The parcel is placed in a roll container at depot Hengelo together with all other reverse parcels. The reverse roll containers are transported to the central reverse depot. At this central reverse depot, the parcel is sorted in a roll container for webshop.nl. Suppose that the warehouse of webshop.nl is in Den Bosch. The roll containers for webshop.nl are delivered to the warehouse in Den Bosch, when it is possible roll containers for other customers are placed in the same truck and the route can deliver multiple customers.

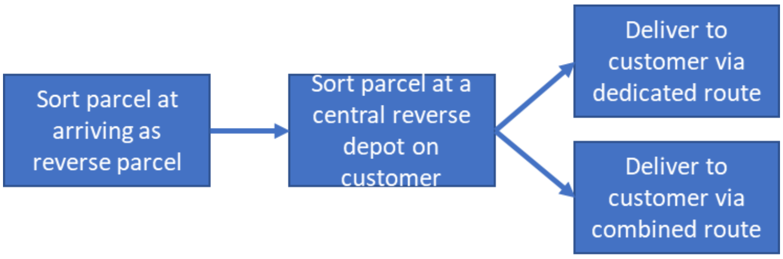

Figure 26 Central reverse depot

4.2 Radical innovations for process improvements

In this section we answer the research question: what radical innovations can we think of for the solution of problems encountered? We first study in what way radical innovations can be found. A literature study in creative solution generation methods is conducted. Thereafter, they are applied at PostNL, solutions found are presented in Section 4.2.2.

4.2.1 Creative methods

In literature two methods are found that are applied in this research, Brainstorming and Mind mapping. First it is explained why those methods are suitable for the situation at PostNL and how these methods can be implemented. At the end of this section we discuss the results of the application at PostNL.

4.2.1.1 Brainstorming

Brainstorming is a good solution generation tool if the problem is well defined. Brainstorming is first described by Alex Osborn. It can be used for generating operational and strategic solutions (Higgins, 1996). There are four important rules in brainstorming:

- No criticism of any idea is allowed.
- All ideas, even the absurd, are welcome.
- Quantity is sought, the more ideas the better. The quality of ideas can be determined later.
- People are encouraged to combine ideas and to piggyback on the ideas of others.

The brainstorm leader manages the process and makes sure that the rules are followed. A recorder notes all the ideas visible for the participants so that they can use the ideas of others as input for new ideas.

4.2.1.2 Mind mapping

Mind mapping is an individual brainstorming technique designed by Buzan, just as in brainstorming it is about the quantity of ideas and not the quality. It is an excellent technique to generate solutions and ideas (Higgins, 1996).

In mind mapping the main problem is written down to the middle of a piece of paper as a first step. Subsequently each major facet of the problem and potential solutions is noted around the problem. Those facets are the new center in a branch of the mind map.

4.2.1.3 Application at PostNL

We first organized a brainstorming session with logistics designers and project managers that are responsible for a certain part of the process of PostNL. The problem we stated in this brainstorm session was: "We need to get reverse parcels from the depot were the parcel has been collected, to the customer within 24 hours". At this moment feasibility and costs are not relevant. Ideas generated in this brainstorm are used as start point of a mind map. Via this mind map we developed ideas further and created multiple applications of ideas.

4.2.2 Solutions generated

During the brainstorm, multiple new ideas occurred. A picture of the output can be found in Appendix 5. There is a difference between the ideas in terms of feasibility. The very out of the box ideas as jet fighters to deliver parcels will not be discussed. Some ideas provide a new product for PostNL or involve the collection stage since this stage is outside the scope of this research, these ideas will also not be discussed further. Nevertheless, those ideas can be useful for PostNL and therefore are shared within PostNL. Ideas that are specific enough and within the scope of this research are discussed in this section.

There are two directions of reasoning that resulted in valuable ideas during the brainstorm: depot transcending truck routes and early sorting between reverse and non-reverse parcels. The depot transcending truck route process is discussed in Section 4.2.2.1. The idea of sorting between reverse and non-reverse parcels is not worked out in detail during the brainstorm. Therefore, we created a mind map. The question we answer in this mind map is: "What kind of processes can we think of, when a parcel is directly sorted when entering a depot?". This resulted in multiple new process flows. We made a distinction in these processes by naming one category sorting as a reverse parcel and the other category sorting with distinction between reverse parcels. For both categories it holds that the sooner a parcel is recognizable as reverse parcel, the sooner the advantages of combining those parcels can be utilized. Sorting reverse parcels at the central reverse depot and from that depot on deliver to the customer is described in Section 4.1.3 and therefore not described in this chapter. Another way of using a central reverse depot is using the central reverse depot as sorting location and transport the sorted parcels to hubs that are used as distribution location. This process is described in Section 4.2.2.2. Parcels can be resorted at the depot where they are first put in a reverse roll container as well, this process is described in Section 4.2.2.3. When a parcel is sorted as a cluster of reverse parcels, such a cluster can be transported to a decentral reverse depot. In that situation the sorting on customer level can be conducted at multiple reverse depots. The idea of multiple reverse depots is discussed in Section 4.2.2.4.

4.2.2.1 Depot transcending truck routes

Each depot has its own delivery area, this delivery area is created based on distribution routes. Reverse customers are assigned to depots according to the same postal code areas as consumers. This might not be optimal. Optimal assignment of reverse customers can be different than when at the same location a consumer should be assigned to a depot. One of the ideas is to create truck routes to deliver roll containers to multiple customers in one route and assigning the route to one of the depots. This assignment and route planning should be a transport optimization instead of a process optimization, since the transport costs are the highest costs considering the reverse parcels.

The depot transcending truck routes can be applied in the ideas in the next section as well as a stand-alone process. It can be applied in the combined routes from the multiple reverse depots. As stand-alone process, the tours can depart before the regular distribution shifts depart. The process is schematically shown below in Figure 27. The parcels can be sent to the reverse depot as a shift-0 parcel, this will make it easy to implement in the current process. We now describe the possible route of the parcel to create a better understanding of the process.

Suppose someone from Enschede has ordered something at webshop.nl that does not satisfy his/her demands. The parcel is delivered to a PostNL service point in Enschede. From the PostNL service point the parcel is transported to a depot close by, in this case depot Hengelo. At depot Hengelo the parcel is sorted on destination depot and shift-0. The parcel is placed in a roll container at depot Hengelo together with other parcels with the same destination and shift. Suppose that the warehouse of webshop.nl is close to depot Halfweg. Then the container is transported by truck from depot Hengelo, maybe via cross dock Nieuwegein, to depot Halfweg. At depot Halfweg the parcel is sorted based on customer and placed in a roll container. The roll containers for all customers that are in the truck tour are placed in the truck. The truck drives among the different customers and delivers the roll containers with the reverse parcels to the right customers.

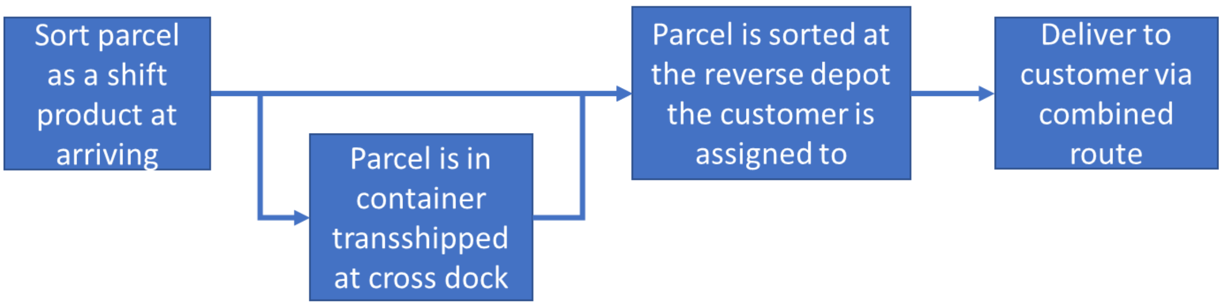

Figure 27 Depot transcending truck routes process

This solution only affects the small and medium size reverse customers. The number of parcels for a customer should be in a range that it is able to fill at least a roll container. There is no maximum restriction on the number of parcels that a customer can receive via this process. Either, when a customer receives a full truckload it is not likely to combine the customer with another customer in a route.

4.2.2.2 Central reverse depot with hubs

The idea of the central reverse depot with hubs is that the sorting of the reverse parcels is conducted at a central location and that the distribution is conducted at multiple locations. From these distribution locations, the parcels are delivered to the customers. This can be in a truck route via multiple customers or via direct transport.

An advantage of this process is that no sorter capacity is required at the reverse depots and the reverse parcels are transported as one type of parcels until the central reverse depot. Therefore, the roll containers have a high fill rate. From the central reverse depot to the reverse depot, the parcels are in a roll container for the specific client. At the reverse depot the roll containers can be stored temporarily after which efficient routes with reverse parcels can be made.

In Figure 28 we give an overview of the process in a flow chart. To create more feeling with the process we describe the way of the parcel below.

Suppose someone from Enschede has ordered something at webshop.nl that does not satisfy his/her demands. The parcel is delivered to a PostNL service point in Enschede. From the PostNL service point the parcel is transported to a depot close by, in this case depot Hengelo. At depot Hengelo the parcel is sorted as reverse parcel. The parcel is placed in a roll container at depot Hengelo together with other reverse parcels. The reverse roll containers are transported to the central reverse depot. At this central reverse depot, the parcel is sorted in a roll container for webshop.nl. Suppose that the warehouse of webshop.nl is in Den Bosch. The roll containers for webshop.nl are transported to a hub close to Den Bosch. From this hub onwards, the parcels are delivered to the customer. If possible, roll containers for other customers are placed in the same truck and the route will deliver multiple customers.

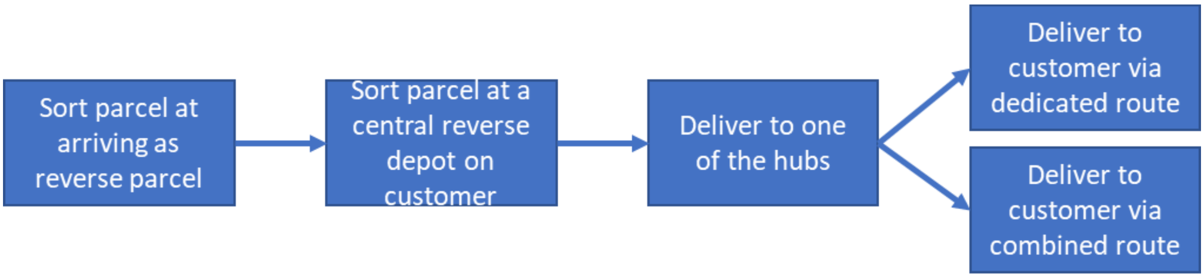

Figure 28 Process flow chart central reverse depot with hubs

4.2.2.3 Dedicated sorting at all depots

Besides resorting the parcels at a central reverse depot, the parcels can be sorted on customer at the arriving depot as well. After the first sorting stage is finished and all regular parcels are handled, the reverse parcels are sorted again. At this moment the parcels are sorted on customer level. When the parcels are sorted on customer level they can be transported from all depots to the reverse depot(s). From the reverse depot on, the parcels are delivered to the customer. In this solution all customers have a roll container at each depot since the parcels are sorted on customer level. At the reverse depot the roll containers can be combined, this requires additional handling. On the other side, the sorting can be conducted directly at night at a moment that the sorter has capacity and the transport can be conducted after the peak hours at night.

In Figure 29 we give an overview of the process in a flow chart. To create more feeling with the process we describe the way of the parcel.

Suppose someone from Enschede has ordered something at webshop.nl that does not satisfy his/her demands. The parcel is delivered to a PostNL service point in Enschede. From the PostNL service point the parcel is transported to a depot close by, in this case depot Hengelo. At depot Hengelo the parcel is sorted as reverse parcel. The parcel is placed in a roll container at depot Hengelo together with other reverse parcels. The reverse roll containers are stored until the end of the “Verzend”. Thereafter the reverse parcels are sorted on customer level and placed in a roll container for a specific customer. The sorted reverse roll containers are transported to the central reverse depot, or reverse hub. At this location the roll containers for webshop.nl are combined. From this location the parcels are delivered to the warehouse of webshop.nl. If possible, roll containers for other customers are placed in the same truck and the route is delivering multiple customers.

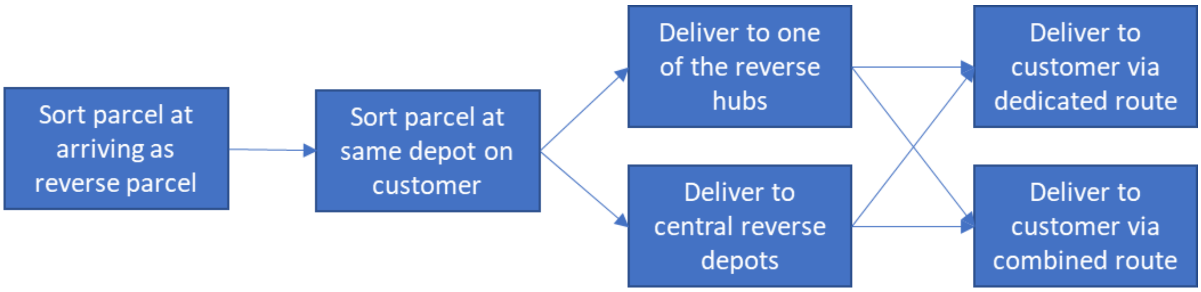

Figure 29 Process flowchart dedicated sorting at all depots

4.2.2.4 Decentral reverse depot

We now discuss the process we can think of when the first sorting is at multiple reverse depots. In the first sorting stage, reverse parcels can be sorted on 'i' categories of reverse parcels. 'i' refers to the number of reverse depots that exist. The parcels are sorted at the reverse depots on customer level and transported from there on to the customer. The difference with the existing "Hengelo/Nieuwegein" process is that smaller customers can be fitted in this process as well since there are combined routes. Besides, the location of the decentral reverse depots should be determined based on efficiency to form routes along different customers. The sorting of the reverse parcels can be conducted after the "Verzend" in the evening and before the distribution starts. When the parcels are sorted, they are placed in a trailer. This trailer can be connected to a truck in the morning when the parcels are transported to the customer. A process flowchart of this process is given in Figure 30. To create more feeling with the process we will describe the way of the parcel.

Suppose someone from Enschede has ordered something at webshop.nl that does not satisfy his/her demands. The parcel is delivered to a PostNL service point in Enschede. From the PostNL service point the parcel is transported to a depot close by, in this case depot Hengelo. At depot Hengelo the parcel is sorted as reverse parcel. The parcel is placed in a roll container at depot Hengelo together with the other reverse parcels that are handled via reverse depot 'i'. The reverse roll containers are transported to the reverse depot 'i'. At this reverse depot, the parcel is sorted in a roll container for webshop.nl. Suppose that the warehouse of webshop.nl is in Den Bosch. The roll containers for webshop.nl are transported to Den Bosch, if possible roll containers for other customers are placed in the same truck and the route will deliver multiple customers.

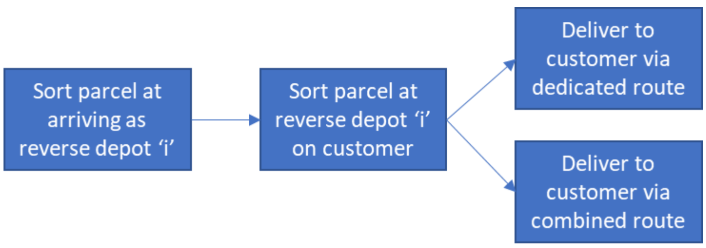

Figure 30 Sort as reverse depot 'i'

4.3 Conclusion ideas for improvement

In this chapter we have collected the ideas that already exists for improving the reverse process within PostNL and generated new ideas. The new ideas are generated by a brainstorm and mind mapping. We conducted a first quick test on which ideas are feasible and meet all requirements for process ideas. The new ideas that are incorporated in the next section are:

- Central reverse depot
- Depot transcending truck routes
- Central reverse depot with decentral reverse depots/hubs
- Dedicated sorting at all depots
- Decentral reverse depots

5 Model design

In this chapter we develop models that we use to determine the most cost-efficient allocation of customers to the processes of PostNL. The research question is answered by creating a conceptual model. After the conceptual model we propose a mathematical model and solution method. The research question that is answered in this chapter is:

- How should a model be designed to be helpful in evaluating solutions for the problems encountered at PostNL?

This research question is answered in three subsections. First, we describe the conceptual model in which we describe the model in words. Thereafter, we give a mathematical formulation of this model. Thirdly we discuss the Monte Carlo simulation that is used and we conclude this chapter by explaining the experimental design.

5.1 Conceptual model

In this section we introduce a model to determine the most cost-efficient allocation of customers to processes. The model is described in words to explain what the model should do. The conceptual model is created and discussed with the problem owner at PostNL.

The goal of the model is to assign customers to reverse processes at minimal costs. There are two variables, a process can be open or closed and the different customers can be assigned to a process. Depending on the experiment conducted, the model can assign each customer to one of the following processes, when the current processes are applied:

- Hengelo
- Nieuwegein
- "Ritsortering"
- "Verzend"

When the new processes are applied as well, the next processes are added to the options to assign customers to:

- Central reverse depot
- Depot transcending truck tours
- Central reverse depot with decentral reverse depots/hubs
- Decentral reverse depots

Restrictions on the assignment of customers are:

- A customer should be assigned to exactly one process.
- Capacity of a process cannot be violated. This can be in the number of assigned customers or in the number of parcels.
- A service level of 98.4% should be reached.
- Customers can only be assigned to a process that is open.

The number of parcels for a customer is stochastic. In a deterministic version of a model, the demand per customer is fixed at a certain number. In a stochastic model, the demand of a customer is described by a chance distribution. Only the demand at Mondays is considered since at Mondays the demand is always higher than at the other days of the week as shown in Chapter 2. In a stochastic model, constraints can be changed such that they are met with a certain probability, these constraints are called chance constraints. A service level of 98.4% should be reached. When we assume that demand can be violated at Mondays only, we will have a service level for Mondays of 92%. This 92% is calculated by an overall fail rate of 100%-98.4%=1.6%. This 1.6% is assumed to be only at Mondays, so in 20% of the days. The 92% is than calculated as follows: $\left(1 - \frac{1.6\%}{20\%}\right) = 0.92$. Therefore, we want to be 92% sure that demand does not violate the capacity on Monday.

Two models are developed to test if the additional complexity of chance constraints does add value to the solution. The solutions will be tested by a Monte Carlo simulation of customer demand. In all instances generated by the Monte Carlo simulation the utilization of the processes will be computed. A low average utilization of a process indicates over capacity. A utilization above the 100% results in shortage in capacity. Both parameters will be used to evaluate the solutions.

5.2 Proposed model

In this section we first propose the mathematical formulation of the stochastic and deterministic model. We conclude this chapter with proposing a solution method for both models.

5.2.1 Mathematical model

First, we describe the deterministic model. Secondly, we describe the stochastic model. The variables and parameters stay the same, therefore those are only stated once.

5.2.1.1 Deterministic model

The deterministic model we created is based on the standard knapsack model, such as the model of Dawande, Kalagnanam, Keskinocak, Ravi, & Salman (2000) and on hub and spoke models, such as the model of Zhou, Pan, Chen, Yang, & Li (2012). First, we state the variables and parameters, secondly the goal function and constraints. At the end of this section the constraints are explained.

Variable:

$$A_{i,j} = \begin{cases} 1, if\ customer\ j\ is\ assigned\ to\ process\ i \\ 0, if\ customer\ j\ is\ not\ assigned\ to\ process\ i \end{cases}$$

$$P_i = \begin{cases} 1, if\ process\ i\ is\ used \\ 0, if\ process\ i\ is\ not\ used \end{cases}$$

Parameters:

$mcp_i = marginal\ costs\ per\ parcel\ of\ process\ i$

$mcr_i = marginal\ costs\ per\ roll\ container\ of\ process\ i$

$fc_i = fixed\ costs\ of\ process\ i$

$fcc_i = fixed\ cost\ for\ customer\ in\ process\ i$

$demp_j = demand\ in\ parcels\ of\ customer\ j$

$demr_j = demand\ in\ roll\ containers\ of\ customer\ j$

$npr_j = number\ of\ parcels\ in\ a\ roll\ container\ customer\ j$

$capp_i = capacity\ of\ parcells\ in\ process\ i$

$capr_i = capacity\ of\ roll\ containers\ in\ process\ i$

$n = number\ of\ customers$

$m = number\ of\ processes$

$maxcust_i = the\ maximum\ number\ of\ customers\ that\ can\ be\ served\ by\ process\ i$

Goal function:

$$\min\left(\sum_{i=1}^{m}\left(P_i * fc_i + \sum_{j=1}^{n} A_{i,j} * fcc_i + mcr_i * \sum_{j=1}^{n}\left(A_{i,j} * demr_j\right) + mcp_i * \sum_{j=1}^{n}\left(A_{i,j} * demp_j\right)\right)\right)$$

Constraints:

$$demr_j = \frac{demp_j}{npr_j}, \forall j \tag{1}$$

$$\sum_{j=1}^{n} A_{i,j} * demp_j \le capp_i * P_i, \forall i \tag{2}$$

$$\sum_{j=1}^{n} A_{i,j} * demr_j \le capr_i * P_i, \forall i \tag{3}$$

$$\sum_{i=1}^{m} A_{i,j} = 1, \forall j \tag{4}$$

$$\sum_{j=1}^{n} A_{i,j} \le maxcust_i, \forall i \tag{5}$$

The goal function is to minimize the total costs related to the reverse process at PostNL. This is a summation over all processes. For each process that is used fixed costs occur. Then, for each customer in the process fixed delivery costs of parcels occur. An example of costs independent of the number of parcels is the stop costs. Marginal costs are in the processes as well. Constraint (1) computes the number of parcels in a roll container for customer j. Constraint (2) and (3) state that the sum of the demand assigned to a process may not be more than the demand available in the process. Variable P_i ensures that there is only capacity available in a process if a process is open. Constraint (4) state that a customer can only be assigned to one process. Constraint (5) makes sure that if there is a restriction on the number of customers in a certain process, this restriction is not violated.

5.2.1.2 Stochastic model

The stochastic constraints in this model are based on the model of Beraldi, Bruni, & Conforti (2004). In the stochastic model the variable $demp_j$ is changed from a deterministic variable to a stochastic variable. $demp_j$ is now described by the distribution $N\left(\mu_{j-Monday}, \sigma_{j-Monday}{}^2\right)$. The constraints where this parameter is used are now chance constraints. For constraints (1), (4) and (5) this does not affect the notation of the constraints. Constraints (2) and (3) are changed and described as (2-S) and (3-S).

$$P\left(\sum_{j=1}^{n} A_{i,j} * demp_j \le capp_i * P_i\right) \ge 0.92 \tag{2-S}$$

$$P\left(\sum_{j=1}^{n} A_{i,j} * demr_j \le capr_i * P_i\right) \ge 0.92 \tag{3-S}$$

Constraints (2-S) and (3-S) state that the volume assigned to processes i may not be violated with a certainty of 92%. To be able to compare the outcome of the stochastic and deterministic model, the same number of parcels are used to compute the costs in the minimization function.

5.2.2 Solution method

A different solution method is used for the stochastic and the deterministic model. The deterministic model is solved using the CPLEX algorithm and the presolver of AIMMS as described in Section 3.2.1. To solve the stochastic model, the method of Ben-Tal and den Hertog (2011) is combined with the CPLEX algorithm for quadratic problems.

The model is implemented in AIMMS and optimized using the CPLEX 12.8 solver. AIMMS is used since it is easy to implement a mathematical model in AIMMS and supervisors of the project have positive experience in solving related problems in AIMMS.

To be able to give the derivation of our probability constraint to the quadratic constraints as is conducted by AIMMS in our simulation we followed the derivation steps of Lejeune & Margot (2016). We present an example of the derivation in Appendix 8. The presented quadratic constraints might be slightly different than the quadratic constraints used by AIMMS. The derivation method applied by AIMMS is not transparent, therefore we are not sure if the presented quadratic constraints are exactly equal to the constraints formed in the AIMMS implementation.

5.3 Monte Carlo simulation

The assignment of customers to processes suggested by the cost optimization model is tested with a Monte Carlo simulation. Two statistics are computed in the Monte Carlo simulation to evaluate the solution. The first statistic is the average fill rate over all iterations and the second statistic is the percentage of days that the fill rate is above 100%.

The Monte Carlo simulation is structured as follows: A random number on the interval [0;1] is used to determine the day of the week, if the random number is <0,8, the day is a non-Monday. If the random number is >0,8 the day of the week is a Monday. The demand for a specific customer is estimated by a random number from the distribution of the specific clients' demand. The demand of a customer cannot be negative.

The demand of the customers in a specific process is summed up. The fill rate of each process is stored per iteration. The two earlier described statistics are computed after all iterations are conducted.

5.4 Experimental design

In this study we want to investigate what PostNL should do regarding their reverse process. We study what PostNL should do at this moment and in five years from now. Therefore, we create an experimental design. In this experimental design we state what experiments we conduct in the next chapter. We refer to current and new processes. The current processes are the processes that are already applied at PostNL as described in Chapter 2. The new processes are the processes we introduced in Chapter 4. The new processes are always combined with the existing processes. An overview of the experiments that we created is stated in Table 7. In the remainder of this section we refer to experiments that are stated in this table with the corresponding number. For each experiment we determine the cost optimization and analyze the solution by the Monte Carlo simulation.

For each experiment first the deterministic or stochastic model from Section 5.2.1 is optimized. This depends on the experiment that is conducted. After this optimization, the assignment of customers to processes is used as input for the Monte Carlo simulation. The output of the Monte Carlo simulation, the average fill rate and days of shortage in capacity, are used together with the impact on stakeholders and information about the scalability and robustness as input for the evaluation of the solutions. The costs for a solution as determined in the optimization of the deterministic or stochastic model are used in this evaluation as well. In Figure 31 we give an overview of the cohesion between these steps.

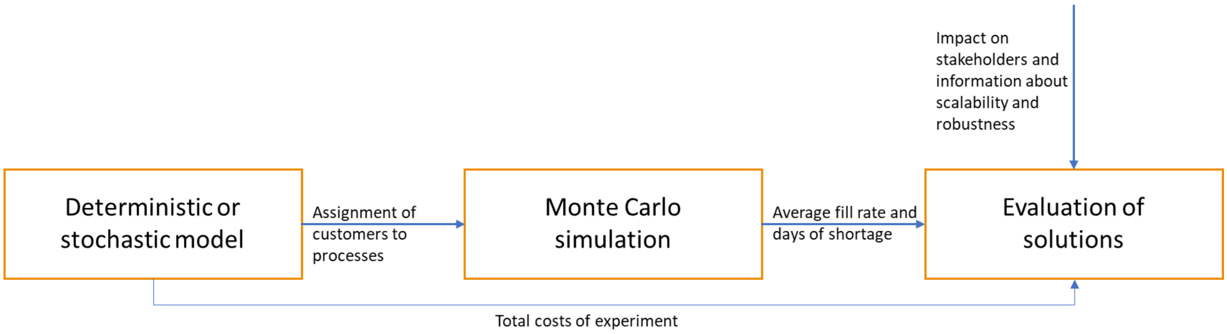

Figure 31 Overview steps in experiment

Experiments 1 until 4 are created to advice PostNL what they can do with their reverse process at this moment. Experiments 5,6 and 13,14 are designed to advice PostNL what they should do in the coming five years.

The values of the input parameters, the delivery costs and parcel size, are estimated as being the same of the national average. To study the impact of deviations between the estimation and reality, we created experiments to test the impact of small changes in those parameters. Since the goal of this research is to investigate what PostNL should do to be able to handle all reverse parcels in five years from now, we also test the impact of the parameters for that situation. We study the impact on the stochastic and deterministic model. Experiments 7 until 12 are designed to study the impact of the estimated parameters.

For the depot transcending truck route process, there is uncertainty in the estimated delivery costs. To study the impact of this uncertainty in delivery costs, we created Experiments 18 and 19. Those two experiments are compared with Experiment 13. In Experiment 13 the initial delivery costs estimation is used. In Experiment 18 and 19 a medium and low costs estimation is used.

In the deterministic model, we use a percentile of the customer demand when we are assigning the customers to processes. It is not known what the best percentile is. When we use the 98.4 percentile, we know for sure that for each customer at least a service level of 98.4% is reached. But due to the pooling effect, deviation in customer demand is leveled over multiple customers. Therefore, we conduct experiments to determine a good percentile. Since the goal of this research is to investigate what PostNL should do to be able to handle all reverse parcels in five years from now, these experiments are conducted in the situation in five years based on the expected volume growth. Experiments 13,15, 16 and 17 are designed to determine what a good percentile is.

Experiment	Demand	Processes	Deterministic/ stochastic	Percentile	Parcel size	Transport cost
1	Current	Existing	Deterministic	98.4	Customer specific	Customer specific
2	Current	Existing	Stochastic	-	Customer specific	Customer specific
3	Current	New	Deterministic	98.4	Customer specific	Customer specific
4	Current	New	Stochastic	-	Customer specific	Customer specific
5	Five years	Existing	Deterministic	98.4	Customer specific	Customer specific
6	Five years	Existing	Stochastic	-	Customer specific	Customer specific
7	Five years	New	Deterministic	98.4	Customer specific	Average
8	Five years	New	Stochastic	-	Customer specific	Average
9	Five years	New	Deterministic	98.4	Average	Average
10	Five years	New	Stochastic	-	Average	Average
11	Five years	New	Deterministic	98.4	Average	Customer specific
12	Five years	New	Stochastic	-	Average	Customer specific
13	Five years	New	Deterministic	98.4	Customer specific	Customer specific
14	Five years	New	Stochastic	-	Customer specific	Customer specific
15	Five years	New	Deterministic	95	Customer specific	Customer specific
16	Five years	New	Deterministic	90	Customer specific	Customer specific
17	Five years	New	Deterministic	75	Customer specific	Customer specific
18	Five years	New Medium delivery costs	Deterministic	98.4	Customer specific	Customer specific
19	Five years	New Low delivery costs	Deterministic	98.4	Customer specific	Customer specific

Table 7 Experimental design

5.5 Validation

In this section we study the validity of the model. To study this validity, we set the current assignment of customers to processes as input for the Monte Carlo simulation and discuss the outcomes with the problem owner.

When discussing the Monte Carlo simulation outcome of the current situation, the problem owner said that the number of parcels presented are close to reality and give confidence in the results of experiments. The numbers of parcels and the ratio between the different processes are like reality. In Table 8 we give the percentage of the weekly demand in the different processes when we put the current distribution into the Monte Carlo simulation. When we compare those numbers with Table 5, we note that the numbers are close to each other. The positive feedback from the problem owner and comparison with Table 5 implies that the model is valid. The results from Table 5 are placed in this table as well to make it easier to compare.

	"Verzend"	**"Ritsortering"**	**Hengelo**	**Nieuwegein**
% of weekly demand	58%	11%	16%	15%
Main findings Table 5:				
% of weekly demand according to expert	60%	10%	15%	15%
% of weekly demand according to samples	63%	10%	13.5%	13.5%

Table 8 Diversion volume per process validation

5.6 Conclusion

In this chapter we have created a deterministic and stochastic model to assign customers to processes. These models are based on the models of Dawande, Kalagnanam, Keskinocak, Ravi, & Salman (2000) and Zhou, Pan, Chen, Yang, & Li (2012). The output of those models is used as input for the Monte Carlo simulation that is used to analyze the results. The model is validated by conducting the Monte Carlo simulation for the current assignment of customers to processes. We conclude that the model is a valid description of reality.

6 Evaluation of solutions

In this chapter we analyze the solutions gathered in Chapter 4. We analyze the solution by studying the impact on the stakeholders and implementing the solutions as new processes in the optimization model of section 5. In this section two research questions are answered, and the cost optimization is computed. The research questions that are answered are:

- 6.1 What are the pros and cons of the solutions for the stakeholders, and which solutions are feasible?
- 6.3 What is the best solution found?

In Section 6.2 the cost optimization is conducted, and results of the cost optimization are given. In Section 6.3 we study which processes occur most in Section 6.2 as one of the most cost efficient processes and how these processes score on the quantitative criteria as studied in Section 6.1.

Unfortunately, we cannot give data about specific customers regarding the specific parcel size, geographical location and average demand due to confidentiality. Therefore, we discuss per section some customers of which we can give that specific data. This regards Section 6.2.1 to Section 6.2.8. For an overall understanding of customer demand, we refer to Section 2.1.3.

6.1 The pros and cons of the solutions

In this section we first discuss which solutions are feasible, this is discussed with the problem owner at PostNL. For the feasible solutions, we study the parameters that are used to evaluate the solutions. First the cost structure is discussed, thereafter the scalability and robustness. We conclude with studying the impact on the stakeholders. Next to the new generated solutions, we discuss the currently existing reverse processes at PostNL and evaluate them together with the newly formed reverse processes.

6.1.1 Feasibility of solutions

To determine which solutions are feasible, hard limits are determined per criterion. A solution should be able to deliver the parcel the next day to the customer. A solution should be realizable at a depot. In other words, a process should be feasible in the existing processes of PostNL. When it is not possible to conduct the process, the process is infeasible. As stated before, the capacity available for the regular process may not be reduced by the changes of the reverse process. Considering those hard criteria, one solution is not feasible. Dedicated sorting at all depots is not possible during the night. At the depots where the dedicated sorting cannot be conducted during the night, the dedicated sorting should be conducted during the next afternoon. This delay is not acceptable and therefore this solution is excluded from the feasible solutions. The remaining feasible solutions are:

- Central reverse depot
- Depot transcending truck routes
- Central reverse depot with decentral reverse depots/hubs
- Decentral reverse depots

6.1.2 Cost structure new solutions

Just like in Section 2.1.2, the costs of a transport action for one roll container are set at 100 due to confidentially. All other costs are relative to this 100. The cost structure per process is first discussed, at the end of this section the costs per process are summarized in Table 9.

For the proposed solutions we assume that when a solution is involving a cross dock, the percentage of transport via cross dock is the same as in the current situation, namely 65%. In the situation of a central reverse depot we assume that due to the number of parcels, direct transport will be conducted between all depots and the central depot. If the parcels from the central reverse depot are transported to decentral hubs, direct transport is assumed as well.

For all new processes two sorting stages are required. Firstly, to sort a parcel as a reverse parcel and secondly, to sort the parcel at customer level. After the first sorting stage the parcels require handling within the depot. After the second sorting stage, those handling activities are incorporated in the delivery costs.

All trucks should be unloaded at the location where the distribution starts. In the situation of a central reverse depot with decentral hubs, the trucks should also be unloaded at the central depot.

The major difference between the costs in the processes is the delivery costs. The delivery costs for the new designed process should be estimated since no data about the delivery is known. Delivery costs for truck routes are estimated based on a pilot at depot Waddinxveen with 14 customers and two delivery trucks. The estimated costs of delivery with truck tour are 243. To test the impact of this estimation, that might be too high, we use 202 for the medium cost scenario and 162 for the low cost scenario.

The costs of delivery from a central reverse depot are estimated based on a weighted average of the transport costs from depot Utrecht towards the depot close to the big customers. In this analysis the customers that receive more than 1,000 parcels on a Monday are considered. Those customers account for 82% of the reverse volume. This results in transport costs per parcel of 108.

When reverse parcels are delivered by truck tours, on average half an hour is required to stop at the customer, deliver the parcels and handle the administration. These costs are 676.

Action + cost	**Central reverse depot**	**Depot transcending truck routes**	**Central depot with decentral hubs**	**Decentral reverse depots**
Transport roll container- 100	1	1.65	2	1.65
Sorting -2.32	2	2	2	2
Roll container handling within depot after sorting-16.33	1	1	1	1
Transshipment handling - 16.5	0	0.65	0	0.65
Unloading truck-8	1	1	2	1
Delivery in truck tour 243	0	1	1	1
Transport from central depot 676 + 108*nr of roll containers	1	0	0	0

Table 9 Cost structure new solutions

6.1.3 Impact on stakeholders

In this section we study the impact of solutions on stakeholders. The impact on the stakeholders is studied based on the question: How will stakeholder Y be affected by solution X? The stakeholders that we incorporate are mentioned in Section 2.5. A stakeholder can be affected by a solution if the solution makes it harder or easier for the stakeholder to process reverse parcels, the customer can be affected by receiving the revers parcels in a different way. For all potential reverse processes, the impact on the stakeholders is discussed in this chapter. The impact is rated according to the next rating schema: - - very negative, - negative, +/- neutral, + positive, ++ very positive.

The control room is handled in a different way. When a process operates as it should, the control room is not affected. During the processes in the night, the control room can significantly influence the processes. Therefore, the influence of the control room on a process is discussed.

Per solution the rating for each stakeholder is discussed in Appendix 2. In this section we discuss highlights and give the conclusive ratings in Table 10. Below this table we discuss the main conclusions that we draw from the table.

Process name / impact on	**Reverse process logistic designer**	**Regular process logistic designer**	**Depot management**	**Control room**	**Customer**
“Verzend”	+	-	+/-	+/-	+/-
“Hengelo/ Nieuwegein”	-	+/-	+/-	-	-
“Ritsortering”	-	-	- -	+/-	+/-
Central reverse depot	+	+	+	-	+/-
Depot transcending truck routes	-	+/-	-	-	+
Central reverse depot with hubs	-	+	+/-	+	+/-
Decentral reverse depots	-	-	-	-	+

Table 10 Summary rating processes

The most positive impact on the stakeholders is generated by the central reverse depot. We note that only the control room is negatively affected. For the depots and logistics designers the process gets better manageable, this is the main cause for the overall positive vibe.

The most negative impact on the stakeholders is generated by the decentral reverse depot and the “Ritsortering”. The negative impact of the decentral reverse depot is mainly caused by additional process steps and complexity that is added to handle reverse parcels at different locations. It should be noted that the very negative impact of the “Ritsortering” process on the depot management is based on too large customers in the process. The “Ritsortering” process is designed for delivering parcels to consumers. When a bigger customer is in this process, several actions need to be taken to handle the parcels for this customer in an appropriate way. The required customized actions make that the process becomes less pleasant for the depot management.

The “Hengelo/Nieuwegein” process has a negative impact on the stakeholders as well. This is mainly caused by the dependency for capacity. In those two processes the capacity that is left after the normal processes is the capacity available.

The other processes have a neutral impact on the stakeholders.

6.1.4 Scalability and robustness

In this section we discuss the scalability and robustness of the solutions. As stated before, PostNL wants to know what they should do to be able to deliver the same or a better service in five years from now. In earlier sections we notice that the expected growth in reverse parcels is 100% for the next five years. Per new designed process we therefore discuss the capacity as well, this discussion is placed in Appendix 3. When we discuss robustness, we discuss what will happen if parts of the process fail. We do not study the situation that the entire system of PostNL fails caused by external factors. When such a failure occurs none of the processes can handle parcels and therefore all processes fail.

A detailed discussion per process can be found in Appendix 3. In this section we give a summary in Table 11 of the scalability and robustness per process. In our discussion we assume that the number of depots of PostNL will increase further. In 2018 three depots will be opened and the increase of the number of depots shall increase even more in the upcoming years. The findings in this table will be used to determine what the best processes are for PostNL. This is discussed in Section 6.3.

Process	Scalable	Robust
“Verzend”	Limited, the number of parcels can increase but the number of customers cannot.	Yes, when one depot is in failure, the parcels are handled at another depot.
“Hengelo/ Nieuwegein”	Limited, during peak periods the capacity in this process can be reduced.	Limited, parcels can be transported to another depot but the process cannot easily be copied.
“Ritsortering”	No, when the total number of parcels of PostNL increases less capacity for reverse parcels in the “Ritsortering” is available.	No, when parcels at a depot cannot be handled they cannot be handled via another depot.
Central reverse depot	Yes, a central reverse depot capacity can theoretically be increased with the current machines to 184.000 reverse parcels per day.	No, when a central reverse depot is in failure, there is not a backup location.
Depot transcending truck routes	Yes, when it is required more trucks can be assigned to this process and thereby more routes can be created.	Limited, when a depot is in failure, a route can be changed to another depot. But this will not be possible in one day.
Central reverse depot with hubs	Yes, a central reverse depot capacity can theoretically be increased with the current machines to 184.000 reverse parcels per day. For the hubs no specifics are required. This can be scaled as well.	No, when a central reverse depot is in failure, there is not a backup depot.
Decentral reverse depots	Limited, given the current depot structure of PostNL at maximum a capacity of 48.000 parcels can be guaranteed.	Yes, when one of the decentral reverse depots is in failure the parcels can be handled via another decentral reverse depot.

Table 11 Summary scalability and robustness

6.2 Results experiments

In this section we discuss the output of the experiments as they are stated in Section 5.4. The output is analyzed with a Monte Carlo simulation. The average fill rate and percentage of the days that the fill rate is above 100% are used as criteria in studies regarding the impact of parameters in Sections 6.2.1 6.2.2 and 6.2.3. When solutions for the current situation and the situation in 5 years are compared, the costs of a solution are involved as well. When discussing the difference between the deterministic and stochastic optimization we add the costs in our discussion.

First, we give some general remarks about the optimization and the Monte Carlo simulation. Thereafter, we discuss the output of the experiments. The first experiments that we discuss are used to study the impact of uncertainty in the delivery costs and parcel size. Second, the impact of the percentile is studied. Third, we study the difference between the deterministic and stochastic optimization. Then we study what PostNL should do at this moment and we conclude with studying what PostNL should do in 5 years. The assignment of customers to processes for all experiments is given in Appendix 7. We have been able to solve the deterministic model in a fraction of a second for the different input data scenarios. To solve the stochastic model with the given integrality gap, two to three seconds are required. Two examples of progress overviews from AIMMS are given in Figure 32 and Figure 33.
We have placed the maximum integrality gap for AIMMS at 0.01, for the used CPLEX 12.8 algorithm it is required that a maximum integrality gap is given to prevent the algorithm for endless recalculations. The set integrality gap is the default setting. In practice we recognized that in most instances an optimal solution is found.

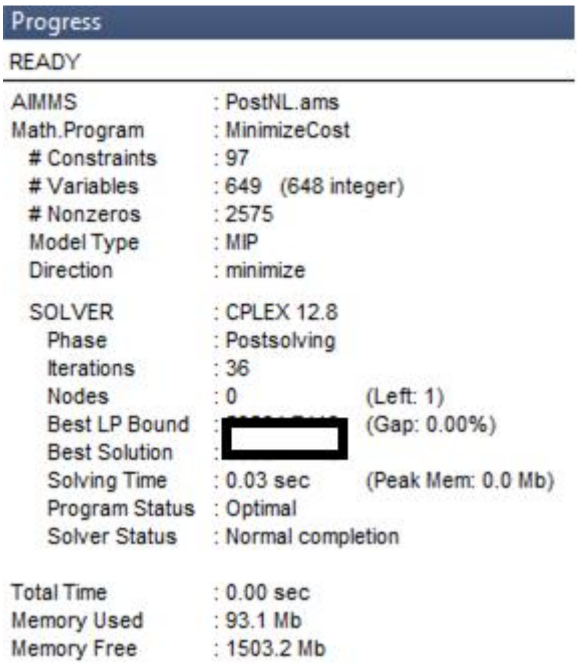

Figure 32 Progress information deterministic optimization

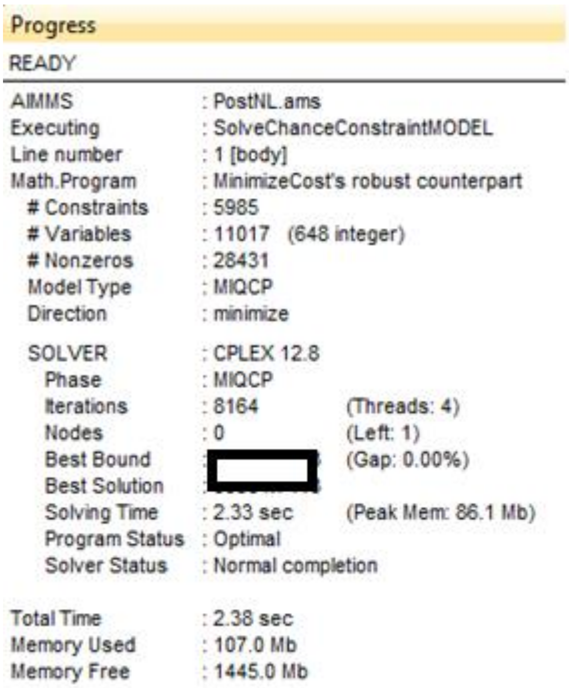

Figure 33 Progress information stochastic optimization

For the Monte Carlo simulations 10,000 iterations are computed. One iteration describes one day. This can by any day of the work week. In one iteration the demand for all customers for the specific day of the week is determined. In Table 12 the average fill rate of the processes is given with a specified number of iterations. For the determination of the number of iterations we used the input parameters of Experiment 3. In Table 12 we see that there is nearly no difference between 1,000 and 10,000 iterations, therefore 1,000 iterations can be sufficient as well. Due to the short computation time and the additional stability we have chosen for 10,000 iterations.

Process/ number of iterations	"Verzend"	"Ritsortering"	Central reverse Depot
10	26.7%	1.79%	25.70%
100	25.8%	1.79%	25.3%
1,000	24.8%	1.75%	25.0%
10,000	25.0%	1.75%	25.1%
100,000	25.1%	1.75%	25.1%

Table 12 Number of iterations Monte Carlo simulation

6.2.1 Impact of specific delivery costs

To study if it is relevant to use customer specific delivery costs instead of average delivery costs, we compare the results of Experiments 9 (Table 13) and 10 (Table 14) with Experiments 11 (Table 15) and 12(Table 16). To study if the delivery costs of parcels matters at all, we set the delivery costs at 0 for some customers when studying the impact of customer specific transport costs. Those customers are discussed separately.

The only customer for which we found a difference between the assignment to a process in a situation with customer specific transport costs and with average transport costs is Customer 58. Customer 58 is located in the center of the Netherlands. Therefore, it makes sence to deliver this customer from the central reverse depot. For all other customers, the customer specific delivery costs do not result in a different assignment to a process.

When studying the customers of which the delivery costs are excluded from the goal function, for some of those customers we note differences, for other customers no differences are found. Customer 14 is assigned to another process where Customers 8, 38, 61, 62, 70 and 73 are assigned to the same process. Customer 14 is a customer that receives a few roll containers of reverse parcels per day, whereas the other customers cannot fill one roll container per day. So, there is an impact if the number of parcels is increasing. This can be explained by the startup costs in some of the processes.

For some customers we note that more detailed information results in a different optimal process. Since we collected the data for this research, PostNL can use the detailed data. But, due to the limited impact on the assignment of customers to processes we do not think that spending time in specifying the delivery costs even more is worthwhile.

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62
Central reverse depot	2;3;4;5;6;9;10;11;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33;35;39; 41;42;43;45;46;47;48;51;52;54;55;56;57;58;59;60;63;64;65;66;67;68;69 72;75;77;79
Depot transcending truck route	1;7;8;12;13;14;15;32;34;37;44;50;53;61;70;71;73;74;78

Table 13 Assignment of customer to processes Experiment 9, demand in five years, new processes, deterministic, perc 98.4, average parcel size and average transport costs

Process	Assigned Customers
“Verzend”	16;36;40;49;76;80
“Ritsortering”	38;62
Central reverse depot	2;3;4;5;6;9;10;11;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33;35;39; 41;42;43;45;46;47;48;51;52;54;55;56;57;58;59;60;63;64;65;66;67;68;69 72;75;77;79
Depot transcending truck route	1;7;8;12;13;14;15;32;34;37;44;50;53;61;70;71;73;74;78

Table 14 Assignment of customer to processes Experiment 10, demand in five years, new processes, stochastic, average parcel size and average transport costs

Process	Assigned Customers
“Verzend”	16;36;40;49;76;80
“Ritsortering”	38;62
Central reverse depot	2;3;4;5;6;9;10;11;14;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33; 35;37;39;41;42;43;45;46;47;48;51;52;54;55;56;57;59;60;63;64;65; 66;67;68;69;72;75;77;79
Depot transcending truck route	1;7;8;12;13;15;32;34;44;50;53;58;61;70;71;73;74;78

Table 15 Assignment of customer to processes Experiment 11, demand in five years, new processes, deterministic, perc 98.4, average parcel size and customer specific transport costs

Process	Assigned Customers
“Verzend”	16;36;40;49;76;80
“Ritsortering”	38;62
Central reverse depot	2;3;4;5;6;9;10;11;14;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33; 35;37;39;41;42;43;45;46;47;48;51;52;54;55;56;57;59;60;63;64;65; 66;67;68;69;72;75;77;79
Depot transcending truck route	1;7;8;12;13;15;32;34;44;50;53;58;61;70;71;73;74;78

Table 16 Assignment of customer to processes Experiment 12, demand in five years, new processes, stochastic, average parcel size and customer specific transport costs

6.2.2 Impact of specific parcel size

To study if the size of an average parcel for a customer is relevant in assigning customers to processes, we compare Experiments 7 (Table 17) and 8 (Table 18) with Experiments 9 (Table 13) and 10 (Table 14).

We do not note differences in the assignment of customers to processes in the conducted experiments. But when we change the volumes of the customers slightly, we note that in some occations differences occur. This is mainly with customer 73 and customer 50. Those customers have large parcels with on average 15 and 20 parcels per roll container instead of the average 35 parcels.

For customers with relative small parcels, 45 or 50 parcels in a roll container instead of the average 35, we do not find a different allocation to processes. Also, when manipulating the volumes of those customers slightly we don’t recognize a difference.

The impact of the parcel size for customers with large parcels is bigger than the impact for customers with small parcels. Therefore, we think that it is useful to use estimations of the average number of parcels per roll container per customer. When it is expected that a customer receives large parcels it might be interesting to study the average number of parcels per roll container. For all other customers estimations can be used due to the limited impact.

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62
Central reverse depot	2;3;4;5;6;9;10;11;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33;35;37;39;41; 42;43;45;46;47;48;51;52;54;55;56;57;58;59;60;63;64;65;66;67;68;69;72;75;77;79
Depot transcending truck route	1;7;8;12;13;14;15;32;34;44;50;53;61;70;71;73;74;78

Table 17 Assignment of customer to processes Experiment 7, demand in five years, new processes, deterministic, perc 98.4, customer specific parcel size and average transport costs

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62
Central reverse depot	2;3;4;5;6;9;10;11;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33;35;37;39;41; 42;43;45;46;47;48;51;52;54;55;56;57;58;59;60;63;64;65;66;67;68;69;72;75;77;79
Depot transcending truck route	1;7;8;12;13;14;15;32;34;44;50;53;61;70;71;73;74;78

Table 18 Assignment of customer to processes Experiment 8, demand in five years, new processes, stochastic, customer specific parcel size and average transport costs

6.2.3 Impact of delivery costs depot transcending truck tours

To study the impact of the delivery on the assignment to depot transcending truck tours, we compare Experiments 13 (Table 19), 18 (Table 20) and 19 (Table 21). We note that in the situation with the estimated costs, that might be too high, seventeen customers are assigned to the depot transcending truck tour process. With the medium costs in Experiment 18 (Table 20), twenty-one customers are assigned to the depot transcending truck tour process. In the low-cost situation, twenty-seven customers are assigned to the depot transcending truck tour processes.

We see that the different cost scenarios have an impact on the number of customers that are assigned to the process.

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62
Central reverse depot	2;3;4;5;6;9;10;11;14;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33;35;37;39; 41;42;43;45;46;47;48;50;51;52;54;55;56;57;59;60;63;64;65;66;67;68;69;72; 75;77;79
Depot transcending truck route	1;7;8;12;13;15;32;34;44;53;58;61;70;71;73;74;78 **(Total 17)**

Table 19 Assignment of customer to processes Experiment 13, demand in five years, new processes, deterministic, perc 98.4, customer specific parcel size and customer specific transport costs, high cost depot transcending truck route

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62
Central reverse depot	2;3;4;5;9;10;11;14;17;18;19;20;21;22;23;24;25;26;28;29;30;31;33;35;37;39;41; 42;43;45;47;48;51;52;53;54;55;56;57;59;60;63;64;65;66;67;68;69;72;75;77;79
Depot transcending truck route	1;6;7;8;12;13;15;27;32;34;44;46;50;58;61;70;71;73;74;78 **(Total 21)**

Table 20 Assignment of customer to processes Experiment 18, demand in five years, new processes, deterministic, perc 98.4, customer specific parcel size and customer specific transport costs, medium cost depot transcending truck route

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62
Central reverse depot	2;3;4;5;9;10;11;17;18;19;20;21;22;23;24;25;28;29;30;31;33;35;39;41;42; 43;45;48;51;52;54;55;56;59;60;63;64;65;66;67;68;69;72;75;77;79
Depot transcending truck route	1;6;7;8;12;13;14;15;26;27;32;34;37;44;46;47;50;53;57;58;61;64;70;71;73;74; 78 **(Total 27)**

Table 21 Assignment of customer to processes Experiment 19, demand in five years, new processes, deterministic, perc 98.4, customer specific parcel size and customer specific transport costs, low cost depot transcending truck route

6.2.4 Impact of percentile

To study the impact of the percentile of the distribution used to determine the demand of a customer in the deterministic model we compare Experiments 13 (Table 22), 15 (Table 23), 16 (Table 24) and 17 (Table 25) with each other.

We have noted that there are no differences between the assignment of customers to the processes for the different experiments. We cannot state that using the one percentile of customer demand is better than using another one in the tested situations. Using a higher percentile should generate a more safe and robust assignment of customers over the processes.

That we do not found a difference between the different percentiles can be explained by that the used number of parcels for all customers decreases. When the 98.4th percentile of customer demand is used, another number of parcels is used than when the 75th percentile is used. The biggest six customers are in the "Verzend" process in all occasions. Therefore, the average fill rate in this process does not differ. As shown in Experiments 1 and 2, an average fill rate of 57% can already be the limit due to the high standard deviation in customer demand. Either, in the situation in those experiments the fill rate in the central reverse depot process does not exceeds the 45.15%. We therefore think that the capacity in the different processes is not a constraint for the solutions.

Process	"Verzend"	"Ritsortering"	Central reverse depot	Depot transcending truck route
% days capacity shortage	0.00%	0.00%	0.00%	0.00%
average fill rate	53.08%	0.02%	45.18%	5.20%
Days in shortage	0	0	0	0

Table 22 Results Experiment 13, demand in five years, new processes, deterministic, perc 98.4, customer specific parcel size and customer specific transport costs

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62
Central reverse depot	2;3;4;5;6;9;10;11;14;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33;35;37;39; 41;42;43;45;46;47;48;50;51;52;54;55;56;57;59;60;63;64;65;66;67;68;69;72; 75;77;79
Depot transcending truck route	1;7;8;12;13;15;32;34;44;53;58;61;70;71;73;74;78

Table 23 Results Experiment 15, demand in five years, new processes, deterministic, perc 95, customer specific parcel size and customer specific transport costs

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62
Central reverse depot	2;3;4;5;6;9;10;11;14;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33;35;37;39; 41;42;43;45;46;47;48;50;51;52;54;55;56;57;59;60;63;64;65;66;67;68;69;72; 75;77;79
Depot transcending truck route	1;7;8;12;13;15;32;34;44;53;58;61;70;71;73;74;78

Table 24 Results Experiment 16, demand in five years, new processes, deterministic, perc 90, customer specific parcel size and customer specific transport costs

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62
Central reverse depot	2;3;4;5;6;9;10;11;14;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33;35;37;39; 41;42;43;45;46;47;48;50;51;52;54;55;56;57;59;60;63;64;65;66;67;68;69;72; 75;77;79
Depot transcending truck route	1;7;8;12;13;15;32;34;44;53;58;61;70;71;73;74;78

Table 25 Results Experiment 17, demand in five years, new processes, deterministic, perc 75, customer specific parcel size and customer specific transport costs

6.2.5 Impact stochastic optimization

In this section we study if stochastic optimization results in a different outcome than deterministic optimization. Therefore, we compare Experiment 1 with Experiment 2, Experiment 3 with Experiment 4 and so on.

Between most experiments no differences are found. We found a difference between Experiments 1 (Table 26) and 2 (Table 27). In Experiment 2 (Table 27), the stochastic variant, the Nieuwegein process cannot meet demand in 1.06% of the times.

The costs in the stochastic optimization are always lower than in the deterministic model if a difference is found. Due to the additional possibilities in the constraints, better solutions are possible.

To conclude, when the capacity constraints are not tight, the deterministic model and stochastic model result in the same solution. When the constraints are tight, the stochastic model results in a different solution. This solution may contain more risk and is less sustainable due to the growth rates of the volumes at PostNL. When the models are optimized with the demand of today and the stochastic optimization outcome is implemented at PostNL, the processes should be changed again after a few months due to the increase in volume. When the growth rates of the number of parcels decrease, and the demand becomes stable the stochastic optimization is useful for PostNL. Stochastic optimization will then result in a solution with lower costs than a deterministic optimization with a 98.4th percentile of customer demand.

Process	**“Verzend”**	**“Ritsortering”**	**Hengelo**	**Nieuwegein**
% days capacity shortage	0.00%	0.00%	0.00%	0.00%
average fill rate	26.63%	3.31%	19.76%	57.99%
Days in shortage	0	0	0	0
Anonymized costs	Anonymized currency 1,091,243			

Table 26 Results Experiment 1, current demand, existing processes, deterministic, perc 98.4, customer specific parcel size and customer specific transport costs

Process	**“Verzend”**	**“Ritsortering”**	**Hengelo**	**Nieuwegein**
% days capacity shortage	0.00%	0.00%	0.00%	1.06%
average fill rate	26.47%	2.97%	0.00%	74.53%
Days in shortage	0	0	0	106
Anonymized costs	Anonymized currency 1,046,919			

Table 27 Results Experiment 2, current demand, existing processes, stochastic, customer specific parcel size and customer specific transport costs

6.2.6 Optimization with the current demand

To determine what PostNL should do at this moment, Experiments 1 until 4 are conducted. Experiments 3 and 4 resulted in the same outcome (Table 29). The results of the experiments are given in Table 26 until Table 29. The current assignment of customers to processes results in operational costs of 1,169,810 according to our computations. It should be notified that in the current situation, depots have separate agreements for the delivery of reverse customers that are in the “Ritsortering” process that are too big to in a normal distribution route. The assumption we have made to compute those costs are likely to be a worst case.

When PostNL wants to keep the processes as they are at this moment, the six biggest customers should be allocated to the “Verzend” process. Depending on the risk PostNL wants to take in being able to handle all parcels, a number of customers should be assigned to the “Nieuwegein”, “Ritsortering” and “Hengelo” process. When PostNL wants to take a lot of risk in not being able to serve all parcels, the Hengelo process can be excluded.

Due to the difference in demand between Mondays and other days of the week, we think it is interesting to conduct the Monte Carlo simulation for Experiment 2 for only Mondays as well. The results of the Monte Carlo simulation for the Mondays is presented in Table 28. We note that in the Nieuwegein process demand cannot be met in 5.35% of the Mondays. This is approximately 5 times the 1.06% as found as shortage when we study the entire week in Table 27.

When PostNL wants to introduce a new process, a central reverse depot results in the lowest operational costs. In that situation, all customers that are not part of the biggest six and have at least 20 parcels per day, should be handled via the central reverse depot. When we compare the cost optimization of the current processes, including the Hengelo process, with the new designed processes, we note a cost reduce in the operational costs of $\frac{1{,}091{,}243-866{,}027}{1{,}091{,}243} * 100 = 21\%$. It should be noted that only the operational costs are included. When we compare the solution of Experiments

3 and 4 with the current situation, we reach a reduction of operational costs of $\frac{1,169,810-866,027}{1,169,810} * 100 = 25.9\%$. This 25.9% should be considered given all remarks. We do not state that in practice the operational costs can reduce by 25.9%, but the practical operational costs can be reduced substantially. When we compare the current situation with the outcomes of Experiment 1, we note that by assigning the customers to processes differently, the operational costs can be reduced by $\frac{1,169,810-1,091,027}{1,169,810} * 100 = 6.7\%$.

Process	"Verzend"	"Ritsortering"	Hengelo	Nieuwegein
% days capacity shortage	0.00%	0.00%	0.00%	5.35%
average fill rate	38.89%	3.27%	0.00%	94.58%
Days in shortage	0	0	0	535

Table 28 Monday only, results Experiment 2, current demand, existing processes, stochastic, customer specific parcel size and customer specific transport costs

Process	"Verzend"	"Ritsortering"	Central reverse depot
% days capacity shortage	0.00%	0.00%	0.00%
average fill rate	24.37%	1.70%	24.84%
Days in shortage	0	0	0
Anonymized costs	Anonymized currency 866,027		

Table 29 Results Experiment 3 and 4, current demand, new processes, customer specific parcel size and customer specific transport costs

6.2.7 Optimization five years from now

To estimate the situation in five years from now, we used the expected growth rate of 100% we have established in Section 2.3. We assume that the standard deviation will increase with 100% as well since, $Var(aX) = a^2 * Var(X)$ and so $\sigma(aX) = a * \sigma(X)$.

We used two scenarios to investigate the opportunities for PostNL, in the first scenario only the current processes can be applied, these are Experiments 5 and 6. In the second scenario the new processes can be applied as well, these are Experiments 13 (Table 30) and 14 (Table 32). The stochastic and the deterministic optimization of the first scenario are not feasible.

We have not found a solution for Experiments 5 and 6 since the required capacity is higher than the capacity available. Therefore, we can state that PostNL cannot handle the reverse parcels in five years from now if the processes are not altered.

When studying the results of Experiments 13 and 14 we note that in both situations the central reverse depot and depot transcending truck route processes are good alternatives.

To gain additional insights in the outcomes, we conducted the Monte Carlo simulation for only Mondays as well for Experiment 13 (Table 31) and 14 (Table 33). We note that the fill rate in the processes is increasing in the Mondays only situation.

Process	"Verzend"	"Ritsortering"	Central reverse depot	Depot transcending truck route
% days capacity shortage	0.00%	0.00%	0.00%	0.00%
average fill rate	53.20%	0.02%	45.00%	55.20%
Days in shortage	0	0	0	0
Anonymized costs	Anonymized currency 1,511,676			

Table 30 Results Experiment 13, demand in five years, new processes, deterministic, perc 98.4, customer specific parcel size and customer specific transport costs

Process	"Verzend"	"Ritsortering"	Central reverse depot	Depot transcending truck route
% days capacity shortage	0.00%	0.00%	0.00%	0.00%
average fill rate	77.76%	0.02%	57.76%	5.43%
Days in shortage	0	0	0	0

Table 31 Results Experiment 13 Monday only, demand in five years, new processes, deterministic, perc 98.4, customer specific parcel size and customer specific transport costs

Process	"Verzend"	"Ritsortering"	Central reverse depot	Depot transcending truck route
% days capacity shortage	0.00%	0.00%	0.00%	0.00%
average fill rate	53.29%	0.09%	45.03%	55.20%
Days in shortage	0	0	0	0
Anonymized costs	Anonymized currency 1,511,676			

Table 32 Results Experiment 14, demand in five years, new processes, stochastic, customer specific parcel size and customer specific transport costs

Process	"Verzend"	"Ritsortering"	Central reverse depot	Depot transcending truck route
% days capacity shortage	0.00%	0.00%	0.00%	0.00%
average fill rate	77.82%	0.08%	56.96%	5.37%
Days in shortage	0	0	0	0

Table 33 Results Experiment 14 Monday only, demand in five years, new processes, stochastic, customer specific parcel size and customer specific transport costs

6.2.8 Concluding remarks cost optimization

In this section we summarize the conclusions of the previous sections. The specified delivery costs for a customer does not have a high impact on the decision to what process a customer is assigned. Estimations for the delivery costs can be used. The parcel size influences the decision only for the customers with large parcels. For customers with small parcels the allocation is not influenced by more detailed information. Due to the small but existing differences in the assignment of customers to processes by more information, we decided to use the information we have in assigning customers to processes.

For the situation with the current demand, we optimized the assignment of customers to the current processes and the assignment of customers to the new processes. When considering the new processes, the central reverse depot seems to be a good option. With the central reverse depot as new process, we can reduce the operational costs with 21%. If we compare the central reverse depot situation with the current situation, the operation costs can be reduced by 25.9%, with all given limitations in our calculations. If PostNL does not want to change the processes, the operational costs can be reduced by 6.7% by a new assignment of customers to processes, again with the given limitations. For the situation in five years we noticed that with the current processes PostNL cannot handle all reverse parcels. The new suggested processes that perform best in the experiments are the central reverse depot and depot transcending truck routes.

Besides, we have seen that stochastic optimization adds value to a solution when the average fill rate of a process is approaching the limit. When there is plenty capacity in the processes, the solution of the stochastic optimization and deterministic optimization are the same. We cannot state that the additional complexity of stochastic optimization adds value for PostNL. Due to the growth in the number of reverse parcels, PostNL shall not implement processes such that they are utilized directly to a maximum. So, in that situation, the stochastic and deterministic optimization result in the same solution. We have not found major differences in using different percentiles of the customer demand.

In the most cost effective assignment of customers to processes, we do not see any customer assigned to the central reverse depot with hubs and the decentral reverse depot process. Therefore, those processes are not mentioned in the tables above. We can explain this absence by the cost structure, the two absent processes are slightly more expensive than the other ones regarding the operational costs.

6.3 Best solution found

The best solution is decided on multiple factors. The outcome of the cost optimization of Section 6.2 is combined with the qualitative criteria described in Section 6.1. First, we study the importance of the different criteria. This importance is studied by pairwise comparison. The weights, that are the result of this pairwise comparison, are discussed with the problem owner at PostNL.

The pairwise comparison in conducted by the problem owner and her manager. The pairwise comparison forms can be found in Appendix 4. A matrix is created to be able to determine the normalized relative weights. Those relative weights are used to determine the weight that is given to each criterion. Those weights are given in Table 34.

	Impact on customer	**Impact on depot**	**Impact on regular process**	**Costs per parcel**	**Scalability/ robustness**
Person 1	19%	4%	17%	27%	33%
Person 2	8%	4%	20%	54%	14%

Table 34 Relative weight per criterium

By applying the method of Alonso (2006) we compute a consistency ratio of 0.36 for person 1 and 0.38 for person 2. According to Alonso (2006) the consistency ratio should be below 0.1 to have a consistent relative weight. So, the weights generated by both persons are not consistently generated. Therefore, we discussed the weights with the problem owner at PostNL and the relative weights are adapted to:

	Impact on customer	**Impact on depot**	**Impact on regular process**	**Costs per parcel**	**Scalability/ robustness**
Concluded weight	15%	5%	10%	45%	25%

Table 35 Concluded weight per attribute

Those weights are not tested on consistency since they are not generated by pairwise comparison. When studying Table 34 and Table 35, we note that the costs and scalability/robustness are the most important criteria where the processes are weighted on. Therefore, we focus most on those criteria when evaluating the solutions in the remainders of this section. The costs are discussed by the output of the cost optimization in Section 6.2, the scalability and robustness are discussed by the output of Section 6.1.4.

In all scenarios the six biggest customers, that fit together in the “Verzend” process, are assigned to the “Verzend” process in the most cost efficient process in Section 6.2. Besides, the process is not complex which is a benefit for the problem owner, the number of parcels that can be handled can increase in the next years. However, the number of customers that are in this process cannot increase and the process has a slightly negative impact on the normal process. Since the costs per parcel has the highest weight and the process scores well on scalability and robustness, the “Verzend” process is seen as one of the best processes found.

The “Ritsortering” process is useful for small customers that receive a few parcels per day. But when the number of parcels for a customer increases, the average process costs increases and the negative impact on stakeholders increases as well. Based on the scores on the scalability, robustness and the impact on stakeholders, the “Ritsortering” is not a good process. Nevertheless, the “Ritsortering” process is a good process for customers with a small number of parcels, up to around 20. For those customers the costs are the lowest within this process. Due to the impact of serving bigger customers via the “Ritsortering” process, the “Ritsortering” process should only be used for small customers.

Depot transcending truck tours are the cheapest way of delivering parcels to the customers for the customers that are between the small and medium size. But additional complexity is a downside of this process. It is easy scalable by just adding more trucks to the process, and therefore, useful in the future. Due to the high scalability and low costs for a specific group of customers in this process we consider this process as a good option. Besides that, the process is easy to implement in the current processes of PostNL. When a combination of customers is such that the costs per roll container decrease, the process becomes more interesting to apply for other customers as well.

One central reverse depot is one of the solutions that occur in all cost optimizations, which is positive. This dedicated reverse depot is relatively cheap for the medium sized and bigger customers and is scalable. Thereby it has a positive or neutral impact on all relevant stakeholders. But, a dedicated reverse depot cannot be created overnight. For the short term this solution cannot be realized, but in the future with the expected growth rates, it can be a interesting solution for the reverse process of PostNL. Due to the low costs, high scalability and positive impact on the stakeholders.

Additionally, the decentral reverse depots are scalable and robust, with a relative neutral impact on the stakeholders. This solution can be interesting if PostNL does not want to have one location that handles most of the reverse parcels. However, the costs of this process are higher than for the other processes and therefore it is not one of the best solutions since, the costs are the most important parameter.

7 Conclusion and recommendations

In this thesis we have answered multiple research questions to be able to answer the main question of this research. In this chapter we answer the main question and give recommendations for PostNL. For answers to the research questions we refer to the previous chapters of this thesis.

7.1 Conclusion

The main question: "*To what extent is the reverse chain of PostNL robust and sustainable and how should it be organized and designed to be robust and sustainable for the next 5 years considering the expected growth?*" will be answered in this section.

We have found that the expected growth in the next five years is 100%. The customer base is expected to be comparable to the current customer base. We have determined the capacity for the existing and newly designed processes. Given the expected stable demand increase per year, and high periodic demands in a year, we think that the current processes PostNL will be able to handle all reverse parcels accordingly for one year longer. After this year, additional capacity should be created.

At this moment the reverse process of PostNL is robust, all reverse parcels can be handled in a satisfying way and there is still some capacity available to grow. We note that in the current distribution of customers, multiple medium size customers are in the "Ritsortering" process. Those customers could be served more cost efficient in a new process or the existing "Nieuwegein" process according to our optimization. If the processes of PostNL do not change in the next five years, and the growth in number of parcels is indeed doubled, PostNL will not be able to handle all reverse parcels.

At this moment, introducing the newly designed processes, the operational costs can be reduced by 21%. To be able to cope with the expected growth, PostNL should introduce new reverse processes. Those processes should be organized as follows: the biggest customers in the "Verzend" process, medium size customers via a central reverse depot process, and small customers via distribution and dedicated tours would be the most cost-effective solution. In this solution potential further growth in the reverse parcel flow can be adapted easily by extending the process at a central reverse depot. A downside of the high dependency to one central reverse depot is the impact of a disruption on one location to the entire reverse parcel handling.

When assuming optimal assignment of customers to the processes on average 6 hours process time at maximum capacity is required on Mondays at a central reverse depot. At the other days, on average 4,5 hours process time is required at a central reverse depot. This means that during the day the central reverse depot can be used for other processes and activities as well. The depot transcending truck tours can start at a depot were capacity is available for an additional shift or at the central reverse depot.

7.2 Recommendations

In this section we give recommendations for PostNL on the short term, recommendations that require extensive further research are discussed in Chapter 8.

We recommend PostNL to reevaluate the allocation of customers to processes based on our assignment of customers to processes in Experiments 1 and 2. We have shown that given the current processes, the operational costs can be reduced by 6.7% by reassigning customers to processes. A short study should be conducted to check per changed customer the operational impact and possibilities. The process of depot transcending truck tours is easy implemented and can reduce costs. Therefore, PostNL should investigate which customers can be combined in logical tours and determine the costs for those routes. As shown by our experiments, the delivery costs have a high impact on the assignment of customers to processes. When a good combination of customer to fit in one tour is found, PostNL can soon implement this new process.

The central reverse depot shows to be the most scalable process that we can think of. Additionally, it is cost efficient. Therefore, we recommend PostNL to study this idea further by investigating the practical implications, costs and possibilities. A central reverse depot does not utilize an entire depot, a combination should be found with processes that utilize the depot at the time when it is not required for the reverse process.

8 Assumptions and further research

In this chapter we discuss the assumptions that have been made in this research and give implications for further research. We make a distinction between further research that is related to the designed processes, the optimized model and further research that can be conducted to improve the reverse process in general. We conclude the chapter with further research that is less relevant for PostNL but is scientifically interesting.

8.1 Assumptions and further research regarding designed processes

In the design of the different processes we assume that all customers can be served by all transport modes. However, in practice some customers cannot be served by a truck. Before a customer is assigned to a new transport mode, it should be checked if the customer can be handled by the new transport mode.

We have not studied the impact on packaging materials (roll containers and pallets) for the different processes in detail. It can be that a process results in surplus of packaging materials at one location and a shortage at another location. By none of the proposed processes we expect extreme differences with the current processes that exists at PostNL. But, if somehow major differences occur, the packaging materials need to be transported from the one location to the other. If there are no trucks at that tour with transport capacity available, additional costs will be charged for this transport.

One of the constraints in this research is that a customer should be assigned to one process. It can be interesting if customers can be assigned to multiple processes. Per depot it can be different what the six biggest customers are, and so which customers would preferably be in the “Verzend” process. Due to the scope of this research we have not been able to study those opportunities. Further research should start with an analysis of the biggest reverse customers per collection depot.

At this moment, a parcel that is delivered to a retail location by a consumer is not separated from the other parcels. Approximately 25% of the parcels that are delivered by a consumer to a retail location are reverse parcels. When those parcels are placed in a reverse roll container at the retail location instead of a general roll container, those parcels do not need to be sorted in the “Verzend”. The total volume in the “Verzend” decreases with 10% and additional capacity for the normal process is created. Besides that, handling of the parcel is excluded from the process, this saves costs. The reverse parcels can directly flow into the reverse network. It should be studied how much reverse parcels a retail location should receive per day to make this splitting worthwhile. Besides, the reverse process should be designed in such a way that there are benefits when the reverse parcels are separated.

8.2 Assumptions and further research regarding the optimization model

In this research it is assumed that when one customer has a peak in volume, the other customers have a peak as well. For the analyzed customers, the peak in the week is at Monday, so in that situation the peak is at the same moment. Besides, the peaks caused by, for example holidays are at the same moment for all customers. Nevertheless, the height of the peak can differ. In this research we assume that there is no correlation between the height of the peaks of the different customers. It can be studied if there is a correlation between demand of multiple customers. This correlation can be used in the Monte Carlo simulation to create a better estimation of real peak days.

Due to limitations in the software used, in the chance constrained model, it is assumed that capacity restrictions can be violated on Mondays only. It is chosen to use Mondays only since the demand at Mondays is the highest. In Section 6.2.6 we show that this assumption of Mondays only is a good prediction for the shortage in capacity for the entire week. In the Monte Carlo simulation, that is used to test the solutions, we considered all days of the week. A more conservative solution is reached when the capacity can be violated on the other days as well. But in the Monte Carlo simulation it is shown that the solutions found stay within the desired service levels. Therefore, further research in this field does not seem worthwhile.

We assume that all customers have the same distribution with different parameters. This distribution is statistically tested on a few customers and generalized for the other customers. Further research could be conducted by analyzing the demand data of all customers and test which distribution is the best fit per customer.

For some small customers that are currently in the “Ritsortering” process we were not able to collect data for a longer period. Nevertheless, we want to consider those customers in our analysis as well. Therefore, we assume that the demand for those customers can be described by one regular Wednesday. The standard deviation is set as a fixed percentage of this daily demand, the percentage is based on other customers of the same size. If the data collection systems of PostNL are extended and reliable, this data can be updated in the model and the model can be optimized again.

8.3 Assumptions and further research reverse process in general

At this moment PostNL is obligated to deliver parcels within 24 hours to the customer. If this requirement can be changed to a longer time span, the transport can be bundled and the sorting of reverse parcels can be leveled out over the week. Besides, the utilization of the transport towards the customer can be increased if parcels can be collected over a longer time span than 24 hours. Further research is required to study how and for which customers this can save costs for PostNL, and if those customers are willing to receive the reverse parcels in a less frequent manner.

In this research we studied the reverse process as a standalone process. PostNL has multiple parcel flows with characteristics that might be comparable with the reverse parcel flow. A high number of parcels is daily delivered to one location. Research could be conducted on how these different parcel flows can be combined to create synergies. All locations were multiple roll containers are delivered can be considered in this study. Besides parcel flows, the postal flows in roll containers can be incorporated in this study.

8.4 Scientifically interesting further research

In this research we found that the tightness of the constraints of the stochastic optimization model determine if the stochastic and deterministic model result in a different solution. However, we studied a limited number of situations so we cannot generalize this statement. It can be interesting to study if this statement can be generalized, and if so in which situations. In literature we have not found research that states when stochastic optimization is worthwhile considering a MILP model and random parameters. The statement that can be used in such a research is: *“stochastic programming does not add value to the solution if the constraints are not tight”*.

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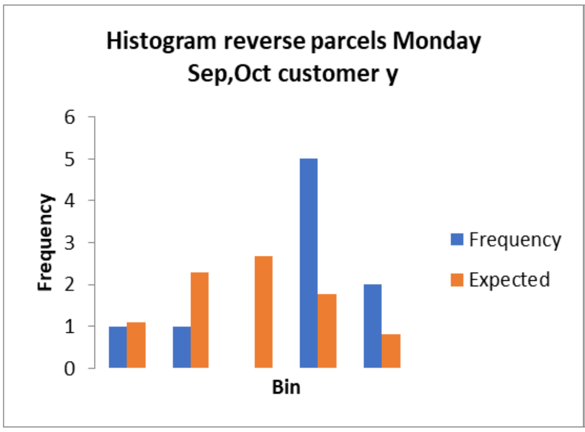
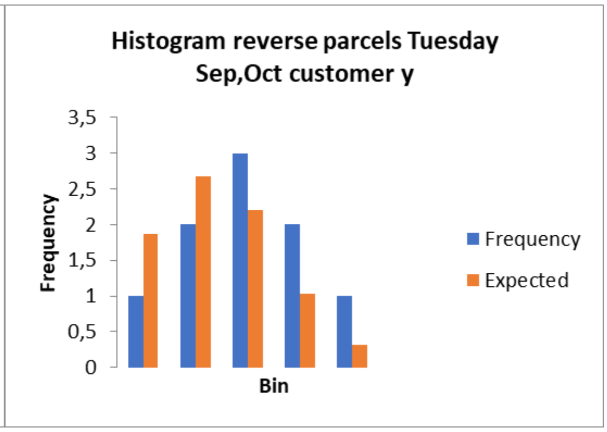
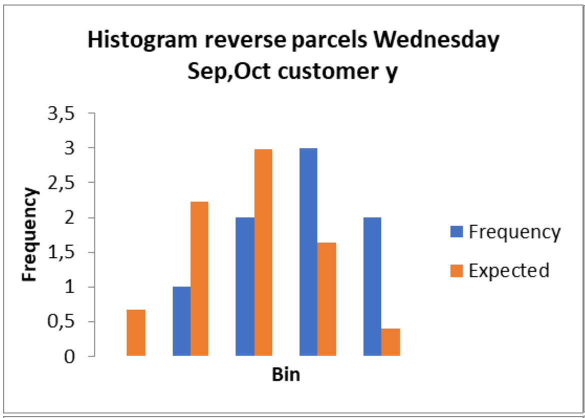
Appendix

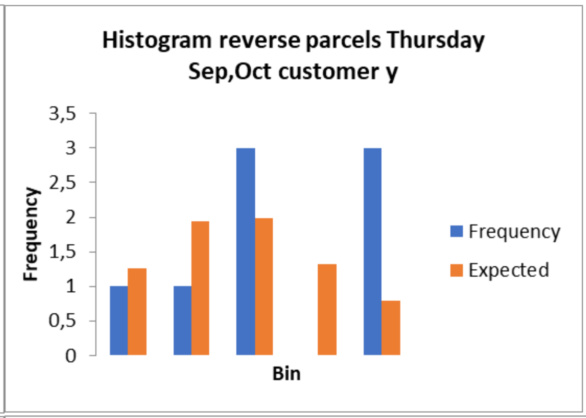
Appendix 1 - histogram reverse parcels over the week

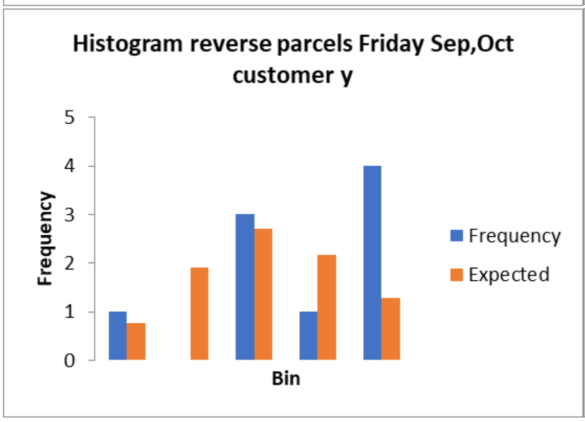
In the figures below histograms of the number of reverse parcels for customer y and x are given. In orange the normal distribution is plotted in those graphs. As stated in the report, the number of parcels at Tuesday until Friday does not differ much. Therefore, also a histogram is made of the demand ad Tuesday until Friday.

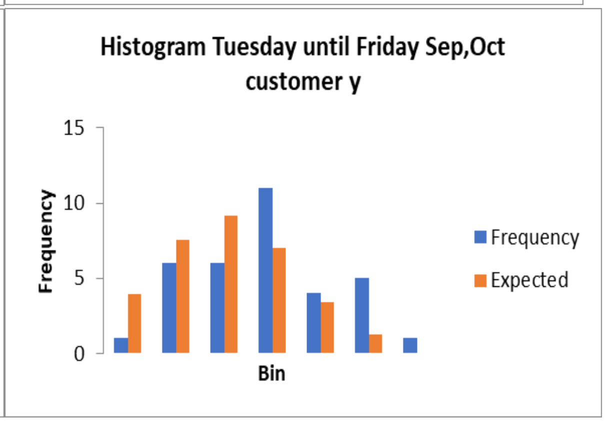


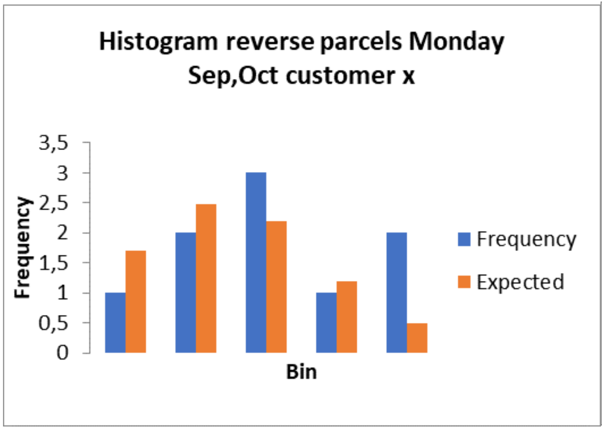


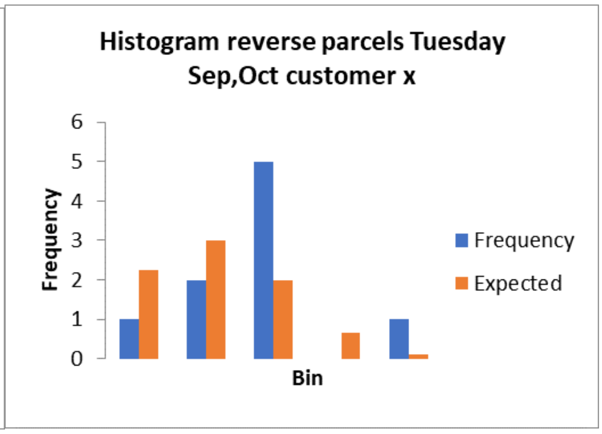


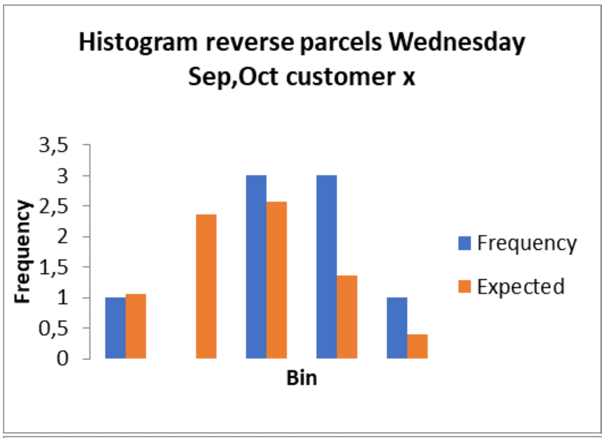


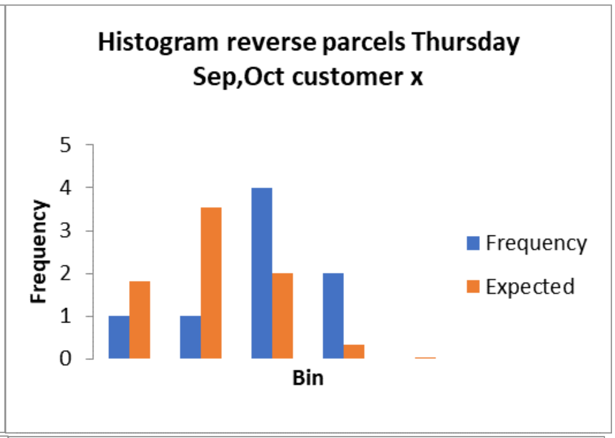


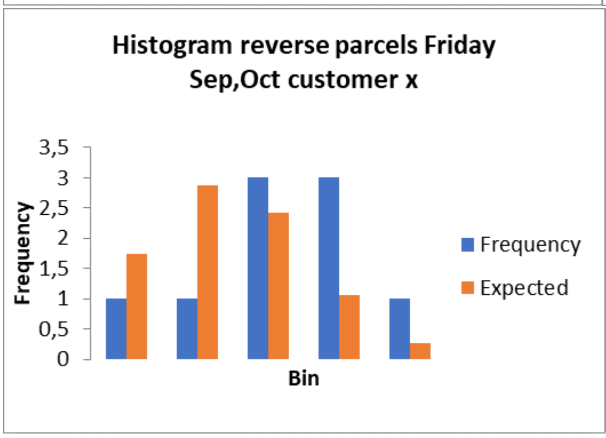


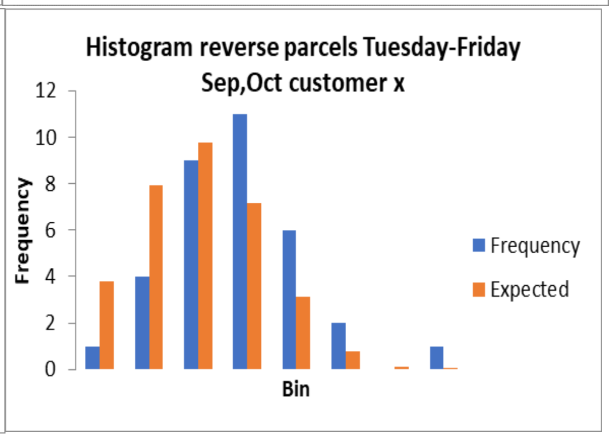

Histogram reverse parcels Monday
Sep,Oct customer x
Frequency
3,5
3
2,5
2
1,5
1
0,5
0
Bin
Frequency
Expected


Histogram reverse parcels Tuesday
Sep,Oct customer x
Frequency
6
5
4
3
2
1
0
Bin
Frequency
Expected


Histogram reverse parcels Wednesday
Sep,Oct customer x
Frequency
3,5
3
2,5
2
1,5
1
0,5
0
Bin
Frequency
Expected


Histogram reverse parcels Thursday
Sep,Oct customer x
Frequency
5
4
3
2
1
0
Bin
Frequency
Expected


Histogram reverse parcels Friday
Sep,Oct customer x
Frequency
3,5
3
2,5
2
1,5
1
0,5
0
Bin
Frequency
Expected


Histogram reverse parcels Tuesday-Friday
Sep,Oct customer x
Frequency
12
10
8
6
4
2
0
Bin
Frequency
Expected

Appendix 2 - impact on stakeholder

“Verzend”

Impact on reverse process logistic designer
Reverse parcels in the “Verzend” process are, when the numbers are high, pleasant for the reverse process logistic designer. Parcels in this process require limited handling activities. But when the number of parcels is to low, a lot of inefficient transport is required. Which is not pleasant for the logistic designer.

Impact on regular process logistic designer
Reverse parcels in the “Verzend” can become a problem for the logistic designer of the regular process. When the number of depots is increasing, the number of roll containers in the “Verzend” required for the regular process increases. When reverse roll containers occupy the roll container locations, this is a complexing factor for the regular process logistic designer.

Impact on depot management
This process does not have any other requirements of the depot management than the regular process has. And therefor does not influence the activities at the depot.

Impact on control room
Reverse parcels in the “Verzend” do not influence the control room.

The control room can significantly influence the reverse parcels in the “Verzend”. When there is a shortage in transport, the control room give a favor to the regular parcels and as a consequence decide to not transport the reverse parcels.

Impact on customer
There will be no impact on the customer. This process is already applied and the process is only suitable for a limited number of customers.

“Hengelo/Nieuwegein”

Impact on reverse process logistic designer
The “Hengelo/Nieuwegein” process is a relative complex process, for example the temporarily storage of parcels in Utrecht results in additional complexity. The capacity for the process in Nieuwegein can be shortened during peak days, in that days the logistic designer should find solutions for this shortage in capacity.

Impact on regular process logistic designer
The “Hengelo/Nieuwegein” process operates when the regular process is not using the depots. Therefor it does not influence the regular process. When the capacity is needed for the regular process, the reverse process will have less operating time.

Impact on depot management
The “Hengelo/Nieuwegein” process is a separated process at the depot when otherwise the depot is idle. The depot management need to handle this process. A nonstandard process requires additional attention from the depot management. This results in a neutral impact on the depot management.

Impact on control room
The second sorting stage in Nieuwegein is after the peak in the night, for the control room this is a calm period. During the second sorting stage in Hengelo the control room is not actively involved in the process. Therefore, they cannot influence this process. But the temporarily storage in Utrecht is an additional process the control room supervises.

The influence the control room has on the “Hengelo/Nieuwegein” process is at the transport after the first sorting stage. When there is a shortage in transport, the control room can decide to not transport the reverse parcels and give a favor to the regular parcels. Besides the control room can decide to shorten the capacity of the “Nieuwegein” process to gain more capacity for the “Verzend”.

Impact on customer
There is nearly impact on the customer when this process is applied. When a customer is handled in Nieuwegein it can happen in peak days that not all parcels are handled. This will result in a delay of one day for the customer. A customer will not be pleased by this delay.

“Ritsortering”

Impact on reverse process logistic designer
Not all reverse parcels in the “Ritsortering” can be tracked as a reverse parcel. Therefore, the impact on the reverse process logistic designer is limited. As shown in Section 2.1.2 this process is relatively expensive for larger customers and therefore not favorable for bigger customers.

Impact on regular process logistic designer
Reverse parcels in the “Ritsortering” are using capacity of the regular parcels in the entire process. When a customer receives a lot of reverse parcels a dedicated tour is required. This reduces the number of delivery tours available for the normal parcels.

Impact on depot management
The “Ritsortering” process has a high negative impact on the depot management. This reverse process requires process capacity during the peak hours at a depot and special actions need to be taken. For example, dedicated tours with delivery vans. This make it more complicated for the depot management.

Impact on control room
Reverse parcels in the “Ritsortering” process are handled as if they are regular parcels. This process does not influence the control room.

Since the parcels are seen as regular parcels, the parcels always have a high priority. Therefore, in case of any distortion of the process those parcels get priority. The control room will not negatively influence those parcels.

Impact on customer
There will be no impact on the customer when this process is applied since the reverse parcels are in the regular process of PostNL. The parcels in this process are handled with a delivery time of one day.

Central reverse depot

Impact on reverse process logistic designer
If all reverse parcels are handled at the same location in the same process it is easy to manage for the logistic designer.

Impact on regular process logistic designer
If reverse parcels are handled at a central reverse depot, those parcels will not be in the normal process. In the “Verzend sortering” less roll containers for the reverse process are needed. This leads to more roll container slots and thus capacity available for the regular process. The regular process will have more capacity available when the retour parcels are handled via a central reverse depot.

Impact on depot management
Depot management of regular depots do not need to arrange dedicated routes for the reverse customers anymore. Besides, less parcels will be in the distribution and in the “Verzend sortering” less different roll containers are used which make the processes simpler.

For the depot management of the central reverse depot it can be favorable to have one process. The team can become experts in this process.

Impact on control room
Handling the reverse parcels differently from all other parcels leads to an additional supply chain wide process that the control room has to manage during the night. The "Verzend sortering" gets less complicated since all reverse parcels flow into one roll container.

The control room can influence this process by the diversion of transport. When disruptions occur the control room have to manage those.

Impact on customer
A central reverse depot impacts the time at which a customer can receive the reverse parcels. Due to different transport that is required, a customer can get the reverse parcel sooner or later than in the current situation. For customers that are in the "Ritsortering" process at this moment the way in which they receive the reverse parcels might change. At this moment they receive the parcels via a delivery van, when they are handled via a central reverse depot, they receive the reverse parcels in roll containers by truck.

Depot transcending truck routes

Impact on reverse process logistic designer
Depot transcending truck routes adds complexity to the process. Combinations of customers should be made and one should be sure that the parcels are in the right sequence in the roll container. The truck routes make the entire system less flexible. Changes cannot be made for the customers that are in the tour when the truck is loaded. The truck driver can easily make mistakes by delivering the wrong roll container to a customer. This is an additional risk in the process for the logistic designer.

Impact on regular process logistic designer
For the depots where the truck routes depart less capacity is available for the regular process. This is negative for the logistic designer of the regular process. At other depots capacity will come available. The result for the regular process is neutral.

Impact on depot management
For the depot management the process might be complicated. They should be keen on the loading of the trailers to prevent mixture of customers through the trailer. This additional complexity results in a negative influence on the depots.

Impact on control room
Delivery tours by truck results in more complexity for the transport planning of the trucks. Additional trucks are required that have deliver the roll containers with the parcels.

The control room can influence this process by assigning the trucks to other tours. A risk is that the trucks planned for the routes are used to cover transport problems in other processes.

Impact on customer
For customers that are now delivered by delivery vans, this solution is beneficial. Instead of a few hundred loose parcels, a customer will now receive a few roll containers with parcels. Some customers already receive the parcels in roll containers, but this is a deviation to the normal process.

Central reverse depot with decentral hubs

Impact on reverse process logistic designer

A central reverse depot with decentral hubs adds complexity to the reverse process. Different handlings at different locations can make it hard to manage the processes. Due to the decentral hubs, a buffer can be introduced at the end of the process, this result in additional flexibility.

Impact on regular process logistic designer
When the reverse parcels are handled via the central depot with decentral hubs, the distribution unburdened. This is positive for the regular process logistic designer.

Impact on depot management
A new process needs to be started at the depots. In the first period this is complex for the depots. In the "Verzend sortering" at night it can become easier since all reverse parcels can be put in the same roll container.

Impact on control room
New moments of transport and transport directions are required. This adds complexity to the network. But, since the transport towards the hubs is not during the peak hours of the transport, transport during the peak is reduced. This is favorable for the control room.

The main influence of the control room on this process shall be in the transport from the normal depots towards the central reverse depot. This transport is during the peak hours. Diversions in transport are hard to fix during the peak.

Impact on customer
A central reverse depot with decentral hubs impacts the time at which a customer can receive the reverse parcels. Due to different transport that is required, a customer can get the reverse parcel later than in the current situation. For customers that are in the "Ritsortering" process at this moment the way in which they receive the reverse parcels might change. At this moment they receive the parcels via a delivery van, when they are handled via a central reverse depot, they receive the reverse parcels in roll containers by truck.

Decentral reverse depots

In analyzing the decentral reverse depots, we assume that the decentral reverse depot is a regular depot where a specified reverse process is used. At this moment, and in the next five years, the reverse volumes are expected to be not that high that multiple dedicated depots are required.

Impact on reverse process logistic designer
Multiple decentral reverse depots add complexity to the process. Due to the different transport flows and locations of processes. During peak days the reverse parcels might not be handled at the decentral reverse depots, the capacity is than reduced to be able to fulfill the demand of the normal parcels.

Impact on regular process logistic designer
The logistic designer of the regular process shall have less capacity available for the regular process. Tuning between the regular process and reverse process is required.

Impact on depot management
Depot management gets an additional process to manage. The complexity that comes with the non-standard processes are negative for the impact on the depot management.

Impact on control room
Decentral reverse depots add complexity for the control room. More distinct transport flows have to be managed.

Transport is needed during the peak in the night. When there are problems in transport the regular parcels might get the preference over the reverse parcels.

Impact on customer

Decentral reverse depots can result in an early delivery of reverse parcels to a customer. This is positive for the customer. Besides for customers that are now delivered by delivery vans, this solution is beneficial. Instead of a few hundred loose parcels, a customer will now receive a few roll containers with parcels. Some customers already receive the parcels in roll containers, but this is a deviation to the normal process.

Appendix 3 - scalability and robustness

"Verzend"

When the network of PostNL increases, the number of roll containers needed for the regular parcels increases as well. This will lead to fewer roll container slots available for the reverse customers. So, the number of reverse customers that can have a dedicated roll container in the "Verzend sortering" decreases when the network increases. PostNL encounters this problem and, all newly build depots are equipped with more gutters and roll container locations. Still based on the current situation, at the end of 2018 all container slots are used at the end of 2018. This results in limited scalability for the "Verzend" process.

When one depot has a failure, the parcels can be transported to another depot and sorted at the other depot. This process works well in adapting to failures of individual depots.

"Hengelo/Nieuwegein"

The reverse process "Hengelo/Nieuwegein" has still some unused capacity in a regular period as stated in Section 2.3. Either during peak periods when the demand can be twice as high as in regular periods the capacity limits are almost reached.

When the process in Hengelo or Nieuwegein fails, the parcels can be transported to another depot and be handled there, this can be all to one depot or separated over multiple depots. Either Hengelo and Nieuwegein are prepared for the current processes, a new temporarily depot will always reach a lower efficiency.

"Ritsortering"

When the number of regular parcels in the "Ritsortering" increases, the process is higher utilized. When the number of parcels in this process increases, the capacity available for the normal parcels decreases. Nevertheless, with the number of depots increasing, more capacity in the "Ritsortering" is created. It is not reasonable to assume that PostNL can build depots in the same speed as the number of parcels is growing. This shall result in an increasing number of parcels per depot and thereby less capacity available for reverse parcels per depot.

When a failure occurs at one of the depots, the parcels cannot be handled at another depot.

Central reverse depot

The current sorting machine of PostNL can handle 8.000 parcels per hour. When a depot is created as a dedicated reverse depot and we assume that a sorting machine placed there has the same capacity as the current sorting machines of PostNL. The central reverse depot can handle 23 hours * 8.000 parcels per hour = 184.000 reverse parcels per day. This is in the situation that the sorter is operating 23 hours. At least one hour is needed for maintenance. This is purely the sorting capacity. When the parcels are sorted 23 hours per day, a transit time of 24 hours cannot be guaranteed in this situation. If the transit time of 24 hours is required, PostNL has less time to sort the parcels. Therefore, we assume that there are 12 hours available to sort the reverse parcels. This leads to a capacity of 8.000*12=96.000

Unsorted reverse parcels enter the system of PostNL during the "Verzend sortering". Those parcels must be transported to the central reverse depot and be buffered there, a lot of buffer capacity is required if the sorter operates at maximum capacity. Sorted reverse parcels need to be transported to the customers. Those customers can only be delivered in specified time windows. A buffer is required after the sorting to store all those sorted reverse parcels. When creating a central reverse depot PostNL should encounter those buffers as well, the buffers can be the limitation for this process.

This solution is not that robust if failures occur. If all activities are located at one central depot, and that depot fails, there will not be a possibility to handle the parcels else were. When that central depot fails, the delivery of reverse parcels will be delayed.

Depot transcending truck routes

In the depot transcending truck routes the capacity is limited by the number of trucks that can make routes to deliver the roll containers to the customers. When the number of parcels in this process is increasing, more depots can be used as a start point of the depot transcending truck routes. On average truck can be loaded with 48 roll containers * 35 parcels per container=1.680 parcels. If there are 20 trucks used in this process, this results in a total capacity of 33.600 parcels. The trucks can depart before or after the distribution tours depart from the depot. In theory this can be scaled to all depots in the Netherlands with at most 52 customers per depot.

When one of the depots of the truck routes is in failure, another depot can be used to handle the parcels. Most likely this affects the route of the truck. Some arrangements need to be made if one depot is in failure but the reverse parcels can be handled.

Central reverse depot with hubs

The capacity for the central reverse depot with hubs is restricted by the capacity of a central reverse depot as computed in Section 6.1.4.4. This is set at 96.000 parcels. The hubs where the parcels are sent to are most likely the depots of PostNL. The number of parcels that can be handled at those depots depends on the transport availability. The parcels are already sorted at the central reverse depot, so at the hub the parcels only need to be loaded to the right delivery truck or van.

When the central reverse depot fails, no reverse parcels can be handled. So, this solution is not robust in terms of failure. The structure with multiple hubs from where the parcels are delivered results in flexibility at the end of the process. When one hub cannot handle parcels, those parcels can be shifted to other hubs.

Decentral reverse depots

At this moment the number of reverse parcels of PostNL are not at a level that multiple dedicated reverse depots can be filled to a high fill rate with parcels. In total around ten hours of sorting time is required to sort all reverse parcels. Most regular depots have hours available during the night to sort reverse parcels. Either, at peak days when more capacity is required for the normal process the capacity available in the night can decrease. This will result in less flexibility in the normal process or reduction in reverse capacity. When the number of parcels per depot is increasing, less time is available for the reverse processes. Therefore, this solution is not scalable. If the number of parcels per depot are not increasing and capacity is reserved for the reverse process, then the sorting capacity in the decentral reverse depots is 8.000 parcels per hour. The process can be conducted before the "rit sortering" starts and/or after the "Verzend sortering". The distance from one of the depots+ towards the decentral reverse depots cannot be too high, otherwise the "rit sorting" is started before the reverse parcels can be sorted. Therefore, next to the current reverse depots Hengelo and Nieuwegein only the depots+ are suitable for this process. This are depot+ Waddinxveen, Den Bosch and Amsersfoort. In both situations two hours are available for sorting. This leads to a capacity of 3*8.000=16.000 parcels per depot. So, in total 48.000 parcels.

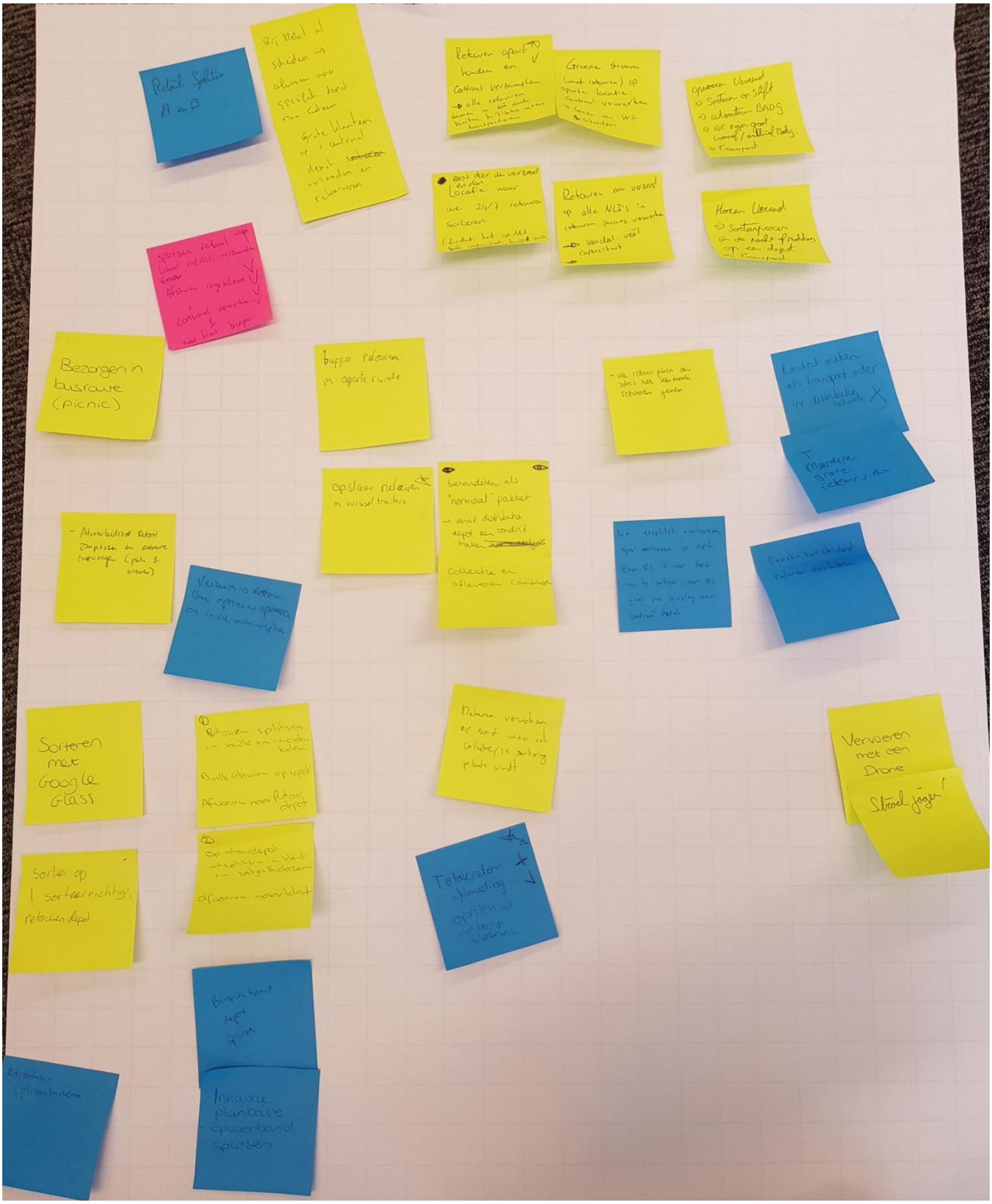
When one decentral reverse depot is in failure, the other decentral reverse depots can still handle reverse parcels. The parcels that need to be handled at the depot in failure will be delayed. During the night in will not be possible to handle the parcels at another depot. But when necessary the parcels can be transported to other depots and sorted there.

Appendix 4 - pairwise comparison form

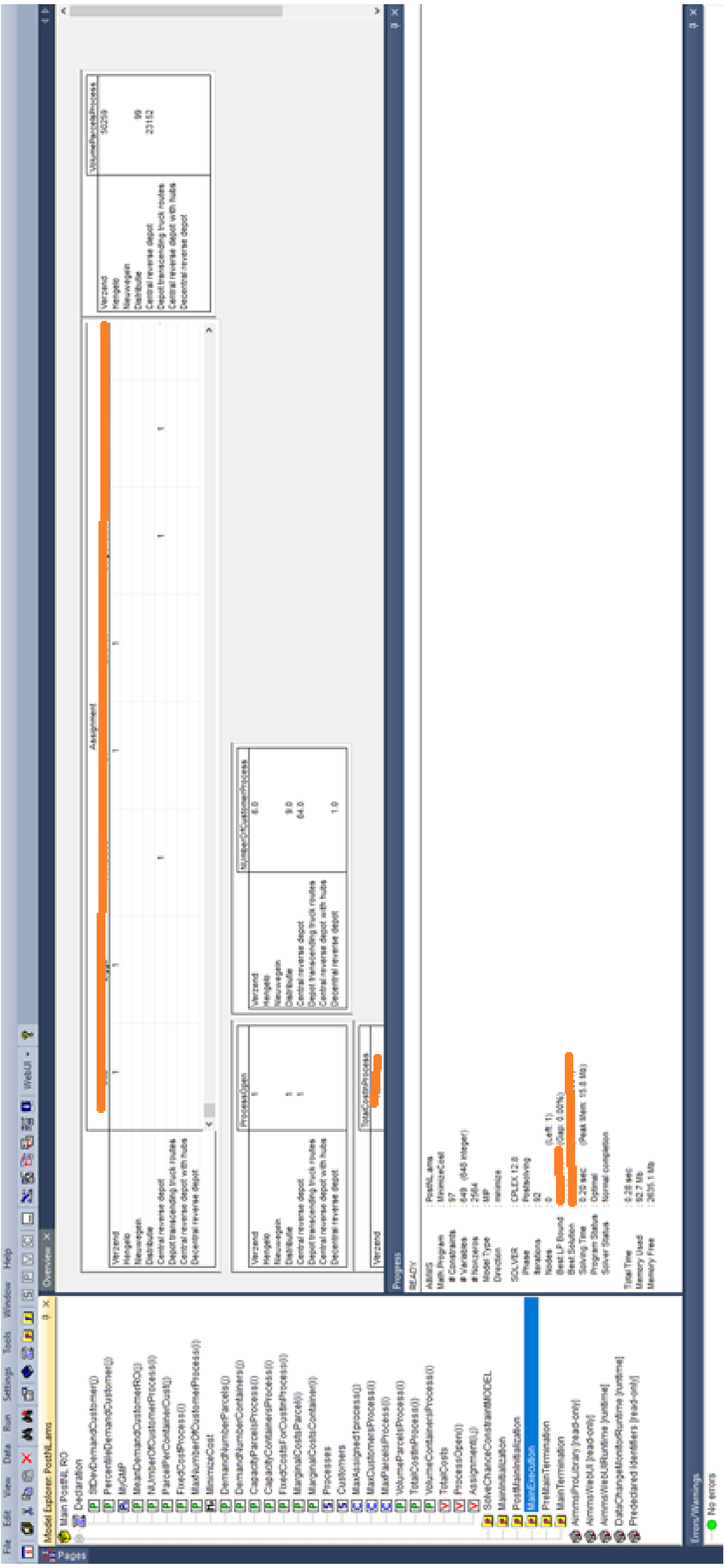
	Extremely more important	Strongly more important	More important	Slightly more important	Equally important	Slightly more important	More important	Strongly more important	Extremely more important	
Impact on customer	9	7	5	3	1	3	5	7	9	Impact on depot
Impact on customer	9	7	5	3	1	3	5	7	9	Impact on regular process
Impact on customer	9	7	5	3	1	3	5	7	9	Costs per parcel
Impact on customer	9	7	5	3	1	3	5	7	9	Scalability / robustness
Impact on depot	9	7	5	3	1	3	5	7	9	Impact on regular process
Impact on depot	9	7	5	3	1	3	5	7	9	Costs per parcel
Impact on depot	9	7	5	3	1	3	5	7	9	Scalability / robustness
Impact on regular process	9	7	5	3	1	3	5	7	9	Costs per parcel
Impact on regular process	9	7	5	3	1	3	5	7	9	Scalability / robustness
Scalability / robustness	9	7	5	3	1	3	5	7	9	Costs per parcel

	Extremely more important	Strongly more important	More important	Slightly more important	Equally important	Slightly more important	More important	Strongly more important	Extremely more important	
Impact on customer	9	7	5	3	1	3	5	7	9	Impact on depot
Impact on customer	9	7	5	3	1	3	5	7	9	Impact on regular process
Impact on customer	9	7	5	3	1	3	5	7	9	Costs per parcel
Impact on customer	9	7	5	3	1	3	5	7	9	Scalability / robustness
Impact on depot	9	7	5	3	1	3	5	7	9	Impact on regular process
Impact on depot	9	7	5	3	1	3	5	7	9	Costs per parcel
Impact on depot	9	7	5	3	1	3	5	7	9	Scalability / robustness
Impact on regular process	9	7	5	3	1	3	5	7	9	Costs per parcel
Impact on regular process	9	7	5	3	1	3	5	7	9	Scalability / robustness
Scalability / robustness	9	7	5	3	1	3	5	7	9	Costs per parcel

Appendix 5 - brainstorm results



Appendix 6 - AIMMS implementation



Appendix 7 - Output experiments

Experiment 1

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	1;6;7;8;12;13;14;15;32;34;37;38;44;50;53;57;61;62;70;71;73;74;78
Hengelo	2;4;17;21;26;31;35;46;47;55;58;59;60;64;79
Nieuwegein	3;5;9;10;11;18;19;20;22;23;24;25;27;28;29;30;33;39;41;42;43;45;48;51;52;54;56;63;65;66;67;68;69;72;75;77

Table 36 Assignment of customer to processes Experiment 1

Experiment 2

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	1;7;8;12;13;14;15;32;34;37;38;44;50;53;57;61;62;70;71;73;74;78
Nieuwegein	2;3;4;5;6;9;10;11;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33;35;39;41;42;43;45;46;47;48;51;52;54;55;56;58;59;60;63;64;65;66;67;68;69;72;75;77;79

Table 37 Assignment of customer to processes Experiment 2

Experiment 3

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	1;7;8;12;13;15;32;34;38;44;50;61;62;70;73;74;78
Central reverse depot	2;3;4;5;6;9;10;11;14;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33;35;37;39;41;42;43;45;46;47;48;51;52;53;54;55;56;57;58;59;60;63;64;65;66;67;68;69;71;72;75;77;79

Table 38 Assignment of customer to processes Experiment 3

Experiment 4

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	1;7;8;12;13;15;32;34;38;44;50;61;62;70;73;74;78
Central reverse depot	2;3;4;5;6;9;10;11;14;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33;35;37;39;41;42;43;45;46;47;48;51;52;53;54;55;56;57;58;59;60;63;64;65;66;67;68;69;71;72;75;77;79

Table 39 Assignment of customer to processes Experiment 4

Experiment 5 & 6

Both not feasible

Experiment 7

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62
Central reverse depot	2;3;4;5;6;9;10;11;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33;35;37;39;41;42;43;45;46;47;48;51;52;54;55;56;57;58;59;60;63;64;65;66;67;68;69;72;75;77;79
Depot transcending truck route	1;7;8;12;13;14;15;32;34;44;50;53;61;70;71;73;74;78

Table 40 Assignment of customer to processes Experiment 7

Experiment 8

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62
Central reverse depot	2;3;4;5;6;9;10;11;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33; 35;37;39;41;42;43;45;46;47;48;51;52;54;55;56;57;58;59;60;63;64;65; 66;67;68;69;72;75;77;79
Depot transcending truck route	1;7;8;12;13;14;15;32;34;44;50;53;61;70;71;73;74;78

Table 41 Assignment of customer to processes Experiment 8

Experiment 9

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62;73
Central reverse depot	2;3;4;5;6;9;10;11;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33;35;39; 41;42;43;45;46;47;48;51;52;54;55;56;57;58;59;60;63;64;65; 66;67;68;69;72;75;77;79
Depot transcending truck route	1;7;8;12;13;14;15;32;34;37;44;50;53;61;70;71;73;74;78

Table 42 Assignment of customer to processes Experiment 9

Experiment 10

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62;73
Central reverse depot	2;3;4;5;6;9;10;11;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33;35;39; 41;42;43;45;46;47;48;51;52;54;55;56;57;58;59;60;63;64;65; 66;67;68;69;72;75;77;79
Depot transcending truck route	1;7;8;12;13;14;15;32;34;37;44;50;53;61;70;71;73;74;78

Table 43 Assignment of customer to processes Experiment 10

Experiment 11

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62
Central reverse depot	2;3;4;5;6;9;10;11;14;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33; 35;37;39;41;42;43;45;46;47;48;51;52;54;55;56;57;59;60;63;64;65; 66;67;68;69;72;75;77;79
Depot transcending truck route	1;7;8;12;13;15;32;34;44;50;53;58;61;70;71;73;74;78

Table 44 Assignment of customer to processes Experiment 11

Experiment 12

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62
Central reverse depot	2;3;4;5;6;9;10;11;14;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33; 35;37;39;41;42;43;45;46;47;48;51;52;54;55;56;57;59;60;63;64;65; 66;67;68;69;72;75;77;79
Depot transcending truck route	1;7;8;12;13;15;32;34;44;50;53;58;61;70;71;73;74;78

Table 45 Assignment of customer to processes Experiment 12

Experiment 13

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62
Central reverse depot	2;3;4;5;6;9;10;11;14;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33;35;37;39; 41;42;43;45;46;47;48;50;51;52;54;55;56;57;59;60;63;64;65;66;67;68;69;72; 75;77;79
Depot transcending truck route	1;7;8;12;13;15;32;34;44;53;58;61;70;71;73;74;78**(Total 17)**

Table 46 Assignment of customer to processes Experiment 13

Experiment 14

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62;73
Central reverse depot	2;3;4;5;6;9;10;11;14;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33; 35;37;39;41;42;43;45;46;47;48;50;51;52;54;55;56;57;59;60;63;64;65; 66;67;68;69;72;75;77;79
Depot transcending truck route	1;7;8;12;13;15;32;34;44;53;58;61;70;71;74;78

Table 47 Assignment of customer to processes Experiment 14

Experiment 15

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62
Central reverse depot	2;3;4;5;6;9;10;11;14;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33;35;37;39; 41;42;43;45;46;47;48;50;51;52;54;55;56;57;59;60;63;64;65;66;67;68;69;72; 75;77;79
Depot transcending truck route	1;7;8;12;13;15;32;34;44;53;58;61;70;71;73;74;78

Table 48 Assignment of customer to processes Experiment 15

Experiment 16

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62
Central reverse depot	2;3;4;5;6;9;10;11;14;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33;35;37;39;41;42;43;45;46;47;48;50;51;52;54;55;56;57;59;60;63;64;65;66;67;68;69;72;75;77;79
Depot transcending truck route	1;7;8;12;13;15;32;34;44;53;58;61;70;71;73;74;78

Table 49 Assignment of customer to processes Experiment 16

Experiment 17

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62
Central reverse depot	2;3;4;5;6;9;10;11;14;17;18;19;20;21;22;23;24;25;26;27;28;29;30;31;33;35;37;39;41;42;43;45;46;47;48;50;51;52;54;55;56;57;59;60;63;64;65;66;67;68;69;72;75;77;79
Depot transcending truck route	1;7;8;12;13;15;32;34;44;53;58;61;70;71;73;74;78

Table 50 Assignment of customer to processes Experiment 17

Experiment 18

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62
Central reverse depot	2;3;4;5;9;10;11;14;17;18;19;20;21;22;23;24;25;26;28;29;30;31;33;35;37;39;41;42;43;45;47;48;51;52;53;54;55;56;57;59;60;63;64;65;66;67;68;69;72;75;77;79
Depot transcending truck route	1;6;7;8;12;13;15;27;32;34;44;46;50;58;61;70;71;73;74;78 **(Total 21)**

Table 51 Assignment of customer to processes Experiment 18

Experiment 19

Process	Assigned Customers
"Verzend"	16;36;40;49;76;80
"Ritsortering"	38;62
Central reverse depot	2;3;4;5;9;10;11;17;18;19;20;21;22;23;24;25;28;29;30;31;33;35;39;41;42;43;45;48;51;52;54;55;56;59;60;63;64;65;66;67;68;69;72;75;77;79
Depot transcending truck route	1;6;7;8;12;13;14;15;26;27;32;34;37;44;46;47;50;53;57;58;61;64;70;71;73;74;78 **(Total 27)**

Table 52 Assignment of customer to processes Experiment 19

Appendix 8 – Derivation quadratic constraints

$$P\left(\sum_{j=1}^{n} A_{i,j} * demp_j \leq \; capp_i * P_i\right) \geq 0.92$$

This can be rewritten according to (Lejeune & Margot, 2016) as:

$$F_j\left(\omega_j^k\right) \geq 0.92$$

$$\omega_j^k \geq \sum_{p=1}^{n_j} \lambda_{jp} * c_{jp} = c_{jl}(j,l), \in L$$

This leads to

$$\omega_j^k = c_{jl}(j,l)$$

$$P\left(\sum\nolimits_{j=1}^{n} A_{i,j} * \varepsilon_j \leq \; capp_i * P_i\right) \geq 0.92$$

$$\sum\nolimits_{j=1}^{n} A_{i,j} * \left(\sum\nolimits_{p=1}^{n_j} \lambda_{jp} * c_{jp}\right) \leq \; capp_i * P_i$$

λ_{jp} and c_{jp} are two new variables that are introduced to handle the probability p in the constraints.