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Specialization:	Transport Engineering and Logistics
Report number:	2016.TEL.8075
Title:	**Improving the control and execution of the mail and parcel collection process under uncertainty in collection volumes.**
Author:	D. Duppen

Title (in Dutch)	Het verbeteren van de aansturing en uitvoering van het collectieproces van brieven en pakketten gegeven onzekerheid in collectievolumes.

Assignment:	Masters thesis
Confidential:	yes (until Nov 21st , 2021)
Initiator (university):	prof.dr.ir. G. Lodewijks
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Supervisor:	dr. ir. H.P.M. Veeke
Date:	November 21st, 2016

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Assignment type:	Master project
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Specialization:	TEL
Report number:	2016.TEL.8075
Confidential:	Yes until: December 06, 2021

Subject: **Improving the control and execution of the mail and parcel collection process under uncertainty in collection volume**

As the largest postal company in the Netherlands, PostNL is responsible for the shipment of a total of 156 million parcels and 2,4 billion pieces of mail in the last year. The delivery process of these postal items consists of a number of steps, the first of which is the collection. The collection process is defined as all handlings and activities that occur between a customer of PostNL having an item ready to be shipped, and the first sorting and processing step of that same item at a location of PostNL. Specifically, this means that vehicles of PostNL are assigned a route that stops at the different customers. Here, an agreed upon volume of items is collected within a specific time window of between half an hour and two hours.

While the collection process is operational without immediate problems, it is unclear if it still matches with the demands and requirements of the market. Next to that, there is no clear insight as to how well it performs, both from the perspective of PostNL, as well as the customers themselves.
Given the growth of the number of webshops and the increased competition among them, it is expected by PostNL that customers require collection to be performed in ever smaller time windows and at later moment of the day, which is not possible with the current process. Next to that employees notice that vehicle fill rates are not always as high as was expected, indicating possible improvements to the process.

By applying the *Delft Systems Approach* to analyze the current process as well as studying relevant literature, a proposal should made as to how to improve the performance of the collection process. Where possible, these gains should be quantified using for example a simulation model.

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Your assignment is to evaluate the requirements and the current performance of the collection process (both from the perspective of PostNL as well as its customers) and to propose improvements to the control and execution of the collection process at PostNL, quantifying were possible the achievable gains.

The report should comply with the guidelines of the section. Details can be found on the website.

The professor,

Prof. dr. ir. G. Lodewijks

Summary

This research sets out to investigate the performance of the collection process of PostNL and propose possible improvements to it. Based on the initial research objective of investigating in which way the customer demands of the collection process could be fulfilled as efficiently as possible, the current collection process and its performance were analyzed by applying the *Delft Systems Approach* as well as by conducting a number of in-depth interviews with customers of PostNL.

This analysis found that while customers require a certain level of flexibility when it comes to the number of load devices that can be collected on a day-to-day basis, the planning department uses fixed volumes with which collection routes are planned. Next to that, there appeared to be a lack of control and feedback in the collection process. As a result, there is no process in place that checks to which extent the actual collection volumes match the expected/planned collection volumes. It was shown that this had a strong impact on the performance of the collection process. An average deviation of [redacted]% between actual and planned collection volumes was found, making it difficult to efficiently plan the collection routes. Within the context of this research, planning efficiently refers to performing all collection tasks with as few vehicles as possible, while driving as little distance as possible.

The low planning accuracy also had its effect on the vehicle fill rate, which was found to be below [redacted]% for routes including collection at customers (while a vehicle fill rate of more than [redacted]% was expected based on the planned volumes). Finally, two separate departments are responsible for the planning and executing of collection tasks; the mail division collecting mailboxes and smaller customers, and the parcel division collecting larger customers. However, the characteristics of the collection tasks were found to be mostly similar. It was thus expected that this separation further hindered planning all collection tasks as efficiently as possible.

Based on the analysis of the current process, three main issues were found:

- A disconnect between the actual and planned collection volumes
- Decentralized planning of collection tasks limiting planning efficiency
- A lack of feedback and information in the collection process.

By again applying the *Delft Systems Approach,* this time not by describing the *as-is* but the *should-be*, it became clear which forms of feedback and information were required in the collection process. The most important of which was comparing the actual collection volumes of a customer with the planned volumes in order to update the collection task. Next to that, an input of information regarding the expected volume of a customer should be added. Subsequently, the available source of information currently available to PostNL on which expected collection volumes could be predicted were investigated. One of these sources includes pre-shipping notifications. When customers ship parcels, they are equipped with a barcode. In order for PostNL to know which barcode belongs to which recipient, a notification is send from the customer to PostNL that gives the address and name of the recipient corresponding to a certain barcode. While some customers send these notifications only once a day, some customers send them throughout the day as orders come in. Two customers that send these notifications throughout the day were selected, and based on historic data, the predictive value of these notification was investigated. It was found that while it is difficult to translate the number of expected parcel to a number of expected roll containers, improvements to the planning accuracy of up to [redacted]% were possible. However, the downside to improving accuracy is the risk of underestimating the volume presented by a customer, possibly resulting in operational problems such as insufficient vehicle capacity or exceeding the time window due to longer handling times.

Finally, in order to quantify the possible gains of possibly combining the two planning departments, as well as improving planning accuracy, a discrete time simulation model was build and verified. Based on a number of experiments, it was found that combining the mail and parcel division into a single planning department could reduce the number of kilometers

and the number of vehicles used by 15,3% and 18,3% respectively. Next to that, by achieving a similar planning accuracy as was found when using the pre-shipping notifications prediction model, a further reduction in vehicles could be achieved. However, an increased accuracy indeed led to more customers being collected too late, showing the balance between efficiency and punctuality when uncertainty over collection volumes exists.

Summary (in Dutch)

De focus van dit onderzoek is het in kaart brengen van de prestaties van het collectieproces van PostNL, als ook het vinden van mogelijke verbeteringen. Met als initieel doel om te onderzoeken hoe de wensen die klanten hebben met betrekking tot het collectieproces zo efficiënt mogelijk waargemaakt kunnen worden, is het huidige proces onderzocht. Dit is gedaan op basis van de *Delft Systems Approach*, als ook door het interviewen van een aantal klanten van PostNL.

Op basis van deze analyse is gebleken dat klanten een bepaalde mate van flexibiliteit met betrekking tot collectie volumes erg belangrijk vinden. Echter wordt er binnen PostNL gewerkt met een vast planvolume dat elke dag hetzelfde is, en als basis dient voor de planning van de routes. Daarnaast ontbreekt het in het collectieproces aan sturing en feedback; er is geen proces ingericht dat het verschil tussen de geplande en daadwerkelijke volumes monitort en waar nodig bijstuurt. Dit heeft een groot effect op de plan nauwkeurigheid. Gevonden is dat er gemiddeld een verschil van [redacted]% zit tussen het gepland en daadwerkelijk volume, wat het efficiënt plannen van routes bemoeilijkt. In de context van dit onderzoek refereert efficiëntie aan het uitvoeren van alle collectietaken met zo min mogelijk voertuigen die daarnaast zo min mogelijk afstand hoeven te rijden.

De lage planning accuratie heeft een effect op de vulgraad van de voertuigen. Een vulgraad van minder dan [redacted]% is vastgesteld op routes die collectie bij klanten bevatten. Dit terwijl een vulgraad van rond de [redacted]% was verwacht op basis van de geplande volumes. Tot slot wordt de collectie op dit moment gepland en uitgevoerd door twee verschillende afdelingen; de post- en de pakkettenafdeling. Dit terwijl de karakteristieken van de collectietaken voor beide afdelingen grofweg hetzelfde zijn. Het ligt in de lijn der verwachting dat deze splitsing het efficiënt plannen van collectie routes verder beperkt.

Op basis van de analyse van het huidige proces zijn drie hoofdproblemen geformuleerd:

- Het grote verschil tussen geplande en daadwerkelijke collectievolumes
- De mogelijke beperking van decentraal plannen op de procesefficiëntie
- Het gebrek aan sturing en feedback in het proces.

Door opnieuw de *Delft Systems Approach* toe te passen, maar deze keer om een toekomstige staat te beschrijven, konden plaatsen in het proces aangewezen worden waar feedback en informatie nodig is. De belangrijkste is het vergelijken van daadwerkelijke volumes met verwachte volumes. Dit om de collectietaken te kunnen bijwerken. Daarnaast is een informatiestroom die iets vertelt over de te verwachten volumes wenselijk. Zodoende is onderzocht welke bronnen van informatie reeds beschikbaar zijn bij PostNL die dit doel zouden kunnen vervullen. Eén hiervan zijn de zogenaamde voormeldingen. Wanneer een klant van PostNL een pakket verstuurd, wordt deze uitgerust met een barcode. Deze barcode kan gebruikt worden om het pakket te traceren en te koppelen aan de ontvanger. Zodoende stuurt de klant een melding naar PostNL die vertelt welke adresgegevens bij welke barcode (en dus pakket) horen. Hoewel sommige klanten deze voormeldingen slechts eenmaal per dag versturen, zijn er klanten bij die dit door de dag heen doen. Voor twee van deze klanten is onderzocht wat de voorspellende waarde is van deze voormeldingen. Op basis van historische data is gevonden dat een verbetering van de planning accuratie tot [redacted]% mogelijk is, waarbij de vertaalslag van het te verwachte aantal pakketten naar het verwachte aantal ladingdragers het moeilijkst bleek. De keerzijde is echter dat een verhoogde planning accuratie kan leiden tot het onderschatten van het volume, wat operationele problemen zoals een tekort aan capaciteit teweeg kan brengen.

Tot slot is er een simulatiemodel geformuleerd, gebouwd en geverifieerd dat gebruikt is om verschillende mogelijke verbetering te kwantificeren. Deze verbeteringen zijn bijvoorbeeld het combineren van de planningsafdelingen als ook het verbeteren van de planning accuratie. Op basis van een aantal experimenten is bepaald dat het combineren van de planafdelingen kan resulteren in een reductie van het aantal gereden kilometers en het aantal gebruikte voertuigen van respectievelijk 15,3% en 18,3%. Daarnaast is een verdere reductie in het

aantal voertuigen mogelijk wanneer de plan accuratie verbeterd wordt. Dit heeft echter impact op de punctualiteit van het collectieproces, wat verder onderzoek vereist.

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1 Introduction

With more and more people ordering online, the market for parcel delivery is ever growing. The different companies offering the service of shipping parcels are competing by offering an increasing number of delivery options, such as same-day deliver, delivery to a parcel point (either manned or unmanned), or evening delivery. However, the parcel fulfillment process starts with the collection of parcels. While companies focus on the delivery side, having a well performing collection process is a first important step in efficiently, quickly, and successfully shipping a parcel to a receiver.

This research investigates the performance, control, and execution of the collection process at PostNL. With a market share of roughly 70% (Gunst, 2015), PostNL is currently the largest shipper of parcels in the Netherlands. This is done both from the perspective of the customer as well as the perspective of the company.

1.1 Motivation

The initial motivation for performing the research was the lack of insight into the performance of the current collection process at PostNL, specifically for [redacted] sized customers that ship around [redacted] parcels per year. These customers are currently often collected by the mail division where their collection is combined with the collection of mail from mailboxes. While the collection process is operational without immediate problems, it is unclear if it still matched with the requirements from the market. Next to that, there is no clear insight as to how well it performs, both from the perspective of PostNL as well as the customers themselves. As a result, the initial research objective is to evaluate and propose improvements to the collection process, specifically focusing on [redacted]-sized customers of PostNL.

1.2 Structure of the report

The research starts with an introduction to PostNL and its processes described in Chapter 2. First, a brief background will be given, followed by a description of the parcel and mail fulfillment process of which collection is the first step. Chapter 3 will address the current collection process from a theoretical perspective. Using the *Delft Systems Approach*, the current process and its inputs and outputs are defined. This includes discussing the requirements the environment has for the collection process as well as to which extent the collection process currently fulfills these requirements. Based on the findings in Chapter 3, the research question and objective are determined and discussed in Chapter 4. The first part of the research question focuses on the control of the collection process. Chapter 5 addresses in which way the collection process should be controlled, and what information is required to do so. Based on the most important source of information that is currently missing in the collection process, Chapter 6 investigates to which extent current information sources available to PostNL can be used to fill this gap. In order to quantify the possible improvements of using this source of information, as well as other ways to possibly improving the collection process, a discrete time simulation model is defined in Chapter 7 that makes it possible to quickly compare different collection setups. Chapter 8 discusses in which way the improvements brought forward from the research could possibly be implemented. Finally, Chapter 9 presents the main conclusions of this research, as well as a number of recommendations and opportunities for future research.

2 Background

This chapter will provide initial background on the company, its processes, and the environment in which it operates. Next, the complete fulfillment process will be shown and briefly explained. Finally, more detail will be provided about the main subject of research; the collection process.

2.1 Postal market & PostNL

PostNL offers products and services for the postal market. Within the postal market, a distinction can be made between the market for mail and the market for parcels. A major difference between the two is that mail can be delivered through a standardized mail slot, while parcels currently need a person to actually take delivery of them.

PostNL has a long history, tracing back to 1799, when the Dutch state took control of the deliverance of mail. First operating under the name "Administratie der Posterijen en Telegrafieën" (APT) and from 1928 as "Staatsbedrijf der Posterijen, Telegrafieën en Telefonie (PTT) (PostNL, n.d.). The next key moment in the history of PostNL occurred in 1989 with the privatization of the postal and telephony market in the Netherlands. The telephony branch and the postal branch of PTT split, with the telephony branch continuing as PTT Telecom (renamed in 1998 to KPN) and the postal branch continuing as PTT Post. In subsequent years, PTT Post got renamed to TPG Post (2002) and later to TNT Post (2006). Finally, after the split of the courier services and the postal services provided by TNT Post, the former continued as TNT Express while the latter continued as the company PostNL as we know it today.

The postal market is characterized by two major trends; a decrease in mail volume and an increase in parcel volume. The first trend can be attributed to the increased use of digital alternatives (PostNL, 2016, p. 13); a large part of the mail volume is replaced by e-mail.
The second trend can be explained by the increase of people shopping and subsequently ordering goods online. Figure 2.1 (CBS, 2016) shows the increase of the number of webshops in the past nine years, while Figure 2.2 (CBS, 2015) shows that more and more people indeed shop for goods online.
In their evaluation of the postal market (marktscan), the regulatory body responsible for monitoring the postal market, "de Autoriteit Consument & Markt" (ACM), stated a number of key findings which are in line with the previous statements (ACM, 2016); the market for parcel delivery services is growing strongly. Furthermore, competition is mainly focused on price, with large webshops having strong purchase power.

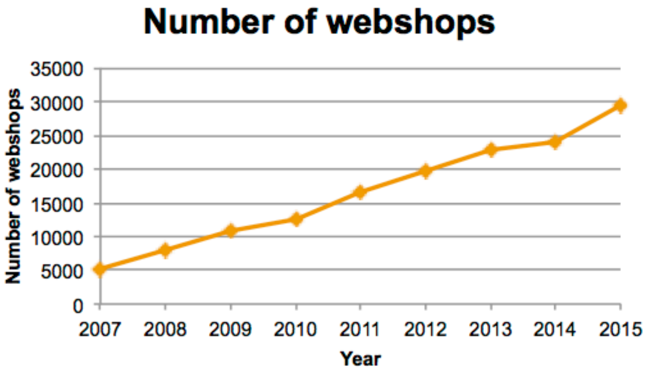

Figure 2.1 – Number of webshops in the Netherlands

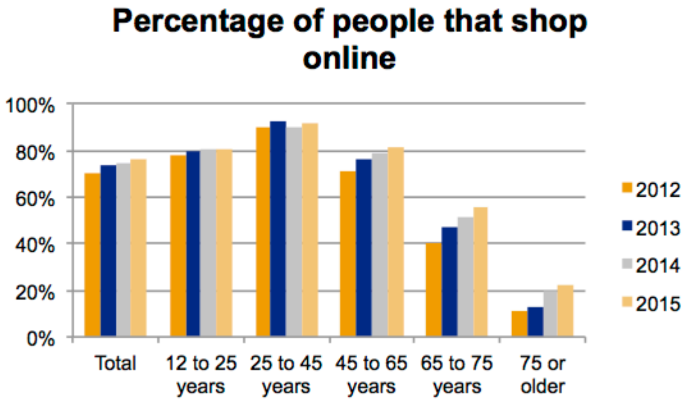

Figure 2.2 – Percentage of people that shop online within an age group (Dutch population).

Looking at the volume development at PostNL as stated in their annual report (PostNL, 2016), these two trends are indeed found. While the mail volume decreased by 11,2 % in 2015 compared to 2014, the parcel volume increased by 9,6% in 2015 compared to 2014 (see Figure 2.3 (PostNL, 2016, p. 39) & Figure 2.4 (PostNL, 2016, p. 40)).

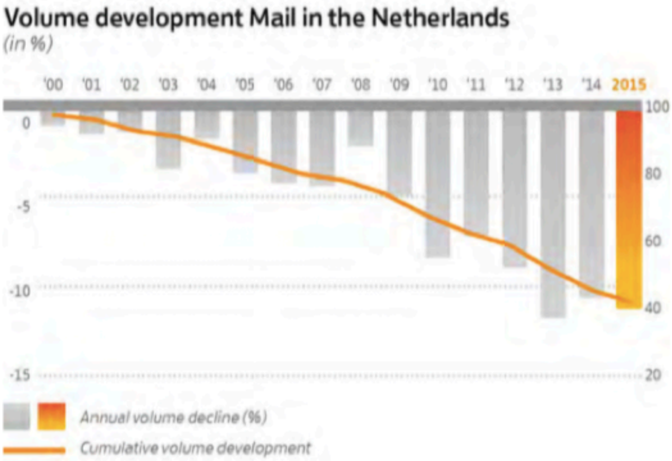

Figure 2.3 – Volume development Mail in the Netherlands.

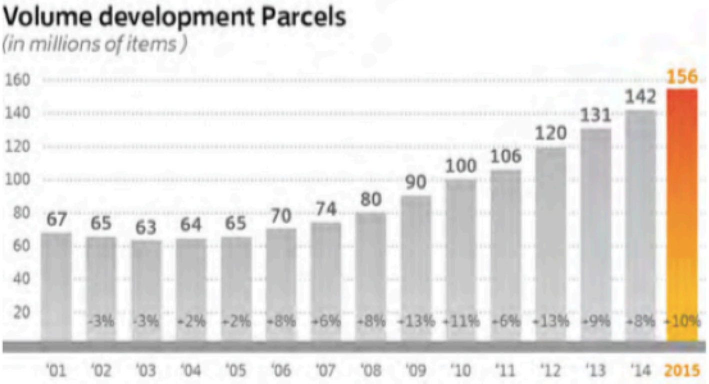

Figure 2.4 – Volume development Parcels shipped by PostNL.

Table 2.1 (PostNL, 2016, p. 39 & 40) compares the change in volume to the change in revenue for both mail and parcels. Looking at mail, it shows that the decrease in revenue from mail is not as large as the decrease in the mail volume between 2014 and 2015. This shows the focus of PostNL on continuously working on increasing the efficiency of their mail operation (PostNL, 2016, p. 18).
With regards to parcels, the large increase in volume is not directly translated into a similarly big increase in revenue. This is likely a result of the increased competition among postal companies and purchase power of webshops, resulting in lower prices paid per parcel. As a result, PostNL focuses on selling additional services with the shipment (such as same-day delivery and shipment insurance), trying to increase the income from every parcel.

	2014	**2015**	***Change***
Mail			
Volume (in mil. letters)	2705	2401	*-11,2%*
Revenue (in mil. €)	2044	1961	*-4,1%*
Parcel			
Volume (in mil. parcels)	142	156	*9,9%*
Revenue (in mil. €)	854	917	*7,4%*

Table 2.1 – Volume development versus Revenue development

2.2 Parcel fulfillment process

While the scope of the research is limited to the collection process, it is worth giving a broad overview of the complete parcel fulfillment process. Figure 2.5 gives an overview of the entire process including the different locations and routes used.

[redacted]

Figure 2.5 – The route of a parcel (PostNL internal document)

The parcel network of PostNL is comprised of [redacted] different depots ("nieuwe logistieke inrichting", or NLI) spread out over the Netherlands [redacted] Next to the depots, the parcel network of PostNL also includes a total of 3150 parcel points available for both customers (be it consumers or webshops) of PostNL to drop-off parcels, as well as for consumers to take delivery of parcels.

Depending on the route that is followed, it is possible that parts of the mail network are utilized to collect the parcels. Relevant for the collection process are the [redacted] "voorbereidingslocaties" (VBL) and six mail depots ("sorteercentrum brieven", or SCB) (in the image referred to as "Hub mail"). A VBL is a small sorting facility where final sorting of mail occurs before the mailman walks his route. The SCBs are used to perform the initial, less detailed sorting of mail on a larger scale. [redacted]

Finally, it is important to make the distinction between a *customer* and a *consumer*. A *customer* refers to a customer of PostNL and thus the entity that initiates the shipment of a parcel. A *consumer* however, is one of the various possible receivers of a parcel. For example, a customer of a webshop is thus referred to as a *consumer* while the webshop itself is a *customer* of PostNL.

Commonly, the *customer* is paying for the shipment of the parcel. An exception to this are returns. For example, consumers purchasing clothing online are often given the option to send back for free the items that don't fit. For this research, no distinction is made between a forward or a return shipment. As a result, a consumer returning purchased goods is now a *customer* as the return shipment is initiated by the consumer, even though the consumer is not paying for the shipment.

2.2.1 Collection

The fulfillment process starts with the collection of parcels. For the purpose of this research, the collection process starts at the customer. Depending on the type of collection, the parcel is either picked up at the customer, or dropped off at a PostNL location by the customer.

In general, three types of collection can be distinguished.

1. **Customer drop-off**. Parcels are dropped-off at one of the PostNL locations. These include for example post offices. From these PostNL locations onwards, the collection process follows the approach of either point 2 or 3. In this case, the PostNL location now acts as a customer.
2. **Collection by van**. Parcels are collected by PostNL at the shipper, and are first moved via the mail network to the first parcel depot. This pickup process is used for customers with smaller parcel volumes. In this case, the pickup is performed by employees of the mail service (see Figure 2.6). The parcels are moved to either a SCB or a VBL where they are consolidated and then shipped to a parcel depot by the parcel division. [redacted].
3. **Collection by truck/trailer**. Parcels are collected by PostNL at the shipper, and are directly moved to a parcel depot. Here, collection is performed by the parcel division. This pickup process has the advantage of being able to collect at a later time, and still arrive in time at the parcel depot for the subsequent steps in the process. This collection process is only offered to webshops shipping a large number of parcels each year. [redacted].

Figure 2.6 – Collection of a roll container using a van of the mail division

Section 2.3 will address the collection of parcels, and the related products offered by PostNL in more detail.

2.2.2 Sorting and transport

The "collection" step ends when the parcel arrives at the first parcel depot. This also marks the moment where the parcels enter the parcel network of PostNL and the "sorting and transport" step of the fulfillment process begins.

After arriving at the first parcel depot, the parcels are individually loaded into the sorter. The parcels are scanned and their weight and size are measured, after which they are sorted for their final depot. Depending on the route and the final depot, the parcels are manually loaded into a roll container (see Figure 2.7) for the given route. These roll containers are loaded into trucks and are driven to the next depot on the route. [redacted].

Figure 2.7 – A roll container used by PostNL for the transport of parcels.

2.2.3 Distribution

When the parcels arrive at the final depot, the "distribution" step starts. The parcels again enter the sorter, are scanned and measured, and then sorted for the specific distribution route. These routes are currently fixed and may thus contain a varying number of parcels depending on the day. The parcels are loaded into the van by the driver in the order or layout he or she prefers. Either a driver employed by PostNL or a subcontractor will execute the route and offer the parcel to the receiver. The receiver can be a PO Box, a store or company, or a consumer. The distribution run ends at the same depot as it started, where parcels that failed to be delivered get returned again for another delivery attempt the next day.

2.2.4 Exceptions

It must be noted that there are a number of exceptions to the described process depending on the type of shipment. For example, PostNL also ships food parcels or white goods, which use an alternative process. Next to that, the parcel fulfillment process might start or end at a location outside of the Netherlands ([redacted]). For the purpose of this research, these cases are excluded. Finally, the described process assumes that the parcel's weight and dimensions are within limits to be sorted by the sorting machine.

2.3 Collection process in detail

As the main subject of focus for this research, the collection step in the parcel fulfillment process will be further elaborated on. First, the different collection products as offered to the customers of PostNL will be described. Next, the process will be described step by step for both products.

Before diving into the process, the term "collection process" should be clearly defined. For this research, the collection process is defined as:

All handlings and activities that occur between a customer having an item ready to be shipped, and the first sorting and processing step of that same item at a location of PostNL.

2.3.1 Collection products

As mentioned before, there are roughly three routes a parcel can follow during collection. These routes correspond to different products offered by PostNL to their customers. Collection by dropping of the parcel at a parcel point is included with the shipment of a parcel and does not require a customer to pay extra. Different types of parcel points are available, each with their own characteristics and meant for different kinds of customers. Parcel points found in post offices, stores, and supermarkets are focused on consumers shipping only a few parcels while business points are available for businesses to drop-off larger amounts of parcels. As mentioned before, the parcel points will be collected in a similar fashion as customers, and as such act as customers to the collection process.

For customers who prefer their parcels to be picked up, two -mostly standardized- options are currently offered.

1. **Collection service mail (less than [redacted] parcels per year):** Customers pay a fee depending on the volume they expect to send for every day they make use of the pickup service. This volume is expressed in either postbags or roll containers. These load devices may contain either parcels, mail or both. The pickup is performed by the mail division and can be combined in a single route with the emptying of mailboxes. This collection route ends at either a VBL or a SCB. From here, the parcels are manually separated from the mail, and are transported to a parcel depot by trailer. The vehicles used have a capacity of six roll containers. As a result, a customer shipping large parcels might exceed six roll containers per day, but still ship less than [redacted] parcels per year. These customers will be discussed internally to come up with a suitable pickup solution, the result of which can be that a customer will still be collected by the parcel division despite not meeting the volume requirements.

2. **Collection service parcels (more than [redacted] parcels per year):** Currently, if a customer sends more than [redacted] parcels per year, they can have their pickup be performed by a trailer that will directly move the parcels to a parcel depot. Doing so means that the customer is able to have their parcel collected till a later time in the day, and still be able to have all parcels delivered the next day. It is not possible to send along mail when using this form of collection. While the boundary to have pickup be performed by the parcel division is set at [redacted] parcels per year, it does not mean that a customer will automatically be changed over to collection by the parcel division when reaching this boundary.

Table 2.2 gives an overview of the most import characteristics of the two collection options currently offered.

	Collection service mail	**Collection service parcels**
Operator	Mail division	Parcel division
Items that can be collected	Parcels or mail	Parcels only
Collection time	Between 16:00 & 18:00 hours	Max 01:00 hours
Typical vehicles capacity	6 roll containers	56 roll containers
Route	Via mail depot to a parcel depot	Directly to parcel depot
Volume boundary (soft)	[redacted] parcels per year	[redacted] parcels per year

Table 2.2 – Main characteristics collection

2.3.2 Arranging a collection product

The process of setting up collection at a customer starts with an account manager of PostNL discussing the possibilities of collection with the customer. He or she will try to translate the (often vague) customer wish into a concrete collection method that is in line with the collection products offered by PostNL. For example, a customer might want to have the parcels collected "sometime at the end of the working day" which, for collection to be arranged, needs to be translated into a specific time window of a certain number of hours in which collection will take place.

Following agreement by the customer, the collection is registered and planned. The way in which this is done depends on whether the collection is performed by the mail or by the parcel service. Both the mail and parcel division operate their own planning department that operate completely separate from each other (including a separate fleet of vehicles and control room to monitor the execution of the process).

While both operate separately, the registration of a customer order looks similar for both divisions. They state:

- Information about the customer such as the company name, address, a customer number etc.
- The expected number of load devices to be collected.
- The time window in which these should be collected.
- The days of the week for which the request applies.

Based on these orders, the planning department of both the mail and parcel division will plan the routes. Both divisions use different software applications to plan the routes, each with different levels of optimization. The software used by the mail division will automatically try to optimize routes, while planning at the parcel division is performed manually, relying on the skill of the planner to best plan the routes.

Finally, if a customer request is less straightforward (for example, a customer has an exceptional request that is not denied straightaway but also not easily implemented), the request is discussed in a weekly meeting ("maakbaarheidsoverleg"). Here, people from different departments, including supply chain planners, supply chain engineers and operational account managers will decide on whether or not it is possible to fulfill the customer wish in a reasonable fashion.

2.3.3 From consumer order to collected parcel

On a day-to-day basis, parcels of the customers of PostNL are collected. To give a clear overview of the collection process, this subsection will describe the different relevant parts of the collection process in detail. While different kinds of shippers are possible, this example will take the perspective of a webshop as the shipper. Finally, while not part of the scope, the process leading up to a parcel being ready for collection will also be briefly addressed for the sake of completeness.

Consumer order

When a consumer places an order, the shipment will be prepared by the webshop. While the order management and picking system or process is of course under control of the webshop, the systems of PostNL will also have to be notified of the order.

Integration between the order management system of the customer and the systems of PostNL can occur in different ways. When a customer makes use of one of the larger e-commerce platforms, a PostNL plugin is available that can be used to make it easy to pre-notify shipments and print labels whenever a consumer places an order. In case a customer uses a proprietary system, the same functionality has to be build in by the customer itself. Alternatively, the customer can also use either standalone software or a web environment made available by PostNL to generate and manage shipments.

Regardless of customer's order management system, from the perspective of PostNL an order by a consumer should result in three things:

- A unique 3S barcode for that parcel
- A pre-shipment notification stating the 3S barcode as well as the name and address of the receiver of the parcel.
- The actual parcel, equipped with a label showing the 3S barcode

There is however an exception possible. Some customers will use a label they can generate on their own without informing PostNL of the used barcode on the actual label. This is referred to as "klantspecifieke stickers" or (KSS). When using these, no pre-shipment notification is send and the first time PostNL will become aware of the parcel, is when it receives the first sorting scan at an NLI. As compensation for the lack of information, PostNL charges a fee for every parcel shipped with a KSS label.

Finally, it is important to note that a pre-shipment notification doesn’t mention the date at which the parcel will actually be presented to PostNL. It is possible to already notify a shipment while the actual shipment will take place days later.

After packing the parcel, sending the pre-shipping notification and printing and applying the label, the parcel is placed into the load device used by the webshop and is ready for collection.

Collection by the mail division

A driver from the mail division will arrive at the customer within a predefined time frame which the drivers are instructed to meet. This can mean that a driver will have to wait at a location before the time frame starts. When planning the route, the time required to collect the parcels, the time required to travel between the different stops, and the different time windows are taken into account. As a result, it should be feasible to meet all the time windows when driving the route.

When arriving at a location, the collection driver will scan a location barcode and pick up the load device carrying either parcels or mail. The scan is simply there so that the control room can keep track of the route. This information can be checked in case a customer calls about a driver not showing up or in case the route appears to get far behind schedule, in which case customers are called proactively.

The parcels found in the load device are not filtered by the driver for having the appropriate size, weight, barcode etc. nor are they scanned. The driver will however use his or her own judgment to make sure that the load can safely be transported and may leave behind load devices in case the customer presents a higher volume for collection than agreed upon.

After finishing the collection run, the driver will stop at an SCB or a VBL. Here, all collected items (mail and parcels) are unloaded and sorted into regular mail, registered mail, and parcels. When doing so, no measure is made regarding the actual collected volume, nor are the parcels scanned at the SCB or VBL. The parcels are simply left standing in a roll container, waiting to be picked up. The parcels are eventually picked up by a trailer from the parcel division, which will move the parcels to a parcel depot.

Sometimes, a number of parcels may be found in a postbag in between the letters. These parcels are manually removed from the flow of mail and added to the parcel flow.

Collection by the parcel division

When collecting is performed by the parcel division, a vehicle will again arrive at the customer within a given time window. The driver will be handed a packing list by the customer which he should check against the actual number of roll containers loaded.

Currently, there is no system in place to either register the arrival of the truck at the location or the amount of roll containers loaded into the truck. Instead, the transport information system will automatically take the start time of the time window as the actual arrival time of the truck, and the planned amount of roll containers as the actual loaded number of roll containers.

After loading and securing the roll containers in the truck, the driver will transport them to the agreed parcel depot.

Handover from mail division to parcel division

Regardless of whether a parcel is collected by the mail or parcel division, the final part of the process is performed by the parcel division. As a result, the handover from the mail division to the parcel division is arranged for every SCB and VBL that is used in the handling of parcels.

There is a document available in which the agreements are registered. This document states at which time, which percentage of parcels will be collected by the parcel division at the SCB or VBL. An important difference between collecting parcels at a customer or at an SCB or VBL, is the availability of the transport information system at these locations. As a result, contrary to with customers, the actual arrival time of the truck as well as its load is registered in the system when picking up parcels at an SCB/VBL.

At the parcel depot

At the parcel depot, the roll containers are unloaded and placed in a special zone where they will wait to be unpacked, and the parcels loaded into the sorter. The parcels are manually moved through a gate which measures 58 cm by 78 cm, thus providing an initial size check. After this, the parcels are automatically measured for both dimension and size, and scanned before entering the actual sorting loop. This first scan marks the end of the collection process as defined for this research.

2.4 The collection of mail

While the focus for this research lays strongly with the collection of parcels, it is inevitable to include the collection of mail to some extent. The parcels that are collected using the collection product of the mail division are combined with the collection of mail as well. As mentioned before, the load devices collected via the mail division may contain either mail or parcels and the difference is only identified once the load devices arrive at the SCB or VBL. Given that for mail, the first step in processing occurs at the SCB or VBL, the collection is considered to be complete at the same time mail is identified as such.

In practice, this means that for this research, collection involves load devices containing either mail or parcel ready for shipment at the customer of PostNL being transported to the first PostNL location, where further processing of the specific type of item occurs. For a parcel this location is an NLI while for mail, this can either be a VBL or SCB.

3 Current collection process

While the previous chapter gave a broad overview of the collection process, as well as related or connected processes, this chapter will provide a more structured analysis of the current collection process.
This will be done following the *Delft Systems Approach* (Veeke, Ottjes, & Lodewijks, 2008). First, the root definition of the primary process, as well as a description of its boundaries, inputs and outputs will be given. Next, the collection process will be described using PROPER models at different aggregation layers. The goal of doing so is to identify the positions in the process where problems might occur. Finally, the performance of the current collection process will be addressed.

3.1 Primary function and process

The primary function under investigation concerns the process of transforming load devices into collected items and empty load devices. This function should meet certain requirements that are imposed by the environment in which it operates. In return, the function delivers a certain performance that should match the requirements as closely as possible (see Figure 3.1).

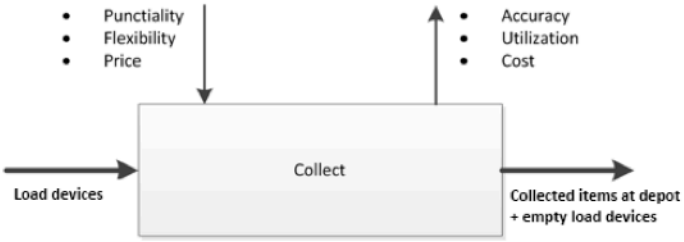

Figure 3.1 – The primary function, its input, output, requirements and performance.

3.1.1 Root definition

The root definition, describing among other things the transformation and its actors of this function, is given as:

A system that utilizes the employees and other resources of PostNL to perform all the necessary handlings to move the item (such as a parcel), loaded and transported in a load device, from the shipper (such as a webshop) to the depot as efficiently as possible, while meeting the agreement with the shipper, with the goal of providing the shipper the convenience of not transporting the parcel to a depot themselves.

While the root definition helps to define the primary function under investigation, it also calls for further definitions.

The input "requirements" are posed by both the customer of the function (the shipper) as well as the owner of the function (PostNL). The customer wants to have certain agreements and wishes to be met by the function. For this specific case, these include:

- Accuracy with regards to the agreed upon collection time and time window.
- A certain flexibility regarding the volume to be collected.
- A low price.

Next to that, PostNL will strive to perform the function as efficiently as possible. This includes:

- Minimizing the cost.

- Maximizing the utilization of the resources used (for example maximizing the fill rate of the collection vehicles).
- Performing the transformation on schedule as to minimize disturbances on subsequent processes.

The performance output should indicate how well the process has performed with respect to the requirements mentioned before.

3.1.2 Description of input to the process

The physical goods being transformed by the function are mainly parcels loaded in a load device. For the purpose of this research, parcels are defined as:

An item, appropriately packaged, within a certain dimension and weight, suitable for shipment and equipped with a barcode label.

Again, this definition entails a number of terms that need further explaining. Internally, PostNL uses the following guidelines when it comes to "appropriate packaging" of a parcel:

- The strength and sturdiness of the packaging must be in line with the contents of the parcel.
- Pressure points such as protrusions and corner should be avoided.
- Weight should be distributed as evenly as possible by using filler material.
- A heavy parcel requires better packaging than light parcels.
- The contents of the parcel should be fixed in place inside the packaging.
- Fragile parcels should have a buffer between the outside of the packaging and the item inside.
- Avoid empty spaces within the packaging.

With regards to "certain dimension and weight", PostNL communicates a maximum dimensions for a parcel of 175cm x 78cm x 58cm with a maximum weight of 31,5kg to its customers. No minimum size and weight are defined, though the parcel should have enough space to accommodate a barcode label.
Internally however, PostNL makes a distinction between parcels that are suitable for automatic sorting and parcels that need to be sorted manually. The maximum dimensions for automatic sorting are 100cm x 70cm x 58cm with a maximum weight of 30kg. The minimum dimensions for automatic sorting are 10cm x 10cm x 1cm.
Next to the given dimensional and weight limits, a parcel will also be sorted manually if its shape is not suitable for automatic sorting. An example would be round parcels that risk rolling of the sorter.
Parcels exceeding the stated maximum dimensions are filtered at the parcel depot and afterwards treated as piece goods. These goods are further transport by PostNL Cargo, the division responsible for the transport of larger piece goods and palletized items. This means the shipper will be charged an additional fee, and the agreed upon throughput time might not be kept.

As the collection process is not dependent on the suitability of the parcel to be automatically sorted, any parcel not exceeding the maximum size mentioned before will be within the research scope. Larger parcel that need to be transported by PostNL Cargo will however not be considered. Figure 3.2 gives an overview of the different size and weight limits, their suitability for either automatic or manual sorting, and their inclusion in the scope of this research.

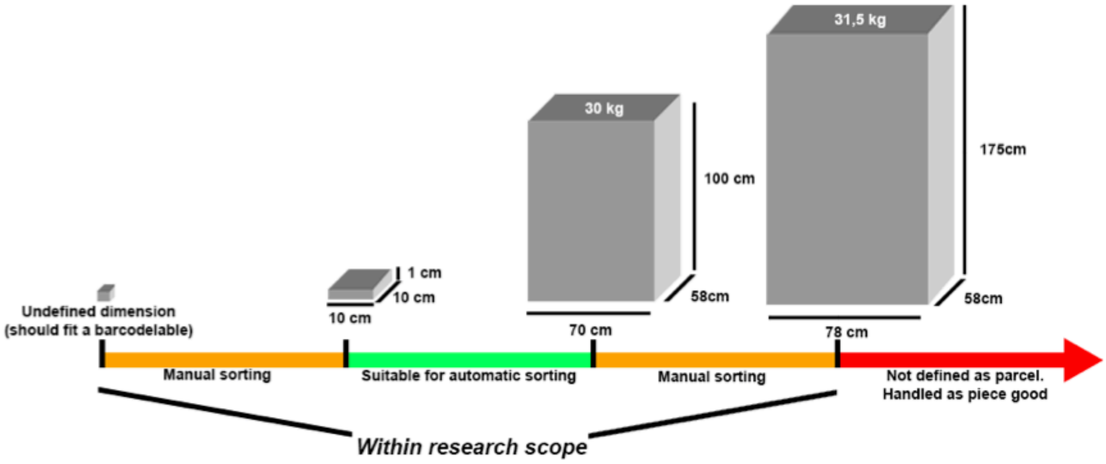

Figure 3.2 – Different parcel weight and dimension limits

It must however be noted that this definition of a parcel is meant as the intended input to the function. As mentioned, the collection driver will not actually check the parcels that are collected against these standards. As a result, it would be possible to have parcels collected that exceed dimensions or do not contain a barcode. This will however only be noticed at the end of the collection process when the parcels enter the sorter.

3.1.3 Variation in input to the process

Chapter 2 already stated the total number of parcels that are shipped in a year. With regards to the collection process, there are however a number of ways in which there is variance in the parcel volume.
First of all, the volume is not evenly distributed throughout the year, as can be seen in Figure 3.3. The input of the function has a number of peaks, the biggest of which occurs at the end of the year. This peak in volume can be contributed to the winter holidays.

[redacted]

Figure 3.3 – Parcel volume throughout the year of PostNL

Similarly, the volume is not evenly distributed over the days of the week either. Most parcels are collected on Monday through Friday, with a very small number of customers getting offered collection on Saturday as well. As a result, parcels ordered on Saturday through Monday are collected on Monday, resulting in a peak of parcels arriving at the depot. Figure 3.4 shows an example of the distribution for the last week of May 2016.

[redacted]

Figure 3.4 – Parcel volume throughout the week for a single parcel depot

Furthermore, different collection pickups will have different planned volumes to be collected. As mentioned before, parcels are carried using a load device, predominantly a roll container. As a result, the expected input to the process as agreed upon with the customer is expressed in the number of load devices. To get a sense of the variation in pickup size, Figure 3.5 shows the planned number of pickups in Week 27 of 2016, for each number of roll containers. Since the biggest vehicle used for collection can carry 56 roll containers, this is the highest possible number of roll containers for a single pickup.

[redacted]

Figure 3.5 – Distribution of the agreed number of roll containers to be collected at a customer.

Finally, the volume that customers actually present for collection shows great variation, regardless of the size of the customer. Figure 3.6 shows the realized collection volume (expressed in the physical volume of the collected parcels) for three different customers.

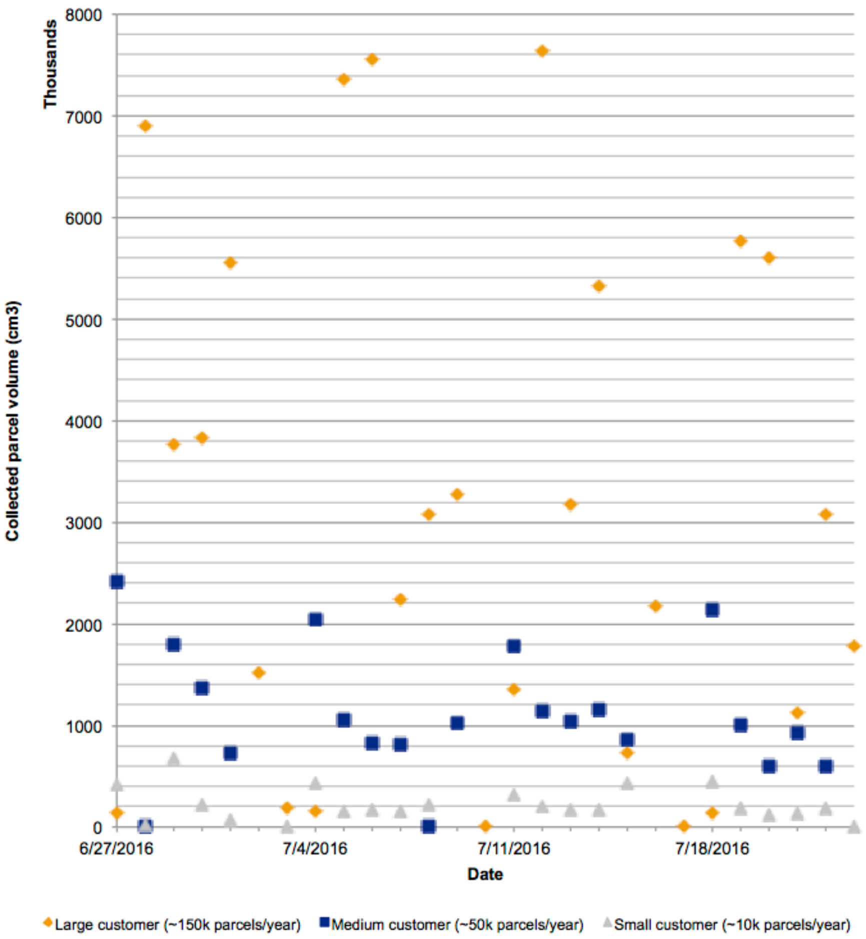

Figure 3.6 – Variation in collection volume

3.1.4 Boundaries

Next, the boundaries of the function should be defined. The boundary on the input side lies with the shipper of an item. As mentioned before, while the item will mostly be a parcel, it is possible for it to be a mail item as well in the case collection takes place using the mail division. The item that is being collected is assumed to be ready for shipment, comply with the definition mentioned before, and is loaded in the agreed upon load device. As such, all handlings performed by the customer to prepare the order (and thus the parcel) are outside of the scope of this research.

On the output side, the boundary lies at one of the locations of PostNL. As mentioned before, the collection process will end after the item arrives at the location of PostNL where the first step in sorting and processing takes place. For mail, this means the arrival at a mail location (VBL or SCB), and for a parcel the receiving of the first scan at the parcel depot. Processes following after this lay outside of the scope of this research.

3.1.5 Customer requirements

A total of nine different customers of PostNL were interviewed with the goal of identifying their main requirements and wishes with regards to the collection process.
The interviews were performed at the customer location. The interviewees were all responsible for purchasing and setting up the parcel fulfillment service. Next to the interviewer and the interviewee, the responsible account manager of PostNL was present during the interview.
The interview followed a semi-structured approach, starting out with open questions regarding the collection process. If not addressed by the interviewee, the interview will continue as a structured interview, were a number of typical requirements for the collection process were mentioned and asked about the level of importance.

The customers interviewed were selected with the following criteria:

- **As advised by the account managers.**
  Customers that are interviewed are believed to possibly have valuable input with regards to the collection process and its requirements according to the account managers.
- **Currently either dropping-off the parcels themselves or having them collected by the mail division.**
  It is assumed that customers being collected by the mail division will have more input with regards to the requirements as the limitation of collection by the mail division are higher than with the parcel division.
- **Mix of B2C & B2B as well as different industries**
  The customers are selected in such a way that there is a mix of different products and/or services offered by the customers, as well as different target audience (either business-to-consumer or business-to-business).
- **Different company setups**
  There are a number of different setups in which a webshop can be run. The following four setups are formulated:
    - **Retail based (RB)**
      Webshop operated from within a retail store. Offers products both online as well as in a physical store located in commercial area in a town or city.
    - **Industrial based + showroom (IB+S)**
      Webshop operated from an industrial estate, based in a warehouse. Focus on online sales, but as well operating a small showroom for customers to visit and experience products in person (commonly on appointment).
    - **Industrial based (IB)**
      Same as previous, but without offering a showroom.
    - **Home based (HB)**
      Webshop operated from home (and thus located in a residential area) without the possibility of customers visiting the webshop.

  All four of these possible setups are represented in the nine customers that were interviewed.

Table 3.1 shows the main characteristics of the nine customers that were interviewed.

Customer	***Parcel volume (2015)***	***Product/service***	***Company setup***	***Collection method***	***Focus***
#1	[redacted]	Outdoor supplies	RB	Pickup	B2C
#2	[redacted]	Beauty products	RB	Pickup	B2C
#3	[redacted]	Fulfillment	IB	Drop-off	B2B
#4	[redacted]	Electronics	IB+S	Pickup	B2B
#5	[redacted]	Electronics	IB+S	Pickup	B2B
#6	[redacted]	Electronics	HB	Drop-off	B2C
#7	[redacted]	Health & Fitness	IB+S	Pickup	B2B
#8	[redacted]	Fashion	RB	Drop-off	B2B
#9	[redacted]	Fashion	IB	Pickup	B2B

Table 3.1 – Characteristics interviewed customers

Based on the interviews, a number of important as well as less important requirements were found. Next to that, some requirements were inconsistent among the group of interviewees.

Finally, a number of relevant points of interest are found. All of these can be found in Table 3.2.

Important	
Flexibility in collection volume.	All customers mention the need for flexibility in the collection volume as they see fluctuations in order volumes throughout the week.
[redacted]	[redacted]
[redacted]	[redacted]
Not important	
[redacted]	[redacted]
[redacted]	[redacted]
Inconsistent	
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

Points of note	
[redacted]	[redacted]
[redacted]	[redacted]

Table 3.2 – Findings customer interviews.

While Table 3.2 gives a complete overview of the interview findings, the most important findings related to the presented research are:

[redacted]

- Customers seem to have little interest in the collection process. While [redacted], the collection process is simply there to unburden them.
- As a result of the previous point, customers seem to see flexibility in volume as the most important requirement. Customers want to have all their parcels collected without problems, even if the volume exceeds the agreed upon levels, which they believe should be possible. Their reasoning is that exceeding the agreed volume is positive for PostNL as it means additional parcels that are shipped and thus more income for PostNL.

3.2 PROPER model

While the overview of the main function as shown in Figure 3.1 provides an initial insight into the system under investigation, a further, more detailed description is required. Following the methodology of the *Delft Systems Approach*, an industrial system can be analyzed by addressing three different *aspects* of the system; the material flow, the order flow and the resource flow. In this case, the material flow represents the flow of items, the order flow the customer wish to have parcels collected, and the resource flow the use of different people, vehicles, and other means to execute the collection. To do so, a PROPER ("PROcess-PERformance") model of the collection process will be defined (Veeke, Ottjes, & Lodewijks, 2008, p. 95).

3.2.1 First aggregation level

Figure 3.7 gives a high level overview of the system under investigation. A customer wish is transformed into a handled customer wish by the responsible departments. This transformation results in a task that is executed by the *collect* function. This function transforms "load devices" into "collected items & empty load devices". To do so, the *collect* function assigns resources to execute the *collect* function. The application of these resources are found in the *use* function, which transforms these "resources" into "used resources".

Above the three aspects, the control function is found. Since there are as well control functions within the different aspects, this control function is named *coordination control* as it coordinates the three aspects.

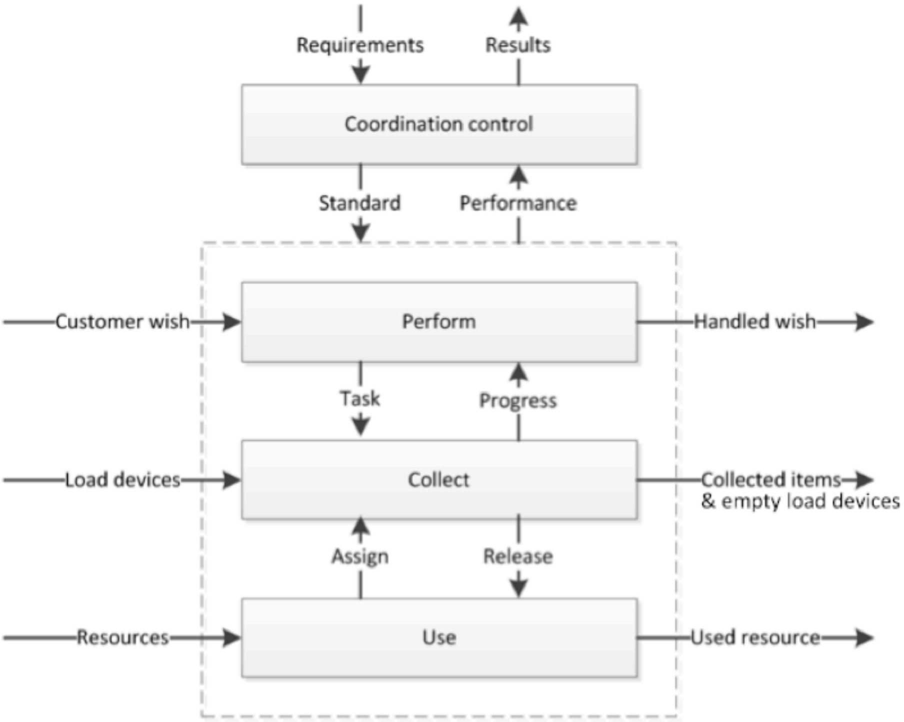

Figure 3.7 – PROPER model, first aggregation layer

However, it must be noted that while the three processes run in parallel, they occur on a different timescale (Figure 3.8). While the customer wish is transformed in a handled wish roughly once a year, the collection process occur daily. This means that the task that is set by the perform process is independent of the input of parcels.
To the contrary, the order flow for the distribution process are the pre-shipment notifications mentioned before, which are transformed in parallel to the material flow (the parcels) on the same timescale. This makes it possible to make adjustments to the distribution (i.e. changes in the distribution route) based on the order flow.

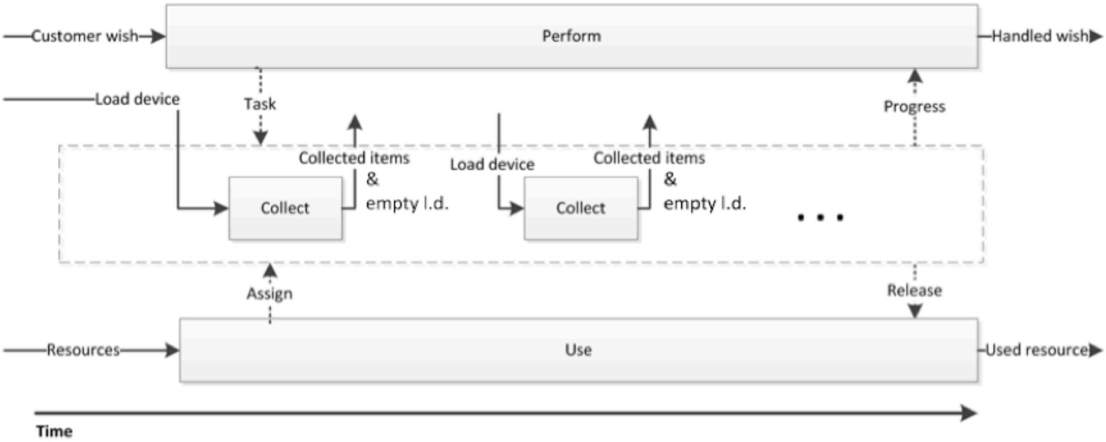

Figure 3.8 – Parallel processes occurring throughout time

Not only are the tasks set for a longer period of time, it is commonly also fixed throughout the week. In practice, this means that a customer will indicate a certain number of load devices (e.g. roll containers) that need to be picked up every day.

3.2.2 Second aggregation layer

The three aspects shown in the first PROPER model contain a variety of processes. As such, we can zoom-in into the different aspects and show their contents with greater detail. Figure 3.9 shows the PROPER model on a more detailed aggregation level.
Based on the process as described in Chapter 2, the different aspects can be filled in, showing the process in detail.

The detailed process brings forward a number of points that deserve addressing. First of all, there appears to be a lack of feedback in the system, where the standards set in the process are evaluated based on the previously achieved performance. An important example is the decision which department (mail or parcel division) performs the collection process. A fixed limit is used to make this decision. Not only is the decision not evaluated on a regular basis, the limit itself is not evaluated either.
Furthermore, the two planning departments use a different approach to planning customers in a route. The mail division uses route optimization while the parcel division relies on the experience of the planners. Regardless, both make their own local optimization without considering the other department on a regular basis.

Within the *perform* function, the customer wish is the only input. As mentioned before, this customer wish is only evaluate on roughly a yearly basis. Given the large fluctuation in parcel volume, one would expect that the input to the *perform* function includes additional forms of information as to make the process perform more in line with the *collect* function.

Finally, the functions show a large number of decisions for which the input is not clear. It appears that decisions are often made based on experience instead of generally agreed upon standard. As a result, the processes could benefit from a more clearly defined control structure including more feedback based in previous performance measures.

[redacted]

Figure 3.9 – PROPER model, second aggregation layer

3.3 Order accuracy

In order to judge the performance of the current collection process, specifically the way in which a customer request leads to a task which is then performed by assigning resources, the planning accuracy will be quantified. This will be done for both the collection as performed by the parcel service, as well as by the postal service. The used measuring in which to express the order accuracy is the *order fill rate* which is defined as:

The ratio between realized volume (i.e. the number of roll containers actually picked up at the customer) and the planned volume (i.e. the number of roll containers found in the customer contract, which is the bases of planning the collection).

3.3.1 Parcel service collection

To quantify the planning accuracy of the parcel division, a comparison is made between the planned and realized volumes of all collection pickups performed in the time of a month. Excluded are incidental or emergency pickups as these cannot be planned beforehand. Next to that, orders that were cancelled beforehand are excluded as well.

Within PostNL, a number of different load devices are used, for example parcel roll containers, postal roll containers, customer specific roll containers, euro pallets, disposable pallets, etc. to make it easier to measure and compare the planned and realized transport, PostNL uses an "equivalent roll container" as the universal measure of transport volume, which equals the size of a postal roll container.

In the month of June 2016, a total of [redacted] transport orders from customer to parcel depot were found. Each of these orders represents a pickup at a customer.
An average order size of 19 equivalent roll containers was found. The average realized pickup size was however found to be a lot lower at [redacted] equivalent roll containers, resulting in an order fill rate of [redacted]%. However, as shown in Figure 3.10, there is also a number of instances found where the picked-up volume exceeds the planned volume. On average, the absolute deviation between the planned and the picked-up volume is found to be [redacted] equivalent roll containers, meaning there is on average a [redacted] error between the planned and the collected volume (see Table 3.3).

Number of orders	**Average order size** (equivalent roll containers)	**Average realization** (equivalent roll containers)	**Average order fill rate**	**Average absolute deviation** (equivalent roll containers)
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 3.3 – Order performance parcel division

[redacted]

Figure 3.10 – Categorization of planned volume vs. realized volume[1]

It must be noted that when referring to the order fill rate, it simply means the percentage of the order size that was actually realized. When translating the order fill rate to the vehicle fill rate (the more conventional meaning of fill rate), the vehicle fill rate can by definition be at most as high as the order fill rate (which is the case where the planned vehicle fill rate is 100%). More commonly however, the vehicle fill rate will be still lower as a vehicle can seldom be planned to full capacity.

3.3.2 Postal service collection

While the parcel division keeps track of the planned versus realized volume for every collection, such information is not available for collections performed by the postal service. Instead, an estimation will be made using other available data.

PostNL keeps track of all scans and measurements that are performed on each individual parcel using their *Track and Trace* system. Based on this source of information, it is possible to give a good estimation of the number of parcels that are collected on a given day. Next to that, the dimensions of each of these parcels is known. Since the dimensions of a roll container are also know, it is possible to determine the expected number of roll containers necessary to carry these parcels.

Since the information is only available on an individual parcel level, it is not feasible to determine the expected realized volume for all customers using this method. Instead, the analysis is made for three different customers that are collected by the postal service and are known to use the service predominantly for parcels.

As mentioned in Chapter 2, parcels that are collected using the postal division are only scanned once they reach the first parcel depot. From the *Track and Trace* system, these scans are found for each of the parcels shipped in the last year. While the scan mentions the date at which the scan occurs, it must be noted that the parcels arrive at the parcel depot late in the evening. As a result, a parcel that is collected at 1-1-2016, may be scanned just after midnight and will thus display 2-1-2016 as the date of the scan. To account for this, the date of the scan will be reduced by one day for every scan that occurs between **0:00** and **3:00**.

Next, the volume of all parcels can be summed up for every day as the volume of the parcels is included in the scan data. By then dividing the daily volume that was collected by the volume of a roll container, the number of roll containers that were collected can be determined. However, since part of the roll container is not filled (due to the different shapes

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[1] Note: a margin of one equivalent roll container is used before a pickup is marked as more or less than planned. In other words, a pickup of [redacted] roll containers when [redacted] roll containers were planned, is still marked as “as planned”.

and sizes of the parcels), a factor is applied to account for this. Figure 3.11 as well as Table 3.4 shows the results of the analysis for the three customers.

[redacted] [redacted]

[redacted] [redacted]

[redacted] [redacted]

Figure 3.11 – Planned volume versus realized volume for three customers (assumed 70% roll container packing density)

Customer	**Order size** (postal roll containers)	**Average realization** (postal roll containers)	**Average order fill rate**	**Average absolute deviation** (postal roll containers)
#1	[redacted]	[redacted]	[redacted]	[redacted]
#2	[redacted]	[redacted]	[redacted]	[redacted]
#3	[redacted]	[redacted]	[redacted]	[redacted]

Table 3.4 – Planning performance mail division for three customers

Again, the collected volume is in general a lot lower than the planned volume, leading to a low order fill rate. Furthermore, the graphs show the large variety in collection volume, which makes having a fixed planning volume less than ideal.

3.4 Impact on vehicle fill rate

Closely related to the order accuracy is the vehicle fill rate. The vehicle fill rate describes to which extent a vehicle is utilized during transport. The actual definition depends on the measure used for vehicle utilization. McKinnon (2010) describes five different measures for vehicle utilization which are found in Table 3.5.

Level of empty running	The proportion of truck-kms run empty.
Weight-based loading factor	The ratio of the actual weight of goods carried to the maximum weight that could have been carried on a laden trip.
Tonne-km loading factor	The ratio of the actual tonne-kms moved to the maximum tonne-kms that could have been moved if the vehicle had been travelling at its maximum legal weight.
Volumetric loading factor	The proportion of cubic space in the vehicle occupied by a load. It is a 3-dimensional view of vehicle fill.
Deck-area coverage	The proportion of vehicle floor (or deck) area covered by a load, representing a 2-dimenisional view of vehicle loading.

Table 3.5 – Measures for vehicle utilization

Which specific measure should be used depends on the situation in which it is applied. For example, when transporting items with a very low density, the weight-based loading factor might be very low, while the volumetric loading factor and the deck-area coverage might be close to 100%, making the weight-based loading factor a less suitable measure. In a similar fashion, when the height to which products can be stacked is tightly constraint (for example due to stability or strength of the product), the 2-dimensional measure of deck-area coverage is preferred over the 3-dimensional measure of deck-area coverage. Finally, the tonne-km loading factor can specifically be applied to trips where the load varies (for example due to different pickups and drop-off during the trip).

When deciding on a suitable measure for the vehicle utilization during the collection process, the following characteristics are important to note:

- At an average volumetric mass density[2], of [redacted] kg/m^3 parcels have a similar density to [redacted] (Engineering Toolbox, n.d.), making weight-based measures unsuitable as the utilization will be constrained by size and not by weight.
- As it is not possible to stack roll containers, a 3-dimensional measure is not applicable.
- A single trip will contain multiple pickups and drop-offs.

Given these characteristics, none of the aforementioned measures are suitable. While the tonne-km loading factor would make it possible to include multiple pickups and drop-offs in a single trip, the collection vehicles are constrained by deck area and not by weight. Instead a *deck area-hour loading factor* is proposed. The reason for using the time dimension to weigh the different stops instead of using the distance is due to information availability. However, under the assumption that trips will have the same average speed, using the travel time will yield the same results as using the travel distance.

The deck area-hour loading factor is formally defined as:

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[2] Based on the weight and volume measure of [redacted] parcels scanned at a single parcel depot over [redacted] hours.

$$\text{Deck area-hour loading factor} = \frac{\sum_{i \in O} N_i \left(t_i^{dropoff} - t_i^{pickup}\right)}{N_{max}\left[\max\left(\left\{t_i^{dropoff}\right\}_i^{|O|}\right) - \min\left(\left\{t_i^{pickup}\right\}_i^{|O|}\right)\right]} \qquad (1)$$

With:
O the set of transport orders in a trip
N_i the number of roll containers transported for order i
N_{max} the maximum number of roll containers that can be loaded into a truck
t_i^{pickup} the time at which the roll containers for order i are all loaded
$t_i^{dropoff}$ the time at which the roll containers for order i are all unloaded

Or, as the sum of all the roll containers multiplied by the time during which they are part of the trip, divided by the total trip length multiplied by the maximum number of roll containers that can be carried. Figure 3.12 shows a simple example of a vehicle trip with multiple stops, resulting in a vehicle fill rate of 43%.

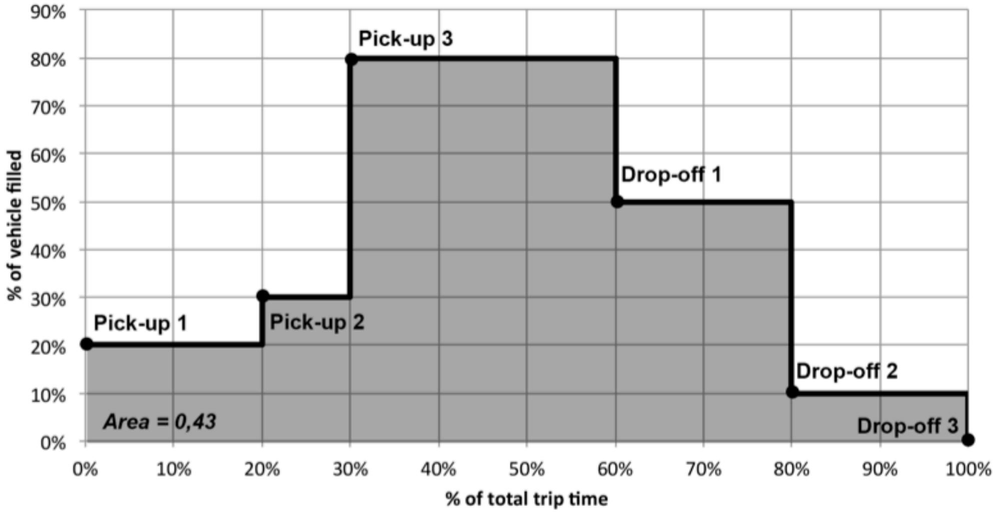

Figure 3.12 – Example of vehicle fill rate calculation with multiple stops

As mentioned before, both the planned as well as the realized collection volume per order is registered in the *transport information system* of PostNL. By combining this information with the route composition (i.e. how orders are combined in routes), it is possible to quantify the vehicle fill rate. However, planning at the parcel division often occurs at a very short term basis as well as ad-hoc. As a result, actual combinations of orders are difficult to match with executed trips. Based on the available information, [redacted] trips taking place in week 26, 27 and 29 are identified for which the information was complete. Furthermore, trips that include cancelled pickups or empty roll containers are excluded. The results of this analysis are found in Table 3.6 below.

	Number of trips	**Average planned "Deck area-hour loading factor"**	**Average actual "Deck area-hour loading factor"**
All trips	[redacted]	[redacted]	[redacted]
Only trips including customer collection	[redacted]	[redacted]	[redacted]

Table 3.6 – Planned and actual deck area-hour loading factor

As is shown in the table, there is a large difference between the planned vehicle fill rate (which is the achieved fill rate in the case that the realized volumes matched the planned volumes for all pickups in the trip) and the actual vehicle fill rate, showing the impact of the order accuracy on the vehicle fill rate.

One critical note with measuring the vehicle fill rate in this fashion (or when using the aforementioned *tonne-km loading factor*) is the impact the pickup order has on the fill rate. See Figure 3.13 for an example.

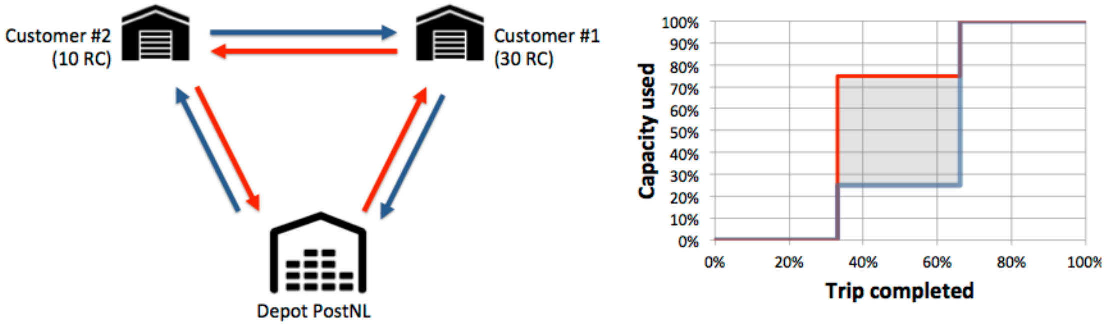

Figure 3.13 – Example of discrepancy when using a weight loading factor

Looking at the graph, the red route which visits the largest pickup first has a higher fill rate than the blue route (the difference is shown by the grayed out area). However, in case all distances are equal, both routes should be believed to be equally as efficient. Better still, one might argue that the blue route is more efficient as picking up the largest volume last could save driving around unnecessary weight and thus fuel.

So while using a fill rate based on the distance or time travelled can be useful to evaluate performance after the fact (as well as being useful to judge the impact of planned vs. realized volumes), it is less suitable as a measure to control the collection process. Doing so might motivate planners to have large pickups occur first, regardless of the detour a driver needs to take to do so, resulting in unnecessary kilometers driven and thus cost.

As an alternative, the trips performed by the parcel division are evaluated using the *deck area coverage factor*. In this case, the number of roll containers present in the truck are taken at each drop-off at a depot, and divided over the total number of roll containers a vehicle can carry. The results of this analysis are found in Table 3.7.

	Number of drops	**Average planned "Deck area coverage factor"**	**Average actual "Deck area coverage factor"**
All drops	[redacted]	[redacted]	[redacted]
Only drops including customer collection	[redacted]	[redacted]	[redacted]

Table 3.7 – Planned and actual deck area coverage factor

Research performed by McKinnon & Ge (2004) considered the vehicle utilization of 53 vehicle fleets used by companies in the United Kingdom used for the transport of groceries between both factories and distribution centers, as well as between distribution centers and supermarkets. They found an average deck-area coverage of 69%, which is notably higher than found at PostNL. Furthermore, they noted that similar to the transport of parcel, *grocery products have a relatively low density they are constrained much more by the available deck area than by the vehicle weight limit* (McKinnon & Ge, 2004, p. 227).
A possible explanation for the lower vehicle fill rate is the fact that the transport network of PostNL is time constrained, meaning that vehicles need to meet a time window which makes it more difficult to combine stops in a single trip and thus negatively impacting the vehicle fill rate. However, the difference between the planned vehicle fill rate and the actual vehicle fill rate shows that it is possible to improve the vehicle fill rate despite dealing with a time constrained network.

While it is of interest to perform a similar analysis on the trips performed by the mail division, it is currently not possible due to the lack of information regarding the realized volumes. However, given the similar results regarding order accuracy as well as the similarities in making agreements with the customers regarding volumes (i.e. using fixed volumes), similar results are expected.

4 Problem diagnosis

Following the analysis of the current collection process and its performance, this chapter will address the problem at hand that should be solved as to improve the collection process performance. First the problem will be defined, followed by the research objective and subsequent research questions. Finally, the subsequent research approach will be discussed.

4.1 Problem definition

Based on the analysis of the current process, three main issues are identified. While they are interrelated, each of them will be briefly addressed separately:

4.1.1 Disconnect between planned and realized volumes

Currently, PostNL customers register their expected collection volume as a fixed value for every day. In practice however, customers experience fluctuations in volume to be collected on a daily basis, resulting in large deviations from the planned volume. These fluctuations are, despite being large, not taken into account when planning the collection runs. This results in inaccurate planning and thus unnecessary collection cost.

Furthermore, within the parcel division, there are incentives in the process of registering a customer that allow the registered number of roll containers to differ from the expected number of roll containers.
[redacted]

[redacted]

4.1.2 Inefficient vehicle planning due to decentralized planning

In addition, collection orders from customers end up at different planning departments, each with their own vehicles and control room. The decision as to which department is responsible for the collection of a specific customer is in general made based on the number of parcels a customer ships on average in a year. Below a certain limit, parcels are collected using the mail collection service and above this limit, using the parcel collection service. Both these departments follow their own approach to determining the routes to collect these parcels. This however means that vehicle assignment and routes can only be locally optimized, instead of globally across all customers to be collected. This again might lead to unnecessary collection cost.

Another consequence of the decentralized planning is the problem that occurs when a customer's demand for collection increases from [redacted] to [redacted] roll containers (for example due to increased sales). Since the peak capacity with collection using the mail division is set at [redacted] roll containers, the customer will be moved to the parcel division.
However, when charging a customer for the collection, the possibilities of combining different customers and the advantage this has to the collection cost, are not taken into account when defining the price that is charged. As a result, it is very well possible that collecting seven roll containers using the parcel division is more costly for the customer than collecting six roll containers using the mail division. This to the dismay of the customer, who is sending more parcels using PostNL (and thus generating more revenue for PostNL), but sees his collection cost increase.

4.1.3 Lack of feedback and information input in the collection process

Finally, while customers mention flexibility in volume as the most important requirement of a collection product, there is currently no process in place to allow either the customer to provide information regarding deviations on the expected volume (they will be charged according to the fixed volume regardless) nor are deviations from the expected/planned collection volume structurally challenged by the planning departments. As a result, the current process doesn't make use of all information available, further resulting in suboptimal collection performance.

4.2 Research Objective

Following the problem definition, the objective of this research is formulated as follows:

To design a control system for the collection process that takes the required flexibility of the customer as well as the efficiency of the process into account and to give an indication of the expected improvement.

Given the known inputs of the process (i.e. customers and the volumes that need to be collected), this research will investigate how the process should be arranged, controlled, and executed as to improve the performance of the process. The goal is to do so while taking a holistic approach and viewing PostNL as one organization, evaluating the collection process across the now two separate executing entities. By first evaluating the way the collection process is controlled on a strategic level, the process requirements can be identified. This is followed by addressing the collection process on a tactical level, proposing an improved way of executing the collection process. Then, using a simulation model, an evaluation can be made of the impact of improvements in the way the collection process is executed.

4.2.1 Research questions

Following the research objective, the following main research question needs to be answered:

How should the collection process be arranged, controlled and executed as to improve the process performance while taking into account the uncertainty in collection volume?

Next to the main research question, the following subquestions are formulated:

Regarding the control of the collection process on a strategic level:

- *How should the collection process be controlled?*
- *What information is required to successfully control the collection process?*
- *What are the requirements for the collection process?*
- *How to measure process performance?*

Regarding the execution of the collection process on a tactical level:

- *What information regarding collection volumes is available at the customer at what moment in time?*
- *What is the impact of the availability of information regarding collection volumes on the process performance?*
- *How should this information be taken into account in the collection process?*
- *Which resources (e.g. vehicles) are necessary to execute the improved collection process?*
- *How should the required resources be used?*

4.3 Research approach

Following the process analysis and problem diagnosis, the approach for the remainder of the research will be defined as follows:

First, the requirements for organizing the collection process on a strategic/tactical level will be addressed in the next chapter. In the subsequent chapter, a model will be developed to evaluate different approaches to using information to better plan and execute the collection process. This is followed by a case study were the model will be tested for a certain geographical area. After evaluating the results of this case study, the implementation of the improved collection process will be addressed. Finally, the research is concluded with a number of recommendations.

5 Controlling the collection process

As discussed in Chapter 4, the analysis of the current collection process brought forward three issues impacting the collection process. While the results of these issues can be seen in the execution of the collection process (in the form of a low vehicle and order fill rate), the reason for these issues starts with the control of the process. Following the *Delft Systems Approach*, this chapter will provide a framework (in the form of revised PROPER models) to successfully control the collection process.
Figure 5.1 once again shows the PROPER model, now explicitly showing the different relevant control levels. By once again zooming-in into the three different aspect systems and describing the should-be process and its control following the *Delft Systems Approach*, the required information flows will become evident. The required information includes the input of information to a process or function to successfully realizing its objective, as well as the output of information from a process or function in the form of performance measures.

The different control layers operate on different levels. The coordination control operates on a strategic level, answering questions such as which products to offer to satisfy market demands. The other functions work on a tactical or operational level. The *perform* function works on a tactical level by evaluating customer wishes resulting in collection tasks for a longer period of time. However, it should also check to what extent these tasks turn out to be accurate and adjust them accordingly, which occurs on an operational level. The *collect* and *use* function represent the day-to-day collection of parcels and the use of vehicles to do so, making them operational in nature.

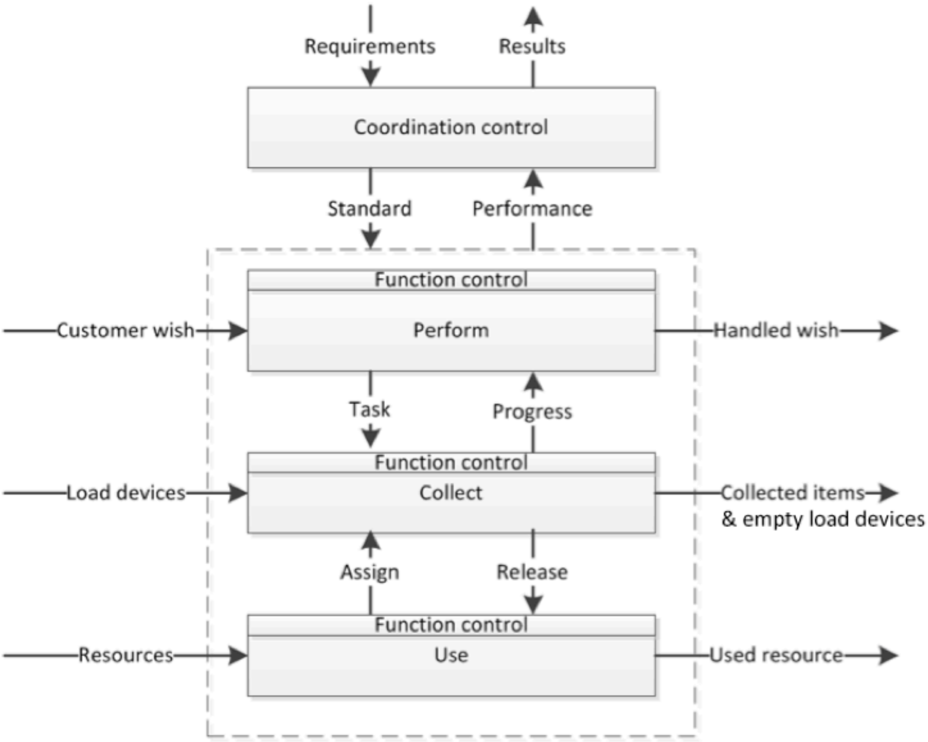

Figure 5.1 – PROPER model including process and coordination control

5.1 Coordination control

The coordination control layer is responsible for translating the *requirements* coming from the environment in which the collecting process operates, into *standards* that the different functions use to control the internal processes. In turn, the *performance* of the different functions is used to reflect on the requirements and provide *results* back to the environment.

The information entering the coordinator control layer are the requirements that are given to the collection process. These requirements come from the environment in which the process is executed. This environment mainly consists of the customers of PostNL having certain requirements when it comes to the collection process, as well as PostNL as a whole. The most important requirement coming from the customers of PostNL was found to be flexibility. One can understand why flexibility might be of importance to a customer, but in order to give shape to it, it is important to further define *flexibility* in this context. When a customer mentions wanting the collection to be flexible, it involves two forms of flexibility:

- Having the collection process be able to deal with a wide range of parameters (most importantly collection volumes) without it impacting the process itself.
- Having a collection process in which changes to these parameters can be discussed and dealt with without too much hassle.

In turn, this also means that PostNL itself requires a form of flexibility. Specifically, having the collection process be able to quickly and easily respond to the flexibility the customer requires without it having a large impact on the operation and its performance.
When reflecting this to what is found in literature, these three forms of flexibility are inline with a number of the elements that define supply chain flexibility as found by Stevenson & Spring (2007) in their extensive literature review on the matter, namely *robust network flexibly, re-configuration flexibility, active flexibility* respectively.

Next to having a collection process that has the ability to respond to the flexibility given to its customers, PostNL has additional requirements to the collection process. In general, PostNL as a whole would require the collection process to function as efficiently as possible while keeping customers satisfied. Next to that, the collection process should not disturb the processes following collection. This means limiting the cost and maximizing the utilization of the resources used in the process while achieving service levels required by the customers and the different departments in charge of the processes following collection.

Based on these requirements, the coordination control sets certain standards to the different functions that should insure that the functions work to achieve the aforementioned requirements. In turn, the functions provide performance measures as an input to the coordination control, making it possible to evaluate to which extent the requirements were met. This results in the output of the coordination control back to the environment; the *results* of the collection process.

5.2 Perform function

Reflecting back on the analysis of the current collection process, the Perform function deals with the customers of PostNL on a tactical level. The input to the function are the collection wishes of the customers which are transformed to eventually a handled customer wish whenever the customer decides to no longer require collection from PostNL. In the meantime, the perform function results in a collection task which will be executed by the different functions. Figure 5.2 shows the revised PROPER model for the perform function.

[redacted]

Figure 5.2 – The *perform* function

The current *perform* function saw a customer wish end up at either the mail or the parcel division, depending on the number of parcels the customer expected to ship in a year. As was stated before however, there is no apparent reason to make this distinction since a collection can simply be seen as a certain volume, to be collected at a certain place, at a certain time, and be brought to a certain destination, regardless of whether the collection is performed by the mail or parcel division. Making a distinction at this point in the process might negatively impact the performance of the collection process (see Section 4.1.1). As a result, the distinction between the mail and parcel division will not be made.

The customer wish first still needs to be translated into a request that can be judged against the possible collection methods and products PostNL decides to offer to its customers. After doing so, a customer wish can be denied if it cannot be met by PostNL. An other option is that a wish can be challenged. This might happen if the request could be made possible in theory, but does not match with the current offerings. In this case further discussion of a customer wish is needed, after which it can still be denied. If this is however not the case, a customer wish can be registered in the appropriate format and enter the "inventory" of all customer collection orders. This inventory of collection orders results in *tasks* that represent the customer wishes and that need to be executed by the other functions.

In a timely manner, the collection orders should however be maintained and updated as necessary. In practice, this means that three different options are possible:

- The collection order is discarded and marked as a handled customer wish. The reason for doing so could be that an existing customer changed its wish. If so, the new wish would flow through the process and when registered as a collection order, the existing order can be marked as handled. Another option would be a customer that no longer wishes to have its parcels collected, also marking the collection wish as handled. In both cases, the update is initiated by the customer.
- The collection order is updated and directly added back into the order inventory. This happens when the changes to the order do not require it to be judged again. For example, orders of which only the volume is changed do not require further judging.
- The collection order is updated after first being judged again. An example when this occurs, might be a customer that changes the items it wants to have collected, or the load devices with which these items are collected.

5.2.1 Information requirements

Given the set-up of the process, information requirements for a number of the transformations in the process become clear. Specifically, four instances in the process require a certain information input in the form of a standard to be set or otherwise, with which the input should be compared.

Translate customer wish

As mentioned before, the goal of translating the customer wish, is to transform a vague customer wish into a set of characteristics which specify the customer wish in terms of parameters.
The control layer sets the standard as to which parameters should be evaluated. These parameters include:

- Collection time window length
- Frequency
- Collection time
- Scans, notifications and information
- Load device used
- Flexibility in arranging/cancelling a collection run
- Pricing policy
- Expected number of items per pickup
- Items to be collected (mail, parcels, both)
- Location for pickup

These points in turn follow from a certain set of requirements, which serve as the information input to the control layer. These requirements are imposed by either the market or are inherent to the process of PostNL. For example, one of the points is the decision for a certain type of load device. While customers will seldom require a specific type of load device, the process following collection necessitates the use of a load device. To the contrary, the amount of flexibility offered to the customer is a requirement following from the market. Having little flexibility is beneficial to PostNL as it helps to plan collection runs and limit cost. However, the interviews with customers of PostNL indicate that flexibility is an import requirement for the collection process.

Judge customer wish

After translating the customer wish, a limited set of customer requirements remain. While PostNL strives to give customers the sense that every collection solution is customer specific, it needs to have a certain number of standardized collection propositions in order to make it operationally feasible. These propositions contain limits for the aforementioned parameters in order for the proposition to be applicable.

Decision as to whether to discuss the customer request

If a customer wish does not match with a given proposition, but is in theory possible to realize, it might be discussed and still made possible. In this case, a collection solution will be (in part) customer specific. In order to make the decision between either denying a customer wish or discussing a customer wish, a certain standard is necessary. This standard contains operational limits within which collection is possible.

Maintaining and updating the collection order

As mentioned, it is important to reevaluate the collection tasks on a regular basis due to changing circumstances at either PostNL (for example changes in the network) or at the customer (for example due to changes in collection volume). Doing so ensures that the subsequent processes are always dealing with the most up-to-date information and that the collection order will closely match the initial customer wish.
In order to do so, a set of standards is necessary that indicates when such a reevaluation should take place. Some of these could be time based (for example, each order should at least be evaluated once a month), or event based (for example, when the difference between realized collection volume and planned collection volume exceeds a certain threshold).

Next to a standard indicating under which circumstances a collection order should be reevaluated, there is a need for information indicating to what extented the collection order matches reality. The most important of which is information regarding the collection volume.

Most parameters describing the collection order do not change on a frequent basis (such as location of the customer, load device used or collection time). One parameter that is however sensitive to change is the collection volume. As was mentioned before, the customers of PostNL notice fluctuations in the volumes they want to have collected, while PostNL uses a fixed value for the collection volume. As a result, there should be information available about both the historic collection volumes, as well as the predicted or expected collection volumes. The need for such information as well as possible sources currently available at PostNL will be addressed in depth in Chapter 6.

5.2.2 Performance measures

Looking at Figure 5.2, it becomes clear that there are two points at which information regarding the performance of the function is desirable.

The first instance is found with the process of discussing a customer request. When a customer request ends up here, there is a disconnect between what PostNL offers and what the customer requires. As a result, it serves as feedback as to what extent the products and operational capabilities of PostNL still match with the requirements from the market. This makes it valuable to know how many customer requests end up being discussed, for what reason, how many of these requests were implemented and what compromises had to be made to do so. Based on this information, the *coordination control* layer can make adjustments to the standards it sets to the different functions (for example, work on adjusting the operating limits of the collection process or providing new collection products to satisfy the demands from the market).

The second instance takes place just before orders enter the "inventory". At this stage, it is possible to gather information about how the customer wishes passed through the function and ended up as a collection order. The measures should provide information as to which extent the standards and the requirements from both the market as well as PostNL as a whole are met.

An important measure would be the amount of time spent to translate the often vague customer wish into a collection task that can be used by the other functions. This is a performance measure typically found of importance in production processes as well, for example when applying *Lean manufacturing* (Bhasin, 2008). In those cases, it is referred to as the *cycle time*, or the time from beginning to the end of a process. Not only that, a similar measure is often used when dealing with the plan cycle in a supply chain process (Gunasekaran, Patel, & McGaughey, 2004), referring to it as the *order cycle time*.
From a customer point of view, the order cycle time shows how easy it is to place a collection order with PostNL. Next to that, it is an indication of the flexibility provided to the customer. As mentioned in Chapter 3, one of the elements of providing *flexibility* is the ease of which changes can be made. The time between a customer wish and a registered collection order is a good indication of this. Not only that, having a short order cycle time is an indication of the efficiency of the process from the perspective of PostNL.

While having a short *order cycle time* indicates the efficiency of translating the customer wish, it does not mean the process was effective as well. In case the collection order does not match close enough with the initial customer wish, the satisfaction of the customer is not guaranteed. As a result, measuring the customer satisfaction with the eventual collection order is of importance to see if the customer wish is actually met. This can again help to make adjustments to the standards and better provide products that match the customer's needs.

Finally, it is worth evaluating and quantifying the actual flow of customer wishes through the function. This approach is also addressed by In 't Veld (1971) when determining required information in business processes. Doing so will indicate the performance of the function on an operational level as well as provide valuable information on the performance of the function from a tactical perspective.

On an operational level, measures should be in place that monitor the quality of the transformation. Important questions to be answered are in this case:

- How many of the collection orders are incomplete (parameters missing)?
- How many of the collection orders are incorrect (parameters not in line with products or operational limits)?

Doing so will ensure that the tasks that result from the collection orders (and thus customer wishes) can be executed without unexpected problems. This is not only important for PostNL to efficiently and effectively run the collection process, it also means that customers will not face problems during collection.

On a tactical level, measuring the characteristics of what comes in and leaves the inventory of collection orders helps to keep track of the market that PostNL is serving with its collection process. It can help to answer questions such as:

- What are typical wishes from the customers?
- What are the characteristics of the group of customers and how do they change?

Having measures in place that answer these questions helps to keep the collection products PostNL offers in line with the wishes of the market and predict how these wishes will change in the months to come.

Next to that, measuring not only the characteristics but also the quantity of collection orders entering and leaving the inventory will help to determine both the current as well as future required collection capacity.

5.3 Collect function

During the problem diagnosis of the current process, the *collect* function did not appear to be a source of issues. However, for the sake of completeness, the *collect* function will be addressed in a similar fashion as the other functions.

The input to the *collect* function are filled load devices. These load devices include roll containers or postal bags. As mentioned before, no formal check whether or not the presented load devices and their contents comply with the standards set by PostNL is performed. While there could be advantages in doing so (such as less interruptions in the subsequent processes following collection), no indication is found that the lack of a formal filter function is required. After receiving the load devices, the subsequent process can remain unchanged from the current process, and can be described as load devices being transported, transshipped (depending on the route), and unloaded at their destination. Figure 5.3 gives an overview of the described process.

[redacted]

Figure 5.3 – The *collect* function

5.3.1 Information requirements

Information requirements in terms of standards are limited for the control and execution of the control function. Actions such as assigning customers to routes and planning the routes themselves are placed within the *use* function. As a result, the information requirements for the execution of the *collect* function is predominantly the route information following from the *use function*. Next to that, a general standard is necessary for the control function that gives requirements to the function as a whole. This could include the requirement that all customers should be collected regardless of the circumstances. By comparing the route information and the general standard to the measures of the actual execution of the collection process (see the next subsection), interventions can be made to the execution of the *collect* function. These interventions are executed by the control room (which are currently operated separately for both the mail or parcels division) and include for example adjusting the routes or notifying customers of delays.

5.3.2 Performance measures

In order to intervene in the process, it is necessary to know the current state of the *collect* function. Currently, a wide range of parameters can be measured during the *collection* process. Drivers are either equipped with a terminal (mail division) or manually register parameters in the *transport information system* (parcel division). These parameters include among others:

- Arrival time at customer
- Throughput time of a collection
- Location of the collection
- Travelled distance
- Time travelled
- Idle time

These parameters are continually measured by the control room and are the basis for deciding on performing any interventions in the execution of the *collect* function.

With regards to the aforementioned general standard, there should be a performance measure leaving the control layer that states the overall performance of the *collect* function.

Most important to include in this are to what extent the mentioned parameters are met as expected and agreed upon with the customers. The most important of which is meeting the time window of collection, which is similar to the typical performance measure of *on time delivery* in a supply chain context on an operational level (Gunasekaran, Patel, & McGaughey, 2004). Furthermore, all other parameters could be include to have a general measure such as the total number or percentage of faultless collections within a time period.

During the customer interviews it became clear that customers are willing to pay for collection so they do not need to worry about their parcels reaching PostNL and thus being successfully shipped to their customers. As a result, the number of faultless collections is an important measure from the perspective of the customer. Not only that, having faults during collection can mean the need for unexpected additional “emergency” collection runs, which are costly for PostNL.

5.4 Use function

Finally, the *use* function is of interest as this function is responsible for assigning vehicles to routes. As stated before, there are currently two different departments responsible for the assignment and planning of vehicles and their routes. Given that each collection task is the same, regardless of the department (a certain volume, needs to be collected at a certain place, within a certain time window, and be brought to a certain location), there is no clear need to split up orders over two departments. As a result, the revised PROPER model shown in Figure 5.4 sees a general process, regardless of the department.

Resources such as vans and trucks are assigned to, and execute a route. After this, the vehicles are “maintained” (which can be anything from refueling and tiding up the vehicle to actual maintenance to the mechanics of the vehicle), before being used again another day. The planning department is responsible for reading and combining the different collection tasks into a number of routes.

[redacted]

Figure 5.4 – The *use* function

5.4.1 Information requirements

As can again be seen from Figure 5.4, a number of processes require the input of information to be successfully executed. The different collection tasks are read and the routes are planned based on certain standards. These standards include the different parameters that are used in the planning software and are already defined by the planning departments and appear to be sufficient. Some examples include:

- Hourly rate per driver.
- Fixed cost per route for each collection vehicle.
- Variable cost per kilometer travelled for each collection vehicle.
- Capacity (both in volume, weight, and number of roll container positions) of each vehicle.
- Average time to load a roll container.
- Fixed time for each stop.
- Optional additional time incurred at each stop.

With this information, the planning software should try to optimize routes as to minimize the cost while not exceeding maximum vehicle capacity as well as making all the time windows as agreed upon with the customer.

However, before being able to plan the routes, there needs to be an input of tasks. This task has to include:

- The volume to be planned for.
- The location of the customer.
- The time window in which collection can take place.
- The destination for the collected volume.
- A customer number.

While the majority of these items follow directly from the translated customer wish, the volume to be planned for is less straightforward. Currently, a fixed volume follows from the customer wish as well, but as was discussed before, these volumes do not accurately represent the actual collection volumes. As a result, the *perform* function should update the expected collection volume on a day-to-day basis and add this volume to the task. This information flow (or the lack thereof) appears to be the main reason for the poor collection accuracy and will thus be addressed in more detail in the next chapter.

Finally, there needs to be a standard for the maintenance of the vehicles. This includes for example the state to which the vehicle needs to be brought after a collection run in order to make it ready for the next collection run. Specific things include where to store the vehicle, how much fuel should be present, etc. Next to that, the maintenance process needs to determine whether or not a vehicle is considered a *used resource* and should be “discarded”.

5.4.2 Performance measures

After executing a collection run, a number of measures should be performed that define the performance of the overall function. The *collect* function already discussed performance measures on a per customer basis, where the focus was mainly on whether or not a collection was performed successfully and within the agreed upon parameters. For the use function, the performance measures should focus on how the different collection stops are combined in a collection run, and to what extent the tasks used to plan the routes are accurate. Two important parameters that are discussed at length already, and serve as the basis for determining how successful the vehicles are used, are the *order fill rate* and the *vehicle fill rate*. While the order fill rate is known for collection performed by the parcel division, it is currently not known for the mail division as collected volumes are not measured, making it impossible to determine the accuracy of the planning. Next to that, combining collection volumes to determine the vehicle fill rate is then impossible as well.

Knowing the order fill rate is specifically important for the parcel division of PostNL as they purchase transport capacity beforehand based on the number of load devices expected to be collected. Having a low order fill rate means incurring cost to collect load devices that are not actually present at the customer. This transport capacity is either purchased at a third party or at the transport department within the parcel division. When doing the latter, the order fill rate is of less importance, but instead the vehicle fill rate will determine how efficient the collection runs are performed.

Finally, not only is the volume realization necessary to determine the order and vehicle fill rate, they are also required to leave the *use* function as an information input for the *perform* function as was discussed before. Based on the realized volumes, the *perform* function can update the collection tasks, which in turn serve as the input for the *use* function.

6 Improving planning accuracy collection volume

The previous chapter addressed the way in which the collection process should be controlled and which information flows are required to do so. This chapter will address the most important input of information that is currently lacking in the collection process and address possible ways of acquiring it; an accurate and up-to-date estimation of the expected volume to be collected.

First, the data regarding the current difference between planned and actual volumes will be complemented by measuring the collection volume of customers being collected using the mail service, as data is currently lacking for these collections. Next, approaches to predicting the expected volume to be collected are discussed as well as the information currently available at PostNL that could be, but is not currently used for this purpose. Two of these information sources are further addressed by testing their applicability. This is done by applying it to a number of collection orders using historical data over a number of months.

6.1 Collection performance mail division

As was mentioned before, the realized collection volumes at the mail division are currently not measured with a sufficient level of accuracy. However, in order to quantify the possible gains of being able to predict the actual collection volumes with greater accuracy, the realized volumes need to be known for the mail division as well.

To achieve this, a manual sample of the collection volumes in the region of Zwolle for PostNL is taken. The reason for choosing this region is the fact that Zwolle houses both a mail depot (SCB) as well as a parcel depot (NLI). For this sample, all customers that have a planned collection volume of one roll container or more are measured for a week. The reason for only measuring these customers is that measuring all collection volumes would possibly impact the collection process too much. Next to that, it is assumed that the larger the collection volume of a customer, the larger the impact of knowing their volume will be.

Table 6.1 gives an overview of the characteristics of the sample. While the majority of pickups is measured, there is still a large number of stops missing. This is due to changes to the routes. The drivers were given a form showing the relevant customers. These forms were made a week before the execution of the routes based on the expected customers per route. However, changes to the routes meant that not all relevant customers were present on the form for the specific route the customer belonged to. Next to that, the forms for nine routes were not filled out at all. This can be due to changes in the name/number of the route, meaning that those specific forms were not handed out at all.

Percentage of pickups measured		[redacted]
Number of pickups measured		[redacted]
Percentage of customers completely measured		[redacted]
Number of customers completely measured		[redacted]
Number of trips measured		[redacted]

Table 6.1 – Overview of sample Zwolle

While a sample of just five days is limited, it is still worth noting the results of the measurements. Table 6.2 as well as Figure 6.1 show the most important results of the sample. While the deviation between planned and realized volume appears smaller than predicted in Section 3.3.2, the realized volumes are on average still lower than the planned volumes. Next to that, a distinction is made between retail locations and collection customers. This shows that the performance for both is comparable, but that the retail locations represent more volume than the collection customers. Next to that, it appears that the total performance is roughly the same day to day. However, it appears that collection volumes for collection customers are high on Mondays (probably because of the peak following from the weekend before) while they are high on Fridays for retail location (the reason of which is unclear).

Description	Sample size	Average order size (equivalent roll containers)	Average realization (equivalent roll containers)	Average absolute deviation (equivalent roll containers)	Deviation from planned
Total	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Retail location	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Collection customer	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 6.2 – Difference between PostNL retail location and collection customer

[redacted]

Figure 6.1 – Overview of the collection performance for the sample

6.2 Predicting collection volumes

The volumes as they are collected every day is considered a time series as they are *a collection of observations made sequentially through time* (Chatfield, 2000, p. 1). A large number of techniques can be found in literature to forecast the future values of such time series. These range from simple techniques such as using a moving average to more advanced techniques such as exponential smoothing (see for example the Holt-Winters method (Chatfield, 1978)). However, these techniques rely on contributing the variation in the time series on the presence of a trend or seasonal behavior (Chatfield, 2000, p. 13). However, while there might be a long-term trend in the ever-increasing number of parcels people order online, the day-to-day volumes per customer do not appear to follow a specific trend. This became clear during the interviews were customers noticed the strong fluctuation in collection

volume as well. This is confirmed by looking for example at the collection volumes as shown in Figure 3.11.
As a result, instead of directly forecasting the collection volumes based on historic volumes, alternative information sources available at PostNL are investigated for their predictive value when it comes to collection volumes.
Although there is currently no process in place that uses alternative information sources, there is information available that might serve this purpose. By scanning the parcels with most steps in the parcel fulfillment process and measuring volumes for a large number of customers, there is a wide variety of information available. The remainder of this section will address information that is currently available, and indicate to which extent or under which circumstances this information is suitable as an input to the collection planning process.

Pre-shipping notifications

As mentioned in Chapter 2, pre-shipment notifications are generated by the customers of PostNL when sending a parcel. Included in this notification are the details of the receiver such as name, address and country, as well as information about the shipper which is necessary to bill the shipper when the parcel is send. Most importantly however, the notification includes the barcode of the label that will be put on the parcel. As a result, the notification links the barcode (which is physically present on the parcel) to all information behind the parcel.

PostNL requires all parcels to be collected to have a barcode. As a result, parcels that are shipped will be notified before collection takes place. However, there are no guidelines as to when the notification should be made. While it is possible for a customer of PostNL, for example a webshop, to notify PostNL the moment the webshop receives an order, not all customers of PostNL do so. Some will continuously send out notifications as orders come in, while others might wait for a number of orders and send out pre-shipping notifications in batches. Finally, some customers might wait until just before collection to notify all parcels to be sent out that day. As a result, pre-shipping notifications cannot always be used as an indication of the number of parcels and thus load devices PostNL can expect to collect at a customer.

Acceptation scans

When a parcel physically arrives at a PostNL location, it will receive an *acceptation scan*. This is the first time data is available that gives the locations and dimensions of a parcel with some certainty. Usually, this scan takes place when parcels are unloaded at an NLI, marking the end of the collection process (as mentioned in Chapter 2). As a result, in these cases the acceptation scan cannot be used in the collection process.
However, when for example a consumer sends a parcel, the acceptation scan takes place at one of the retail locations of PostNL. As mentioned in Section 2.2.1, from a collection perspective, these retail locations act as customers as well. As a result, acceptation scans performed at retail locations can serve a similar purpose as the aforementioned pre-shipping notifications.
Next to that, acceptation scans are always performed at the time a parcel is received at the retail location. Furthermore, the scan data is sent to the central information system every 10 to 15 minutes. As a result, acceptation scans could prove to be more reliable than pre-shipping notifications.

Server calls

While pre-shipping notification can give a good indication of how many parcels are ordered at what moment in time, it is still up to the customer of PostNL to translate a consumer order to a pre-shipping notification. While there is no way for PostNL to know when its customers receive orders from consumers, it is still possible to get an indication based on the number of *timeframe server calls*.
Whenever a consumer orders something at a webshop that uses PostNL to ship parcels, the consumer often gets presented some information that the webshop automatically requests from PostNL. For example, a consumer might see a map showing the nearest pickup locations

to the consumer's address. This information is not stored at the webshop, but is requested and sent from the IT systems of PostNL. This request for information is referred to as a *server call*. It is in theory possible for PostNL to track the number of such server calls coming from each customer, which can then be used as an indication of the number of orders (and thus volume) PostNL can expect to have to collect.

There are however a number of remarks to be made when considering this method:

- Server calls to present information regarding pickup locations or time windows in which delivery can occur, are received by PostNL before a consumer pays for his or her order at the webshop. As a result, it is very well possible that a consumer does not follow through with the order, despite having a server call being sent to PostNL.
- Not every customer of PostNL that uses collection is a webshop and thus not every customer makes server calls to PostNL. Next to that, not every webshop uses the option to show for example pickup locations or time windows in which delivery can take place.
- In order to translate the number of server calls to an expected number of load devices requires a lot of different steps, possibly making any results highly inaccurate.

As neither further information about these remarks nor an overview of server calls per customer is currently easily accessible, the use of server calls to predict collection volume will not be addressed further in the remainder of the research.

6.3 Using pre-shipping notifications

This section will address a prediction model based on the number of pre-shipment notifications or acceptation scans received by PostNL at a certain time of the day.
The prediction model is investigated using two customers known to be sending pre-shipment notifications on a continuous basis. Table 6.3 provides an overview of the key characteristics of the two customers under investigation.

	Customer #1	**Customer #2**
Type of products	Bedclothes	Dental hygiene
# of Parcels in 2015	44.430	19.142[3]
Collection type	Parcel division	Parcel division
Collection time window	22:00 – 22:45	18:00 – 18:30

Table 6.3 – Customer information

6.3.1 Calculation steps

The goal of the prediction model is to translate the number of received pre-shipping notifications ("voormeldingen", or VM's) into the expected number of load devices. Doing so requires three different steps:

- The number of VM's received needs to be extrapolated to the total number of VM's expected to be received just before collection.
- The total number of expected VM's needs to be translated into the total number of expected parcels.
- Finally, the total number of expected parcels needs to be converted into a number of expected load devices.

This approach is similar to the one followed by Chambers & Eglese (1988), where it is applied to predicting the demand for mail order catalogue fashion products.

Figure 6.2 gives a schematic overview of the calculation steps from received notifications to expected load devices.

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[3] Only started shipping parcels with PostNL in August 2015

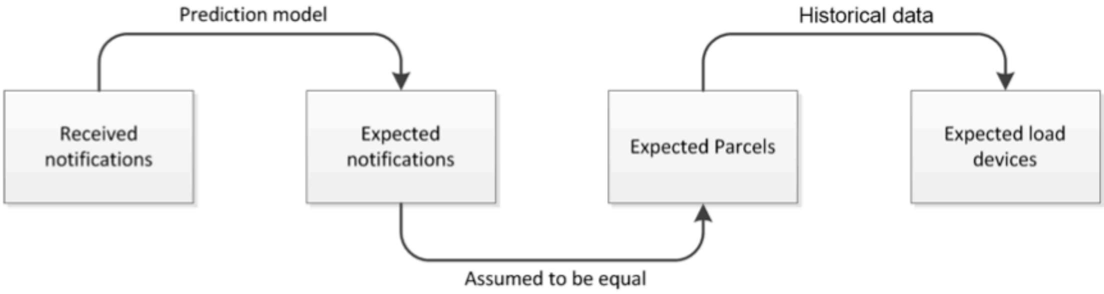


Figure 6.2 – Calculation steps from notification to load device

Received notifications to expected notifications

The first step is to translate the number of received pre-shipment notifications into the total number of expected notifications at the end of the day. As mentioned before, not all customers send out pre-shipment notifications throughout the day. The two customers under investigation in this section are however select since they do send out notification on a continuous basis.

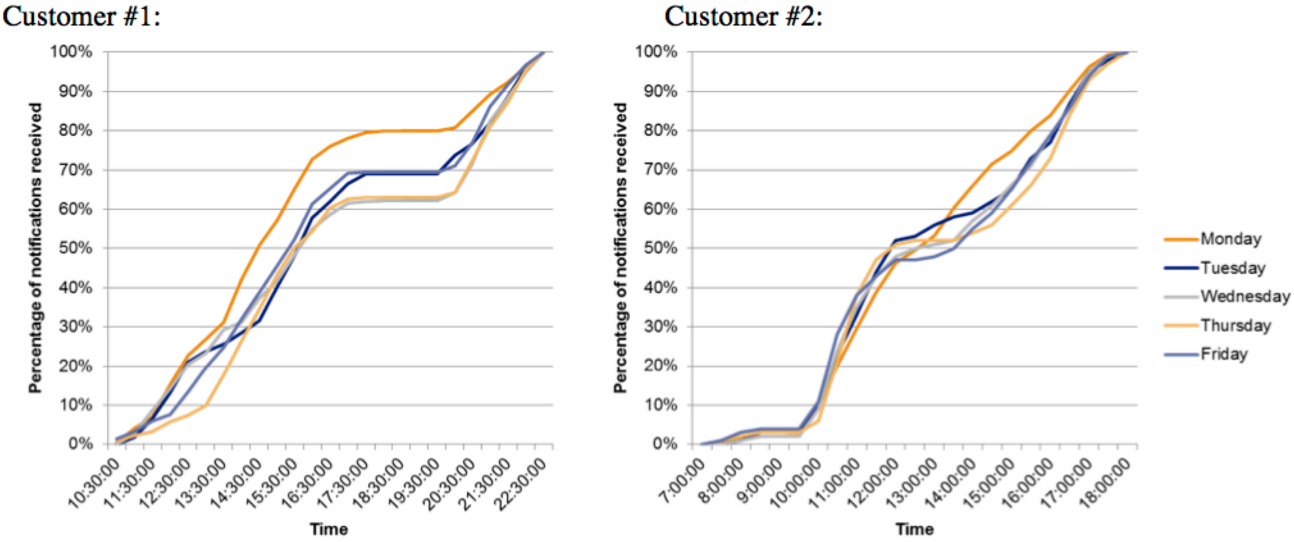


Figure 6.3 – Pre-shipping notifications as received throughout the day (per day average over three months)

Figure 6.3 shows how the pre-shipping notifications are received throughout the day. Looking at the figure, it becomes clear that on Mondays, more notifications are received at an earlier time. The explanation for this is similar to the one given in Chapter 2 as to why more parcels are received on a Monday compared to the other days; consumers will continue to place orders at webshops during the weekend which need to be handled on Monday. As a result, it is expected that customers of PostNL will start on Monday with notifying shipments that were ordered over the weekend, before notifying shipments as they are ordered throughout the remainder of the day.

The customer-specific distribution of notifications throughout the day is used as the input for the prediction model following:

$$VM_t^{Expected} = \alpha \cdot VM_t^{received}, \text{ with } \alpha(t,c) \tag{2}$$

Or, the expected total number of pre-shipping notifications at time *t*, equals the number of pre-shipping notifications received at time *t* multiplied by a factor $\alpha(t,c)$ which follows from the distribution of notifications throughout the day, which is thus both time as well as customer (*c*) dependent (Chambers & Eglese (1988) refer to this distribution as the *trend profile*, which in their case is product category dependent).

It goes without saying the closer time *t* is to the collection time, the more accurate the prediction of the total number of pre-shipping notifications. Figure 6.4 shows the accuracy of the prediction as a function of the time (in this case, the number of hours before collection occurs). Furthermore, a distinction is made between using a distribution independent of the day, a specific distribution for Mondays vs. every other day, and a distribution dependent on the day.

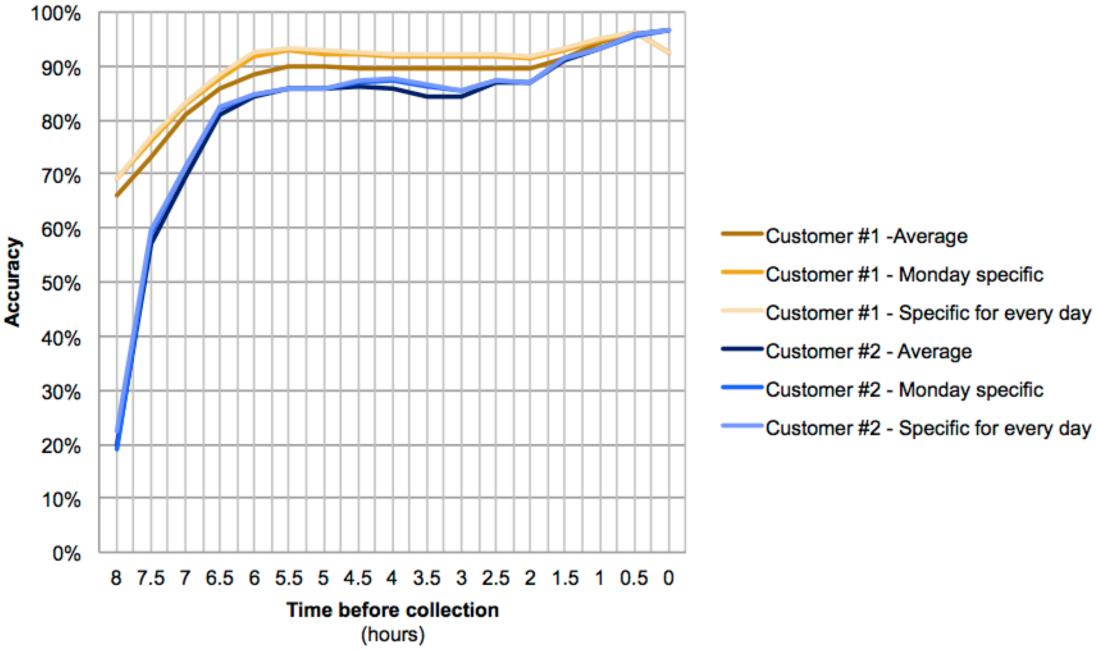


Figure 6.4 – Prediction accuracy (notifications to parcels) as a function of time before collection

As expected, the accuracy will become higher the closer before collection one measures. However, at roughly five hours before collection, the accuracy is already greater than 80%, which means that it should be operationally feasible to take the prediction into account when planning vehicles. Furthermore, the accuracy of the prediction increases as the distribution is more specific, as one would expect. Differences are however small, and the biggest improvement is gained when using a specific distribution for only the Mondays versus using a not-day-specific distribution (see Table 6.4).

Average accuracy	**Not-day-specific**	**Monday-specific**	**All-day-specific**
Customer #1	78,98%	80,59%	81,27%
Customer #2	80,74%	81,46%	81,79%

Table 6.4 – Average accuracy for the different distributions

Expected notifications to expected parcels

The next step in determining the expected number of load devices, is to predict the number of expected parcels based on the number of expected pre-shipping notifications.

Although it is possible for a customer to send a shipping notification for a parcel that will not be presented for collection the same day, it is not common for customers to do so. Usually, they communicate next-day delivery to the receiver of the parcel, meaning that it is necessary to have the parcel collected on the same day as the order comes in.

Table 6.5 shows the accuracy of translating the number of notifications to the number of parcels for that same day. For example, an accuracy of 100% means that the number of notifications was equal to the number of parcels sorted on the same day. Given the high accuracy and the aforementioned explanation, the assumption is made that the number of expected pre-shipping notifications will equal the number of expected parcels.

	Customer #1	**Customer #2**
Accuracy notifications to parcels	98,22%	94,91%

Table 6.5 – Accuracy notifications to parcels

Expected parcels to expected load devices

The final step is determining the expected number of load devices based on the number of expected parcels. Doing so requires information regarding the size of the parcels and thus the average number of parcels that fit a roll container. Figure 6.5 shows the distribution of the number of parcels per roll container for the two customers. As one would expect, the customer shipping bedclothes will fit less parcels into a roll container than the customer shipping dental hygiene products. While the number of parcels per roll container seems to be somewhat normally distributed for both customers (on average around 35 parcels per roll container for customer #1 and 65 for customer #2), the deviation is large, making it difficult to predict the number of parcels per roll container. As a result, the number of parcels per roll container is kept as a variable, along with the time at which the current number of pre-shipping notifications received is measured.

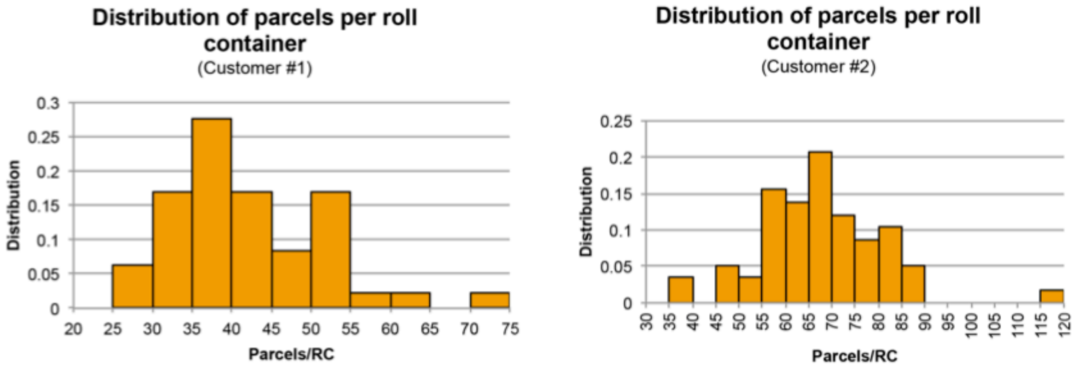


Figure 6.5 – Distribution of the number of parcels per roll container

6.3.2 Results

Following the approach presented in the previous chapter, the performance of the prediction model will be tested for the two customers based on a number of months of historic data. The predicted number of roll containers will be compared to the planned and realized number of roll containers over the measured months. The performance of the model will be measured and compared to the planned volumes using:

- **The average difference between the planned/predicted and realized number of roll containers (i.e. the planning accuracy)**
  This measure represents the interest of PostNL. The lower the difference between planned/predicted volume and actual volume, the less transport capacity needs to be purchased or arranged.

- **The number of occurrences where a customer presents more volume than was planned**
  From the perspective of the customer, the key measure with regards to the accurate planning of the collection, is the number of times the customer has more volume than was planned for. It must be noted that this does not always mean a customer cannot

have all his roll containers collected. It is very well possible that a vehicle run cannot be planned to full capacity. However, it is possible that underestimating the volume can lead to insufficient vehicle capacity, resulting in a discussion with the customer whether or not all roll containers can be collected.

- **The required number of roll containers for collection over the period under investigation**
  While it is interesting to know how many roll containers can be saved by improving the planning, a large reduction in roll containers is not always desirable. For example, planning zero roll containers for every collection run will result in the highest possible number of roll containers to be saved. However, it goes without saying that this does not result in a satisfactory collection process from both the perspective of PostNL (very low planning accuracy) and the customer (high number of occurrences of exceeding capacity).

- **Average order fill rate**
  The average order fill rate is another way of describing the planning accuracy, as was introduced in Chapter 3.

Customer # 1

Figure 6.6 and Table 6.6 show one of the possible results for Customer #1. In this case, the time of measuring the pre-notifications is set at 16:00, or 4 hours before collection. The number of parcels per roll container is varied and set at the value resulting in the smallest average deviation between predicted and realized.

[redacted]

Figure 6.6 – Results for customer #1 (measured at 16:00, or 4 hours before collection)

	Prediction – 36 parcels/RC
Difference planned/predicted vs. realized volume	[redacted]
Occurrences of exceeding planned/predicted capacity	[redacted]
Required number of RCs	[redacted]
Average order fill rate	[redacted]

Table 6.6 – Results for customer #1

The results show that using the prediction model for this measuring time makes it possible to improve the planning accuracy by [redacted]%, resulting in a reduction of transport capacity of [redacted] roll containers to be purchased or planned. Furthermore the number of times the customer of PostNL is possibly confronted with insufficient vehicle capacity is reduced by one occurrence.

It is however worth noting that it turns out that the performance of customer #1 is not typical. The customer is experiencing strong growth, resulting in underestimated planning volumes in the month of July (which is atypical compared to what was found and discussed in Chapter 4). As a result, the reduction in the required number of roll containers is limited as the number that was planned was already low. Furthermore, while the number of occurrences of exceeding the planned/predicted volume decreased, it might still be higher than desirable. Finally, while the average order fill rate improved when using the prediction model, it was already high.

Customer #2

The results for Customer #2 are more in line with the observations found in Chapter 3. Figure 6.7 shows (among other things) the fixed planning volume exceeding the actual volume on all but two occasions. The prediction model is again applied, but now using two different values for the average number of parcels per roll container.

[redacted]

Figure 6.7 – Results for customer #2 (measured at 15:00, or 3 hours before collection)

	Prediction (1) – 74 parcels/RC	**Prediction (2) – 50 parcels/RC**
Difference planned/predicted vs. realized volume	[redacted]	[redacted]
Occurrences of exceeding planned/predicted capacity	[redacted]	[redacted]
Required number of RCs	[redacted]	[redacted]
Average order fill rate	[redacted]	[redacted]

Table 6.7 – Results for customer #2

The first prediction uses [redacted] parcels per roll container and results in the lowest difference between predicted and realized volumes (see Table 6.7, including the results for the other measures). However, when doing so, the number of occurrences of customers presenting more volume than planned/predicted sharply increases (from [redacted] to [redacted] occurrences). This is no surprise given that when trying to plan as closely to the expected volumes as possible, the chance of the actual volumes to slightly exceed the planned volume, is higher than when planned volumes are typically overestimated (as currently is the case).

When striving to keep the number of occurrences at the same level as currently is the case, the best results are achieved when using [redacted] parcels per roll container in the prediction model (see Appendix II for an overview of the results for different values for the number of parcels per roll container). In this case it is still possible to improve the accuracy by [redacted]% and reduce the number of roll containers by [redacted]%.

6.4 Using acceptation scans

As mentioned in Section 6.2.2, there is an alternative to pre-shipping notification that can be used to predict volumes for retail locations; acceptation scans. Based on the limited information regarding actual collection volumes that was gathered for the region of Zwolle, a similar approach can be applied and tested for acceptation scans. Since the approach is similar to the approach of using pre-shipping notifications, details of the analysis will be excluded here, and can be found in Appendix III.

6.5 Applicability of prediction model

While the previous sections showed positive results for the two customers under investigation, there are some remarks about the applicability in general. For the use of pre-shipping notifications, the main criterion is the way in which a customer sends them. For the prediction to work, the pre-shipping notifications should be send consistently, meaning that the pre-shipping notification is sent within a reasonable time after the customer of PostNL knows that a parcel is expected to be collected (so in the case of a webshop, when a customer orders and pays for an order). Next to that, for customers that use the collection service predominantly for the collection of mail, a different form of information is required as there is no equivalent of pre-shipping notifications for mail. Also, customers having multiple collections per day require further investigation as having multiple collections per day make it difficult to assign parcels to a specific pickup. Finally, it is worth noting that there is currently no overview available of which customers do or do not consistently send pre-shipping notifications, hindering implementation of such a prediction model.

The use of acceptation scans as a source of information to predict the actual collection volumes did not prove to be useful for the small sample for which it was tested. However, further investigation is required to determine if this is always the case. Looking into the effect of mailbox parcels and additional collection performed by distribution drivers could help improve the accuracy as well.
Table 6.8 gives an overview for which customer cases the presented approach is applicable.

Applicable	**Not applicable**	**Further investigation required**
Customers being collected by the parcel division that consistently send pre-shipping notifications.	Customers predominantly shipping mail.	Customers having multiple pickups per day.
Customers being collected by the mail division that predominantly ship parcels and consistently send pre-shipping notifications.	Customers predominantly shipping parcels but who do not consistently send pre-shipping notifications.	Retail locations, based on the acceptation scans.

Table 6.8 – Applicability of the presented approach

7 Simulation model collection process

In this chapter, a simulation model will be presented that can be used to quantify the impact of changes to the way the collection process is arranged. Currently, collection volumes are often overestimated. By doing so however, vehicles are less filled than planned for. Next to that, different sets of customers are planned by different planning departments, depending on whether a customer makes use of a collection product offered by the mail division or the parcel division.

It can be expected that combining all customers into a single planning set and having more accurate collection volumes to plan with means being able to combine more customers in a single vehicle, thus reducing the total number of vehicles and divers needed. This in turn reduces the collection cost. However, this does not necessarily have to be the case since collection is bounded by time windows. For example, a vehicle with a capacity of six roll containers now collects two customers both having a planned collection volume of three roll containers. It turns out that in practice, both customers have an actual collection volume of two roll containers. This means that the vehicle can collect a third customer having a volume of two roll containers or less. However, this is only applicable if the time window of the third customer fits with the time window of the other two customers. Next to that, the additional travel distance of reaching the third customer has to be small enough that it is cheaper to add the third customer to the existing vehicle instead of having a dedicated vehicle collecting the third customer.

The main cost drivers for the collection runs are the kilometers travelled (fuel cost, vehicle wear) and the number of vehicles used in a day (capital expenditure, driver wages, and depreciation of vehicles).

By modeling the collection process and applying it to different sets of customers using different sets of vehicles under different planning algorithms and values for the planning accuracy, insights can be gained in the impact of these factors on the aforementioned cost drivers.

7.1 Model description

In order to represent the collection process, a total of three different *classes* are required to be simulated; the customers, the vehicles, and an overarching planning entity that assigns customers to vehicles or vice versa. This subsection will describe these three different classes and where applicable, their process.

7.1.1 Customer class

Each customer is represented by a *customer class* element. This element contains the following variables:

- **A plan volume and actual volume**
  The plan volume of a customer is the volume for which the collection run is planned. Depending on the planning accuracy used, the plan volume and actual volume might be different. In case a customer is visited but not successfully collected, the plan volume is updated to the actual volume since at this time, the collection volume is known to PostNL.
- **A location**
  The location of a customer is represented by a simple X and Y coordinate relative to the depot (which is always located at 0-0). Doing so makes it possible to quickly calculate the distance and expected drive time between different customers. This means however that the simulation model does not take into account the layout of the road network.
- **A time window**
  The time window in which collection should take place is represented by the simulation time at which the time window starts and ends. The start of the time window can be

randomly selected, whereas the time window length (and thus the end of the time window) is determined by the user of the simulation.

Next to the variables mentioned before, there are a number of variables used for the successful execution of the simulation program. These variables can be found in Appendix IV.

7.1.2 Assigner class

In order to plan customers to vehicles, an element of the class *assigner class* is created at the start of the simulation. The assigner class contains the following queues:

- **Assign Queue/Temporary Assign Queue**
  The assign queue is a queue in which all the customers that need to be assigned to a vehicle are placed. In order to sort customers based on different parameters, a temporary assign queue is also created to temporarily move customers to, before moving them back to the assign queue sorted based on a certain parameter.
- **Vehicle Idle Queue/ Vehicle Busy Queue/ Temporary Vehicle Queue**
  The vehicle queues contain all the vehicles used in the simulation. Whenever vehicles are being assigned tasks, they are placed in the Idle Queue. After the planning round is completed, all vehicles are moved to the Busy Queue where they remain until replanning is necessary. During the (re)planning process, it is necessary to sort vehicles based on different parameters. To this extented, there is also a temporary queue for vehicles.

Next to that, the *assigner class* has a number of variables. These include “MyCustomer” and “NextCustomer”, both of type *customer class* used to apply changes to specific customers. Finally, a number of additional variables are again used for the successful execution of the simulation.

Assigner class process

Next to a number of variables, an *assigner class* element also has a process that is executed when the element is started. The main goal of the assigner class process is to generate the routes for the different vehicles. Doing so means finding a solution to a variant of the *vehicle routing problem* (VRP), a well-researched integer programming problem that tries to find the optimal set of routes for a group of vehicles (an extensive introduction and overview to the VRP is given for example by Toth & Vigo (2014)). The variant in question is one where the classic VRP is extended by including a *time window* constraint (VRPTW) (Toth & Vigo, 2014, p. 119). The biggest challenge in solving any VRP is that it is NP-hard, meaning that solving it to optimality is a very computational time-intensive task. When trying to solve to optimality, an exact algorithm such as *branch and cut* is typically used (Mitchell, 2002), which combines a *branch and bound* algorithm (Land & Doig, 1960) with the *cutting planes* method (Gomory, 1963). However, for larger sized problems, applying such an algorithm is still a too time-intensive task. For example, the planning system of PostNL that uses such an algorithm to plan collection routes needs multiple hours to find a solutions that is deemed close enough to optimality to be used. Given that the goal of the simulation is to quickly evaluate different collection scenarios, building routes using an exact algorithm is not desirable. Instead, the simulation will use a heuristic to build a feasible route. A large number of different heuristics can be used to find a solution to the VRP (see for example (Ropke, 2005)). For this research, two variants of the *nearest neighbor algorithm* are used. While it does not necessarily provide a route that is close to the optimal solution, it is deemed to find acceptable routes, is simple to implement, and can quickly produce a feasible route for a large number of customers (Gutin, Yeo, & Zverovich, 2002). Given that the simulation is used to compare scenarios and not to find the best possible collection route or to compare a simulation solution to one found using the current planning system at PostNL, it is deemed acceptable to rely on a nearest neighbor heuristic.

The assigner has two main (re)planning strategies that can be selected by the user. The first is a parallel route building heuristic where different routes are build up simultaneously, while the second one is a sequential one where a vehicle route is finished before building the next one (Solomon, 1987).

1. **Plan vehicles to customers**
   When using the first planning strategy, the customers are sorted on the end of their time window (earliest first), and the first customer is selected. Then, the vehicle closest to the customer that has sufficient capacity left is selected and the customer is added to the Task Queue of the selected vehicle. The assigner then updates the planned location of the vehicle to the location of the customer, subtracts the planned volume of the customer from the planned free capacity of the vehicle and updates the expected idle time of the vehicle to the time at which the customer is collected (including the expected handling time at the customer). The next customer in the Assign Queue is then selected and the process will be repeated until all customers are assigned to a vehicle (resulting in a successful planning) or until there are no vehicles available for the customer (resulting in an "insufficient vehicles created" error).
2. **Plan customers to vehicle**
   When using the second planning strategy, the process is reversed, starting with the vehicle and planning customers to its route. The vehicles are sorted on idle time (earliest first), and the first vehicle is selected. Next, the customers are sorted on distance to the vehicle's location and the first customer is selected. If there is sufficient capacity available in the vehicle, and the customer can be reached before the end of the time window, the customer is added to the task queue of the vehicle. If not, the next customer in the assign queue is selected. After adding a customer to the task queue of the vehicle, the vehicle parameters are updated (plan location, idle time, and planned free capacity) and the customers in the assign queue are sorted relative to the new location of the vehicle. Again, the first element in the assign queue is selected and the process repeats itself. When there are no more customers that can be added to the vehicle, the next vehicle in the vehicle idle queue is selected and the process starts from the top again. This is repeated until all customers are assigned to a vehicle (resulting in a successful planning) or until there are no vehicles available to the customer (resulting in an "insufficient vehicles created" error).

While the above description describes the planning process during the first planning round, there are small changes when using the strategies for replanning tasks.

First, the time window constraint is dropped when replanning, thus simply assigning the closest vehicle to a customer or vice versa. However, to ensure that a vehicle is not assigned too many customers, resulting in the last customer being collected far outside of its time window, a limit can be placed by the user on the expected time with which the time window is exceeded. When doing so, the algorithm will assign a customer to the next to nearest vehicle (or vice versa) if necessary.

Next to that, the simulation user has a choice when it comes to the free capacity required for a customer to be assigned to a vehicle or vice versa. The first option is to only do so when the vehicle has enough free capacity to collect all of the planned volume of the customer. The second option will assign a vehicle to a customer or vice versa if there is any free capacity available in the vehicle, possibly resulting in another replanning later on.

A schematic overview of the decision steps mentioned before is also shown in Figure 7.1.

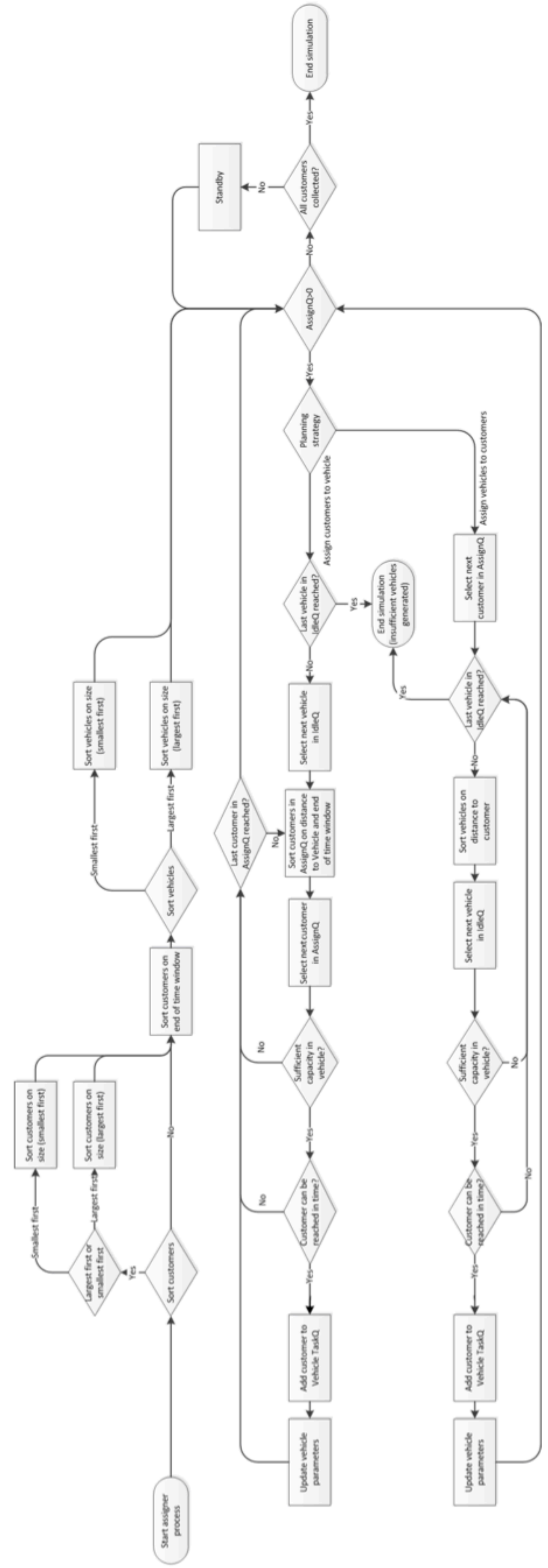


Figure 7.1– Overview of the *assigner class* simulation steps decisions

7.1.3 Vehicle class

The vehicles used to collect load devices at customers are represented by the *vehicle class*. This class contains the following queues and parameters:

- **Task Queue**

  The task queue contains customers that are planned to be collected by the vehicle and are ordered based on which customer is to be collected first.
- **Location (planned and actual)**

  Similar to the customers, the location of the vehicle is represented by an X and a Y coordinate. Next to an actual location, each vehicle also has a planned location. This location represents the location of the vehicle at its idle time. It is used during the planning process and is restored to the actual location after completing the planning.
- **Capacity**

  The capacity of the vehicle is expressed as an integer value for the maximum number of load devices (in the case of the simulation roll containers) that can be carried at once.
- **Free capacity (planned and actual)**

  The free capacity of the vehicle represents the number of roll containers that can still be collected by the vehicle. There is again a distinction between actual free capacity and the planned free capacity. The planned free capacity is the capacity still available in the vehicle at its idle time, while the actual free capacity represents the current free "physical" capacity.
- **Idle time**

  The idle time represents the simulation time at which the vehicle is expected to be available for a next collection. This idle time is both changed during planning (and is restored to the previous value after planning is complete) as well as during execution. Figure 7.2 clarifies the changes made to the idle time during planning and execution.

Figure 7.2 – Changes to the idle time during planning and execution.

  During the planning process, a customer (*customer 1* in Figure 7.2) is added to the task queue after which the idle time is updated to the expected simulation time at which this customers is collected. Based on this idle time, the next customer is then planned (*customer 2* in Figure 7.2). After planning is completed, the idle time is reset to zero. During the execution, the idle time remains at zero until a vehicle starts driving to the first customer (this is done so that the vehicle and its customers can still be replanned if necessary). When the vehicle starts driving to the first customer, the customer is locked to the vehicle and the idle time is updated to the time after the collection is expected to be completed. This is repeated for the second customer. If the vehicle reached its capacity after collecting the second customer, the vehicle returns to the depot and the idle time is updated to the arrival time at the depot.
- **Speed**

  As the name suggests, the speed represents the number distance steps a vehicle can travel in one time step.
- **Vehicle control**

  The vehicle control is an integer value that determines the behavior of a vehicle at a customer when the actual collection volume exceeds the free capacity. If the vehicle control is set to 0, no volume is collected at the customer and the customer is moved back to the assign queue to be replanned. If the vehicle control is set to 1, the vehicle collects as much volume as possible at the customer and returns to the depot. The actual and plan volume of the customer is updated to the remaining volume that still needs to be collected and the customer is moved to the assign queue for replanning.

Again, a number of additional variables is used to ensure the proper working of the simulation model.

Vehicle class process

The *vehicle class* process starts with the vehicle standing-by while the task queue is empty. When customers are added to the task queue, the first customer in the task queue is selected and the drive time to this customer is determined. Next, the vehicle will wait until the moment to start driving to the customer. In the meantime, the drive time to the first customer in task queue is periodically reevaluated. In case a replanning took place, it is possible that a different customer is occupying the first position in the task queue.

If the moment arrives that the vehicle will drive to the first customer in the task queue, the customer is fixed to the vehicle (meaning it cannot be replanned), the vehicle parameters such as the idle time, planning location and planned free capacity are updated, and the vehicle will hold the drive time.

At the customer, two scenarios can occur:

- **The actual collection volume exceeds the free capacity in the vehicle**

  When the free capacity of the vehicle is not sufficient to collect the actual volume presented by the customer, either as much of the collection volume as possible is collected or the customer is directly replanned (depending on the vehicle control mentioned before). Based on the vehicle control method, the vehicle then returns to the depot or stands-by until another customer is assigned to the vehicle.
- **The actual collection volume is less than or equal to the free capacity**

  When the free capacity exceeds or equals the actual collection volume, the customer is removed from the simulation, the vehicle parameters updated (free capacity, location, etc.), and the next customer in the task queue is selected (or the vehicle stands-by incase there are no customers in the task queue).

The described process is repeated until the simulation is stopped. A schematic overview of the decisions in the vehicle simulation process is shown in Figure 7.3.

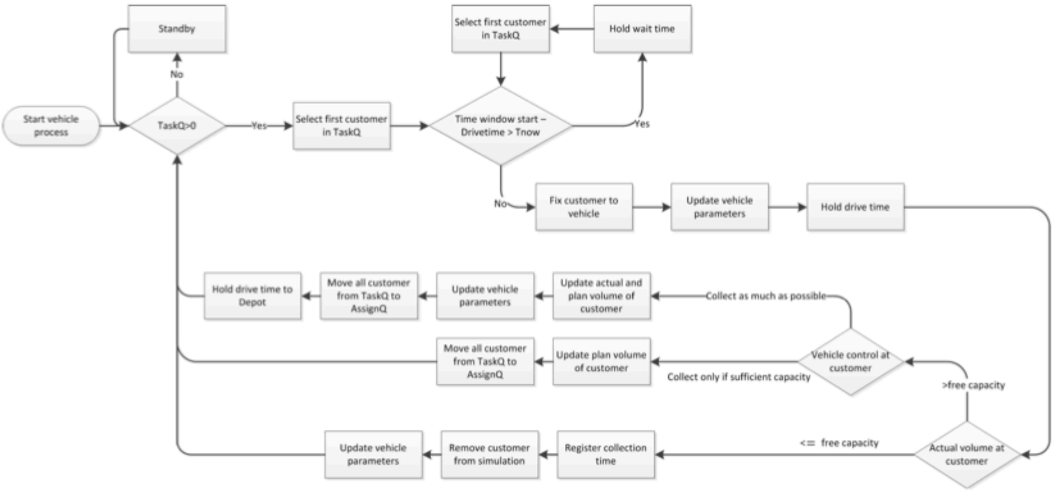


Figure 7.3 – Overview of the *vehicle class* simulation steps

7.1.4 Program Description Language

The main processes described in the previous section can also be expressed using *program description language* (or PDL); a pseudocode description of the process as they would be programmed in a simulation or development environment. The PDL for the *assigner class* and *vehicle class* can be found below.

```
Assigner class process
Sort customers and vehicles if applicable
If sort customers is true then
    Sort customer on planned collection volume.
Sort vehicles on capacity.
Select the first vehicle.

First round of planning
While not all customers assigned to a vehicle
    If using the first planning strategy
    If assigning vehicles to customers then
        Select first customer to be planned.
        Sort vehicles on distance to customer.
        Select the first vehicle.
        If planned free capacity of vehicle >= planned volume of customer & customer can be reached before the end of the time window then
            Assign vehicle to customer.
            Update vehicle parameters.
        Else
            Select the next vehicle closest to customer.
    If using the second planning strategy
    If assigning customers to vehicles then
        Repeat for each customer
            Sort customers on distance to the vehicle.
            Sort customers on end of time window.
            If planned free capacity of vehicle > planned volume of customer & customer can be reached before the end of the time window then
                Assign customer to vehicle.
                Update vehicle parameters.
        Select the next vehicle.
If applicable, remove unused vehicles
Repeat for each vehicle
    If no customers assigned to vehicle then
        Remove vehicle from simulation.
Reset vehicles to starting parameters and start their process
Repeat for each vehicle
    Set vehicle parameters to start values.
    Start vehicle.

During execution of collection
Repeat
    While no customers require replanning
        Standby.
    Replanning
    Repeat for all vehicles
        Remove all customers that are not fixed to the vehicle,  from being assigned to the vehicle.
        Save state of each vehicle (location, free capacity, Idle time)
    Sort customers and vehicles if applicable
    If sort customers is true then
        Sort customer on planned collection volume.
    Sort vehicles on capacity.
    Select the first vehicle.
    While not all customers assigned to a vehicle
        If using the first planning strategy
        If assigning vehicles to customers then
            Select first customer to be planned.
            Sort vehicles on distance to customer.
            Select the first vehicle.
            If planned free capacity of vehicle sufficient & customer time window not exceeded too much then
                Assign vehicle to customer.
                Update vehicle parameters.
            Else
                Select the next vehicle closest to customer.
        If using the second planning strategy
        If assigning customers to vehicles then
            Repeat for each customer
                Sort customers on distance to the vehicle.
```

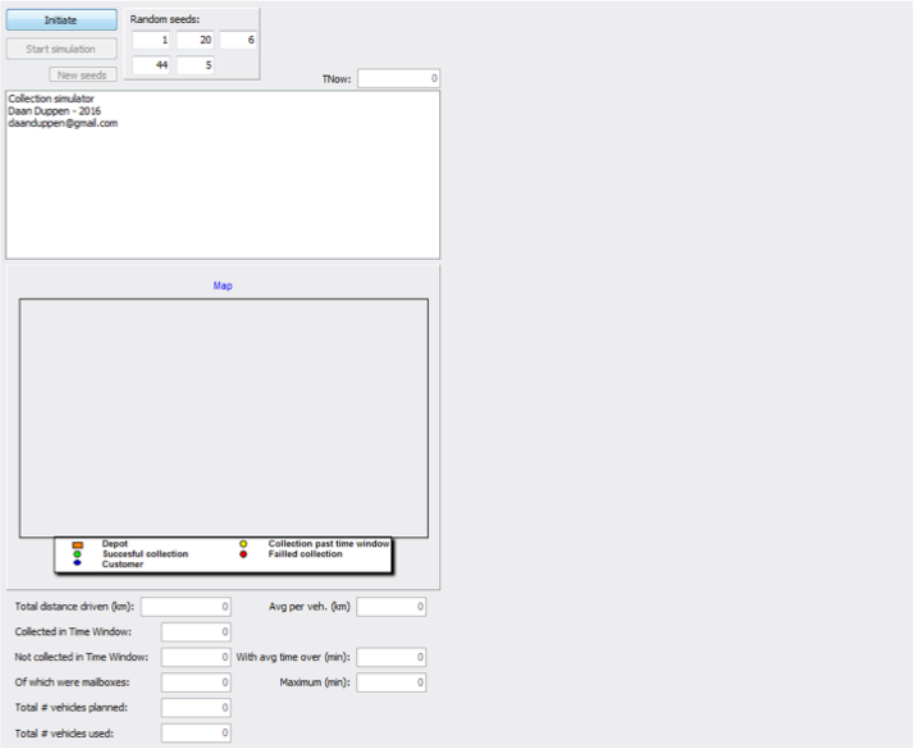
```
                Sort customers on end of time window.
                If planned free capacity of vehicle sufficient & customer window not exceeded too much then
                    Assign customer to vehicle.
                    Update vehicle parameters.
                Select the next vehicle.
Restore vehicle parameters.

Vehicle class process
Repeat
    Wait for a customer to be assigned to the vehicle
    While no customers to be collected
        Standby.
    Select the first customer to be collected.
    Determine drive time to customer.
    Wait till start to drive and reevaluate first customer to be collected
    While current time + drive time < time window start of customer
        Reevaluate which customer is first to be collected.
        Update drive time to customer if another customer is first to be collected.
    Fix customer to vehicle and start driving
    Fix customer to vehicle.
    Set idle time of vehicle to expected time to have finished collecting customer.
    Set plan free capacity to expected free capacity after finished collecting customer.
    Set plan location of vehicle to location of customer.
    Hold drive time to customer.
    At customer
    Update location of the vehicle to the location of the customer.
    If actual collection volume exceeds free capacity then
        If vehicle control set to collect as much as possible then
            Set actual volume of customer to remaining volume not collected.
            Set plan volume of customer to actual volume of customer.
            Hold handling time
            Determine drive time back to depot
            Set plan free capacity of vehicle to the vehicle capacity.
            Set plan location of vehicle to (0,0).
            Repeat for each customer assigned to vehicle
                Unassign customers from vehicle.
            Hold drive time to depot.
            Set location of vehicle to (0,0).
            Set free capacity of vehicle to vehicle capacity.
            Set vehicle idle time to current simulation time.
        If vehicle control set to only collect if all volume can be collected then
            Set plan volume of customer to actual volume of customer.
            Set plan free capacity of vehicle to vehicle free capacity.
            Set vehicle idle time to current simulation time.
            Repeat for each customer assigned to vehicle
                Unassign customers from vehicle.
    If actual volume is smaller than or equal to the free capacity then
        Register if collected in time window or not.
        Remove customer from simulation.
        Update vehicle free capacity (planned and actual).
        Hold handling time
        Set vehicle idle time to current simulation time.
```

7.2 Delphi model

The simulation model is implemented using the Embarcadero Delphi programming language and developing environment. In addition, Tomas is used in order to model the discrete time simulation (Veeke & Ottjes, 2010).

Figure 7.4 gives an overview of the resulting simulation interface as presented to the user. When first starting the simulation interface, the only option presented to the user is to initiate the simulation. Doing so will start the steps shown in Figure 7.5.



Random seeds: 1 20 6 44 5

TNow: 0

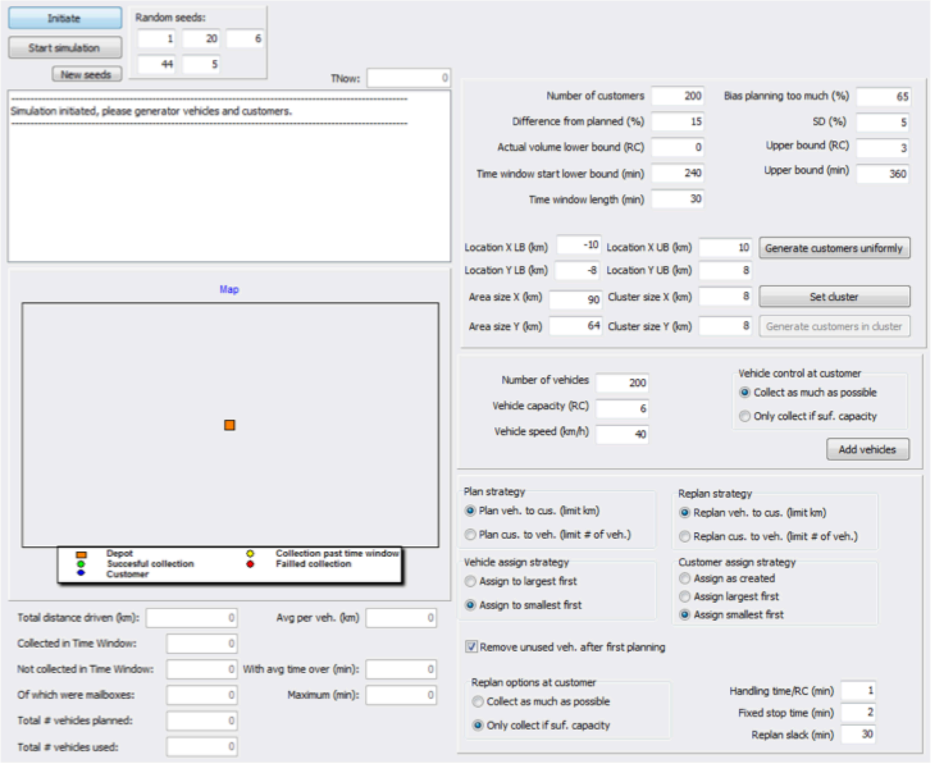
Collection simulator
Daan Duppen - 2016
daanduppen@gmail.com

Total distance driven (km): 0
Avg per veh. (km) 0
Collected in Time Window: 0
Not collected in Time Window: 0
With avg time over (min): 0
Of which were mailboxes: 0
Maximum (min): 0
Total # vehicles planned: 0
Total # vehicles used: 0

Figure 7.4 – Simulation interface after starting.

Figure 7.5 – Simulation steps when initiating simulation

After initiating the simulation, the user is presented with the option to change parameters and to add vehicles and customers (see Figure 7.6).



Random seeds: 1 20 6 44 5

TNow: 0

Simulation initiated, please generator vehicles and customers.

Total distance driven (km): 0
Avg per veh. (km) 0
Collected in Time Window: 0
Not collected in Time Window: 0
With avg time over (min): 0
Of which were mailboxes: 0
Maximum (min): 0
Total # vehicles planned: 0
Total # vehicles used: 0

Number of customers 200
Bias planning too much (%) 65
Difference from planned (%) 15
SD (%) 5
Actual volume lower bound (RC) 0
Upper bound (RC) 3
Time window start lower bound (min) 240
Upper bound (min) 360
Time window length (min) 30

Location X LB (km) -10
Location X UB (km) 10
Location Y LB (km) -8
Location Y UB (km) 8
Area size X (km) 90
Cluster size X (km) 8
Area size Y (km) 64
Cluster size Y (km) 8

Number of vehicles 200
Vehicle capacity (RC) 6
Vehicle speed (km/h) 40

Vehicle control at customer
● Collect as much as possible
○ Only collect if suf. capacity

Plan strategy
● Plan veh. to cus. (limit km)
○ Plan cus. to veh. (limit # of veh.)

Replan strategy
● Replan veh. to cus. (limit km)
○ Replan cus. to veh. (limit # of veh.)

Vehicle assign strategy
○ Assign to largest first
● Assign to smallest first

Customer assign strategy
○ Assign as created
○ Assign largest first
● Assign smallest first

☑ Remove unused veh. after first planning

Replan options at customer
○ Collect as much as possible
● Only collect if suf. capacity

Handling time/RC (min) 1
Fixed stop time (min) 2
Replan slack (min) 30

Figure 7.6 – Main simulation interface before starting the simulation

7.2.1 Generating customers

The simulation allows for two ways in which customers can be created. The first option is to generate customers uniformly over a certain area. The user adjusts the dimensions of the area in which customers should be generated. It is important to note that the simulation will always place the depot at the center of the area at point (0,0).

When pressing the *Generate customers uniformly* button, the steps shown in Figure 7.7 are executed. Next to that, the message window found on the simulation interface will show the names and characteristics of the created customers.

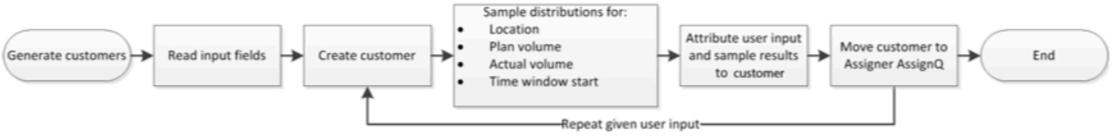


Figure 7.7 – Simulation steps when generating customers

Next to creating customers uniformly across an area, it is also possible to create customers in clusters (for example when representing customers in cities or towns). After defining the area in which the cluster should be positioned following a uniform distribution and the dimensions of the cluster itself, a cluster can be determined by pressing the *Set cluster* button. After doing so, customers can be added to the cluster by pressing the *Generate customers in cluster* button. The *Set cluster* steps are shown in Figure 7.8. The process of the *Generate customers in cluster* button is the same as shown in Figure 7.7, where the location distribution uses the lower and upper bounds as defined with the *Set cluster* button process.

Figure 7.8 – Simulation steps when setting a cluster

7.2.2 Generating vehicles

Similarly, when pressing the *Add vehicles* button, the steps shown in Figure 7.9 are performed. Again, the main characteristics of the just created vehicles is displayed in the message window.

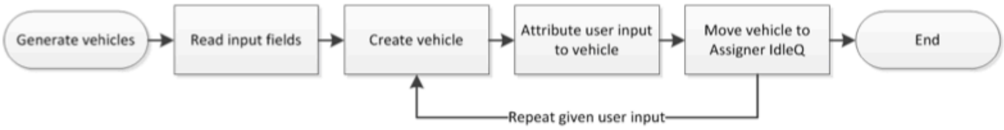


Figure 7.9 – Simulation steps when generating vehicles

7.2.3 Additional simulation settings

Next to adjusting the parameters for the vehicles and customers to be created, the main interface shows the different planning options that were mentioned before. In addition, the user can decide to either remove any vehicles that do not have any tasks assigned to them after the first planning iteration. Finally, the handling time per roll container as well as the fixed handling time per stop can be adjusted.

7.2.4 Running the simulation

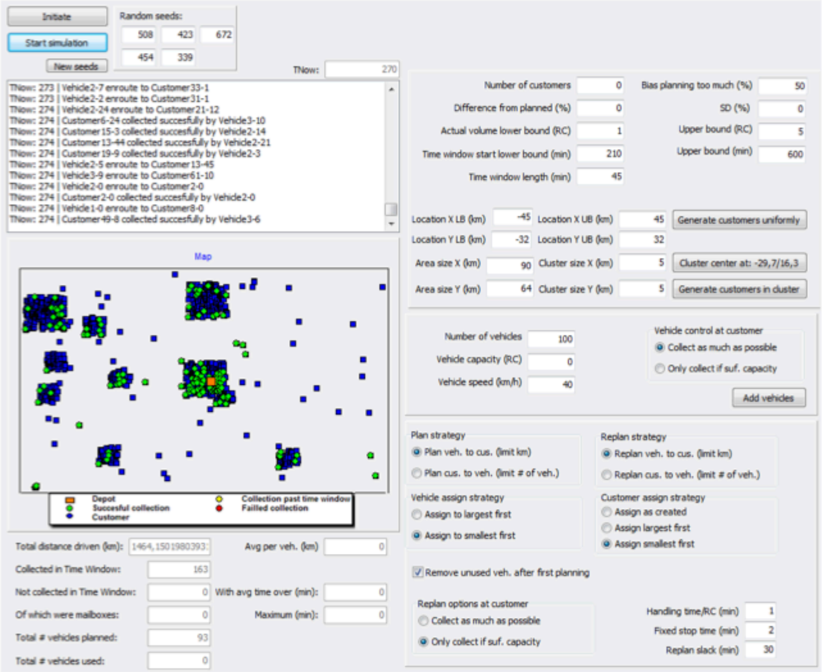
When the user has generated all required customers and vehicles, pressing the *start simulation* will execute the steps in Figure 7.10, starting the simulation.

Figure 7.10 – Simulation steps when starting the simulation

During the execution of the simulation, the user is presented with the interface shown in Figure 7.11. The interface shows a map displaying the location of all the customers (including whether or not they are already successfully collected) as well as the location of the depot.
Next to that, the interface shows a number of performance measures. These include:

- The total distance travelled by all vehicles.
- The average distance travelled per vehicle.
- The number of pickups that are performed within the time window.
- The number of pickups that are performed outside of the time window.
- The number of zero volume (i.e. mailboxes) that were picked up outside of the time window.
- The maximum and average time by which the time windows are exceeded.
- The number of vehicles planned (which represents all vehicles that at one point had a customer assigned to it).
- The number of vehicles used (which represent all vehicles that have successfully performed at least one collection).

After completing a simulation run, all these parameters are also saved to a semicolon delimited text file, making it easy to import them into for example Microsoft Excel.
During execution, all relevant actions are displayed in the message window and can be reviewed after the execution is finished.



Random seeds: 508 423 672 454 339
TNow: 270

```
TNow: 273 | Vehicle2-7 enroute to Customer33-1
TNow: 273 | Vehicle2-2 enroute to Customer31-1
TNow: 274 | Vehicle2-24 enroute to Customer21-12
TNow: 274 | Customer6-24 collected succesfully by Vehicle3-10
TNow: 274 | Customer15-3 collected succesfully by Vehicle2-14
TNow: 274 | Customer13-44 collected succesfully by Vehicle2-21
TNow: 274 | Customer19-9 collected succesfully by Vehicle2-3
TNow: 274 | Vehicle2-5 enroute to Customer13-45
TNow: 274 | Vehicle3-9 enroute to Customer61-10
TNow: 274 | Vehicle2-0 enroute to Customer2-0
TNow: 274 | Customer2-0 collected succesfully by Vehicle2-0
TNow: 274 | Vehicle1-0 enroute to Customer8-0
TNow: 274 | Customer49-8 collected succesfully by Vehicle3-6
```

Number of customers: 0
Difference from planned (%): 0
Actual volume lower bound (RC): 1
Time window start lower bound (min): 210
Time window length (min): 45
Bias planning too much (%): 50
SD (%): 0
Upper bound (RC): 5
Upper bound (min): 600

Location X LB (km): -45
Location X UB (km): 45
Location Y LB (km): -32
Location Y UB (km): 32
Area size X (km): 90
Cluster size X (km): 5
Area size Y (km): 64
Cluster size Y (km): 5

Number of vehicles: 100
Vehicle capacity (RC): 0
Vehicle speed (km/h): 40

Vehicle control at customer
● Collect as much as possible
○ Only collect if suf. capacity

Plan strategy
● Plan veh. to cus. (limit km)
○ Plan cus. to veh. (limit # of veh.)

Replan strategy
● Replan veh. to cus. (limit km)
○ Replan cus. to veh. (limit # of veh.)

Vehicle assign strategy
○ Assign to largest first
● Assign to smallest first

Customer assign strategy
○ Assign as created
○ Assign largest first
● Assign smallest first

☑ Remove unused veh. after first planning

Replan options at customer
○ Collect as much as possible
● Only collect if suf. capacity

Handling time/RC (min): 1
Fixed stop time (min): 2
Replan slack (min): 30

Total distance driven (km): 1464,1501980393
Avg per veh. (km): 0
Collected in Time Window: 163
Not collected in Time Window: 0
With avg time over (min): 0
Of which were mailboxes: 0
Maximum (min): 0
Total # vehicles planned: 93
Total # vehicles used: 0

Figure 7.11 – Main simulation interface during a simulation run

7.3 Model verification

Before using the model to determine the impact of planning accuracy on the travel distance and the number of vehicles used, the model needs to be verified to ensure it performs as intended. The first step in ensuring that the model is coded correctly is by performing a step-by-step walkthrough of the model (Robinson, 1997; Etessami & Gilmore, 2008). Next to that, coding errors should be prevented by following good programming practice such as modular programming (Kleijnen, 1995). Throughout programming the model in Delphi, the code was checked against the PDL and vice versa, ensuring that code is still in line with the intended model. Next to that, after implementing a new section of code, the model was run and checked for errors or unexpected results. Finally, syntax errors are automatically identified by the programming environment when compiling the model.

7.3.1 Manual calculations

Next, the model is tested using an example problem and the model output compared to the expected results as derived by hand (Kleijnen, 1995). The example problem used consists of a set of ten customers (see Table 7.1) and six vehicles (see Table 7.2).

Customer	Location X	Location Y	Planned volume (RC)	Actual volume (RC)	Time window start (min)
0	0	13	1	1	300
1	76	44	1	2	363
2	73	87	1	2	423
3	29	93	3	2	512
4	73	73	1	1	413
5	28	80	5	3	480
6	54	55	2	4	437
7	64	20	2	4	508
8	23	14	1	1	410
9	35	48	1	1	411

Table 7.1 – Sample set of customers

Vehicle	Capacity (RC)	Speed (km/h)
0-0	6	40
0-1	6	40
0-2	6	40
1-0	3	40
1-1	3	40
1-2	3	40

Table 7.2 – Sample set of vehicles

The sample problem is executed by the simulation model using both of the planning strategies. Subsequently, the customers are planned by hand using Microsoft Excel to calculate the distance between any set of customers, as well as the distance between the depot and each of the customers. Next, the customers are sorted on time window (as they are indented to do in the simulation) and the distance between the vehicles and the customer are calculated, as well as the expected arrival time of each vehicle at the customer. This is done by having an input available for the current position of the vehicle as well as the idle time. The customers are then manually assigned to a vehicle after which the location and the idle time of the vehicle is changed. The free capacity of the vehicle is kept track of manually since the set of customers and vehicles is small. After having planned all customers to vehicles, the point at which the planning can no longer be kept due to differences in planned and actual collection volumes is determined. From this point onwards, all customers that are not fixed to a vehicle are un-assigned from a vehicle and replanned using the aforementioned method. This is repeated if another replanning is necessary.

After performing the manual (re)planning, the collection of the same set of customers using the same set of vehicles is simulated using the model. After completion the following points are checked for similarity between the manual and simulated planning and collection.

- The actual collection times for each customer.
- The sequence in which customers are (re)planned to a vehicle.
- The total number of kilometers driven.
- The number of vehicles planned.
- The number of vehicles used.

The detail of this verification is found in Appendix V, but the results of the manual planning for all five points coincides with the results found from the simulation. There was only a very small difference found in the total number of kilometers driven, but that can be attributed to a rounding error in the manual calculation.

It is possible to repeat the verification approach, but with different settings for:

- Vehicle assign strategy (largest or smallest first).
- Customer assign strategy (as created, largest first, or smallest first).
- Replan option at customer.
- Vehicle control at the customer.

However, given the time intensive nature of the verification approach, and the small chance of an error given that these options represent just a difference in a single line of code, the verification approach is not repeated. The general verification of reviewing the code and testing the proper working of new functionality when added to the model (as was done during development) is believed to be sufficient.

7.3.2 Extreme cases

Next to comparing the result of the sample problem to the one derived by hand, a number of extreme cases is simulated and their results compared to what would be expected.

Time window of a single time unit

In practice, having a time window of a certain number of minutes allows some flexibility in reaching the customer. This can be necessary due to for example uncertainty in drive times or having a longer handling time at the customer than expected. However, the model assumes a fixed average speed and distance as well as a fixed handling time per roll container. Next to that, the planning algorithm will only assign a customer to a vehicle or vice versa, if the customer can be reached within the time window. As a result, one would expect that all customers will be collected within the time window, regardless of the length of the time window if the planning algorithm is programmed in the right way. This is however only valid as long as the actual volume of the customer matches with the planned volume.

To test if this is indeed the case, the collection of five sets of a 1000 customers with an actual volume between one and six roll containers and a time window length of a single time unit are simulated using the model. The customers are arranged in four clusters of 200 customers, and the final 200 customers are distributed uniformly. Appendix V shows the detailed results from the simulation, but as expected, all customers are collected within the time window (without having any replanning taking place), indicating that the planning algorithm is properly programmed.

Equaling supply of vehicles and collection demand

The next situation tested is one in which the volume of all customers is the same, and equals the capacity of all vehicles. Next to that, planned volumes and actual volumes are set to be equal and all customers have the same time window. By doing so, three situations can be tested and verified:

- Number of vehicles < number of customers: simulation should result in an error as there is no sufficient total collection capacity available.
- Number of vehicles = number of customers: simulation should result in each vehicle being used to collect one customer.
- Number of vehicles > number of customers: simulation should end in the same results as the case where the number of vehicles and customers is equal to each other, with all the additional vehicles being unused.

Applying the three situation to a set of 100 customers each with a volume of 5 roll containers uniformly distributed over the simulation area and using 99, 100 and 101 vehicles respectively, each with a capacity of 5 roll containers, results in the expected outcome for all three situations. The details of the verification can again be found in Appendix V.

7.3.3 Tomas balance check

Finally, the build-in functionality of Tomas that keeps track of the number of elements in the simulation, as well as the length of all queues is used to perform a balance check. The balance check includes:

- Making sure the number of vehicles present at the end of the simulation equals the read out on the simulation interface.
- Taking the sum of the number of elements that passed the task queue for each vehicle, should result in the total number of customers generated as long as no replanning event took place. The same should hold true for the assign queue of the *assigner* element.

A set of 100 customers uniformly distributed over the simulation area is generated and then collected using the simulation. Checking the elements showed that indeed all 100 customers passed a task queue of one of the vehicles, and that the read-out of the total number of used vehicles on the simulation interface matches the number of vehicles used by the simulation. Details of the verification can be found in Appendix V.

7.3.4 Comments on model validation

The verification of a model is typically followed by a validation of the model. Validation refers to assuring *that the model represents the real system to a sufficient level of accuracy* (Carson, 2002). Verification is done to ensure that the model functions as planned for, while validation ensures that the model represents reality to a high enough level. While the presented model was successfully verified, it is believed to be impossible at this stage to validate the model. Validating the model requires having actual results from practice that are comparable to what the model simulates. However, the planning approach currently used by PostNL is different from the one used in the simulation. Currently, the planning system of PostNL uses an optimization algorithm to plan the collection of customers modeled as a vehicle routing problem. This will yield different results then applying the before mentioned heuristics. Next to that, the planning system takes into account the road network while the simulation does not. The downside to the planning approach currently used is that it takes multiple hours to complete the calculation of a route (PostNL states a cycle time of two days to determine the routes for a completely new set of customers to be planned). This makes the current planning approach unfeasible to test a large number of scenarios, which is the goal stated at the beginning of this chapter.

Next to that, the goal of the model is to compare different situations and state a relative increase/decrease in the cost drivers, not to determine the absolute cost of collecting a certain group of customers. In other words, it is not the goal of the simulation to compare a real-life result with that of a simulation result, but to show the difference in simulation results for different scenarios, given the assumptions and limitation of the simulation model.

7.4 Simulation datasets

This section will address the different data sets that will be generated and solved by the simulation model. First, the characteristics of a typical collection region (the set of customers all assigned to the same depot) will be addressed. Next, the planning accuracy for the different collection options will be once again determined, this time specifically with the goal of using it in the simulation model. Finally, based on the previous sections, a number of data sets will be defined and explained.

7.4.1 Characteristics of a collection region

Before addressing the model options that are simulated, it is important to address the characteristics of a typical group of customers. Currently, the customers being collected by the mail division are planned based on their zipcode which determines to which SCB or VBL a customer belongs. For the parcel division, the collected volume of collection customers is brought to the nearest NLI.

The region of Zwolle is again used, now to determine what a typical group of customers looks like. This region is chosen since for this region the most information is either known or collected during the research.

Figure 7.12 shows all pickups for which the collection volume is either driven to the parcel depot or the mail depot found in Zwolle (both shown in yellow). The green pickups represent collection of small volume by the mail division. These pickups do not consist of filled roll containers but of bags or bundles of mail. Some of these represent actual customers with a time window, while others represent mailboxes without a time window. The red pickups represent collection by the mail division of a larger volume of one roll container or more. These all have a time window. Finally, the blue pickups are collections currently performed by the parcel division and typically represent larger volumes (>6 roll containers).

[redacted]

Figure 7.12 – All pickups assigned to the region of Zwolle

Table 7.3 gives an overview of the actual number of pickups for each of these four options.

Collection type	**Number of pickups**
Mailboxes (no roll containers/no time window)	[redacted]
Mail service collection (no roll containers/with a time window)	[redacted]
Mail service collection (roll containers/with a time window)	[redacted]
Parcel service collection (roll containers/with a time window)	[redacted]
Total	[redacted]

Table 7.3 – Number of pickups in the region of Zwolle for the different collection types.

Next to the number of customer in a region, the following characteristics about the collection region are also noted:

[redacted]

- Due to the different cities in the region, most customers are clustered. One of the larger clusters typically surrounds the depot, as a depot is usually placed in a large city.
- Next to the clusters, some pickups seem to be uniformly distributed over the area. These pickups represent for example mailboxes in very small villages, or a warehouse of a larger collection customers located outside of city.

The different collection types also see different distributions of actual collection volume. Figure 7.13 shows the distribution of the average actual volume of the parcel service collection customers (measured over the month of August), while Figure 7.14 does the same for the mail service collection customer that were measured in the region of Zwolle (over the five days discussed before).

[redacted]

Figure 7.13 – Volume distribution (parcel service)

[redacted]

Figure 7.14 – Volume distribution (mail service)

Regarding pickups that do not involve roll containers, the assumption is that there is always sufficient capacity in the vehicle for customers using postal bags as a load device or simply present collection volume as items being loose loaded. In practice, these collection volumes can almost always be added to roll containers already present in the collection vehicle or in empty spaces found in the vehicle. As a result, collection at mailboxes or customers using a load device other than a roll container will be represented as a customer having an actual and planned volume of zero roll containers.

Finally, Table 7.4 shows the minimum and maximum start time of the time window found for both the parcel as well as the mail division customers. The length of the time window varies from [redacted] minutes to [redacted] minutes. For the sake of simplicity however, the time window length will be fixed to 45 minutes for all customers. The start of the time window will be uniformly distributed between the mentioned minimum and maximum start of the time window in 30 minute increments.

	Min. start of time window	**Max. start of time window**
Parcel division	15:30	22:00
Mail division	16:00	18:00

Table 7.4 - Time window boundaries

7.4.2 Characteristics of the different types of collection

Chapter 3 and later Chapter 6 addressed the performance of the current collection process, as well as the possible improvements to the collection process performance when utilizing the currently available information regarding expected collection volumes.

In these chapters, the planning accuracy was stated as the average deviation between the planned/predicted volume and the actual volume, expressed in a number of roll containers. Doing so gives a sense of how many roll containers can actually be eliminated when improving the collection process. However, the parameter that expresses the planning accuracy in the simulation is the absolute difference between the planned and the actual volume as a percentage of the planned volume. Or:

$$\text{Difference from planned (\%)} = \frac{|Actual\ volume - planned\ volume|}{planned\ volume} \cdot 100 \qquad (2)$$

Using this parameter makes it possible to apply the same accuracy to different sized customers.

While the planning accuracy was already discussed at length in Chapter 3 & 6, the relative planning accuracy as well as the distribution of this accuracy is briefly addressed for each division and collection option.

Planning accuracy parcel division

As was stated before, the largest amount of data on collection performance is available for collection performed by the parcel division. This makes it possible to determine what the average planning difference is for a customer of the parcel division. Based on a month of data (August) for all [redacted] parcel division collection customers, it was found that the average planning difference is [redacted]%, with a standard deviation of [redacted]% (see as well Table 7.5).

It was already found that for [redacted]% percent of the pickups, the planned volume was higher than the actual volume. Next to that, for [redacted]% of the pickups, the collected volume was equal to the planned volume within an error of one roll container. As the bias (meaning the percentage of times where the planning volume overestimates the actual volume) as used in the simulation cannot directly take this into account, half of this percentage is add to the bias to overestimate the collection volume. Note that having the plan volume match the actual volume is still very much possible in the simulation. When sampling the planning difference distribution, it is possible that the difference is found to be low. When this is the case, taking the difference as either positive or negative will result in the same number of roll containers given that the value is rounded to the nearest whole roll container, thus resulting in the planned volume being equal to the actual volume.

Number of customers in data		[redacted]
Mean planning difference		[redacted]
Standard Deviation Planning difference		[redacted]
Bias plan volume exceeding actual volume		[redacted]

Table 7.5 – Characteristics planning difference parcel division

Next to that, plotting the average planning difference for all customers as a histogram, and including a normal distribution with the same mean and standard deviation, shows that the planning difference of a customer can be considered normally distributed (Figure 7.15).

[redacted]

Figure 7.15 – Planning difference distribution for parcel division collection customers

Planning accuracy mail division

Performing the same analysis for the mail division is difficult as the only available data regarding the planning accuracy for this type of collection, is the measurement performed as part of this research. While it is possible to determine an average planning difference, it is only based on a very limit sample size for each of the customers. This also means that there cannot be found a clear distribution for the planning difference. Instead, the assumption is made that the planning difference is normally distributed for the mail division collection customers as well. The mean for the distribution is taken at [redacted]%, which was the average planning difference found in the measure in Zwolle. Under the assumption that having a lower planning difference will also mean a smaller variation, the standard deviation found for the parcel division is scaled based on the mean found for the parcel division and the mail division, resulting in a standard deviation of [redacted] or [redacted]%.

The bias of plan volume exceeding actual volume is derived in the same way as with the parcel division, and is based on the results already presented in Chapter 6.

Table 7.6 gives an overview of the data used for the mail division collection customers.

Number of customers in data		[redacted]
Mean planning difference		[redacted]
Assumed Standard Deviation Planning difference		[redacted]
Bias plan volume exceeding actual volume		[redacted]

Table 7.6 – Characteristics used for the mail division

It must finally be noted that the distribution is only applied to customers using roll containers as a load devices, as other customers will be modeled as customer having zero roll containers for planned as well as actual volume.

Planning accuracy prediction model

For the prediction model, there is only a single customer investigated that shows typical collection planning behavior. While it is preferable to have more customers to base the planning difference one, the results for the single customer will be used to represent planning with improved information regarding actual collection volumes. The mean planning difference as well as the bias is based on the planning difference for the days for which the prediction model was applied. The standard deviation is determined in the same fashion as was done for the mail division collection customers. Finally, this is done for both the predictions as found in Table 6.7.

Overview distribution values

An overview of the distribution parameters for the different collection options is given in Table 7.7 below.

	Mean planning difference	Planning difference SD	Bias
Collection parcel division	[redacted]	[redacted]	[redacted]
Collection mail division	[redacted]	[redacted]	[redacted]
Prediction model (1)	[redacted]	[redacted]	[redacted]
Prediction model (2)	[redacted]	[redacted]	[redacted]

Table 7.7 – Overview of planning differences

7.4.3 Composition of dataset

Based on the characteristics discussed in the previous subsections, a set of customers can be defined to which the different planning strategies can be applied.
First, the total number of customers per collection type, as well as their location needs to be determined. Based on the number of customers found in the region of Zwolle, the distribution of pickups over the different collection types that is used, is shown in Table 7.8.

Collection type	**Number of pickups**
Mailboxes *(no roll containers/no time window)*	[redacted]
Mail service collection *(no roll containers/with a time window)*	[redacted]
Mail service collection *(roll containers/with a time window)*	[redacted]
Parcel service collection *(roll containers/with a time window)*	[redacted]
Total	[redacted]

Table 7.8 –Number of pickups per collection type

Next, the way in which the pickups are distributed over the region needs to be discussed. For the experiments, it is assumed a region has the following main characteristics:

- A total area of size [redacted] km by [redacted] km
- Three large clusters of size [redacted] km by [redacted] km
- Seven smaller clusters of size [redacted] km by [redacted] km
- A number of pickups uniformly distributed over the region

As a result, the customers need to be divided either over the clusters, or uniformly over the entire area. For the mailboxes and mail service collection, it is assumed that the majority of pickups are located in the clusters. Mailboxes are placed based on population density, resulting in a large number of mailboxes in a city and just a small number in rural areas. Next to that, mail service customers are commonly smaller than parcel service customers. As a result, mail service customers are assumed to mostly be located in cities, while a parcel division customer might very well be located outside of the city where there is more space (for example for a warehouse).
With regards to the volume of each customer, the distribution discussed in Section 7.4.1. is in part used. As a simplification however, it is assumed that a part of the customers will have a volume that is uniformly distributed over the total range that was found ([redacted] to [redacted] for mail service customers, and [redacted] to [redacted] for mail service customers), while another part will be distributed over the peak values ([redacted] to [redacted] for the mail service customers, and [redacted] to [redacted] for the parcel service customers). The ratio between these two parts, the assumed total number of customers for each collection type, and the division between the number of customers in cluster and uniformly distributed over the region, is shown in Table 7.9.

Collection type	**Assumed total nr of pickups**	**Uniform**	**In cluster**	**Ratio uniform volume**	**Ratio additional volume**
Mailboxes	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Mail service collection (no rc)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Mail service collection	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Parcel service collection	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 7.9 – Division of uniform versus clustered customers

Based on the before mentioned division, the total number of customers is divided over the three locations (uniform, small cluster, or large cluster) as well as the two volume options (uniform or additional). To help with doing so, Microsoft Excel is used to calculate the number of customers per options. It must be noted that the customer density is kept constant for both the cluster sizes. Finally, the number of customers per option is rounded to the nearest integer, resulting in small deviations from the initial number of customers. Table 7.10 gives an overview of the final divisions of customers for each dataset used in the experiments.

Collection type	**Uniform location/ Uniform volume**	**Uniform location/ Additional volume**	**Large cluster/ Uniform volume**	**Large cluster/ Additional volume**	**Small cluster/ Uniform volume**	**Small cluster/ Additional volume**	**Total**
Mailboxes	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Mail service (no rc)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Mail service	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Parcel service	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 7.10 – Division of customers used in the experiments

Finally, the vehicles shown in Table 7.11 are used in the simulation model. These represent the vehicles currently mostly used by the two divisions. Next to that, the average speed during collection is assumed to be 40 km/h for all vehicles. The number of vehicles generate is chosen in such a way that there are always sufficient vehicles available of each kind during the initial planning.

	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4
Capacity (RC)	0[4]	6	30	56
Division	Mail	Mail	Parcel	Parcel
Average speed	40	40	40	40

Table 7-11 – Vehicle characteristics used

7.4.4 Model settings

When performing experiments using the aforementioned datasets, the simulation is run for 2 weeks (or 10 days) of collection in three different regions in which one large cluster is located somewhere adjacent to the depot, and the other clusters uniformly over the region. Figure 7.16 shows the three regions used, as generated at random by the simulation model.

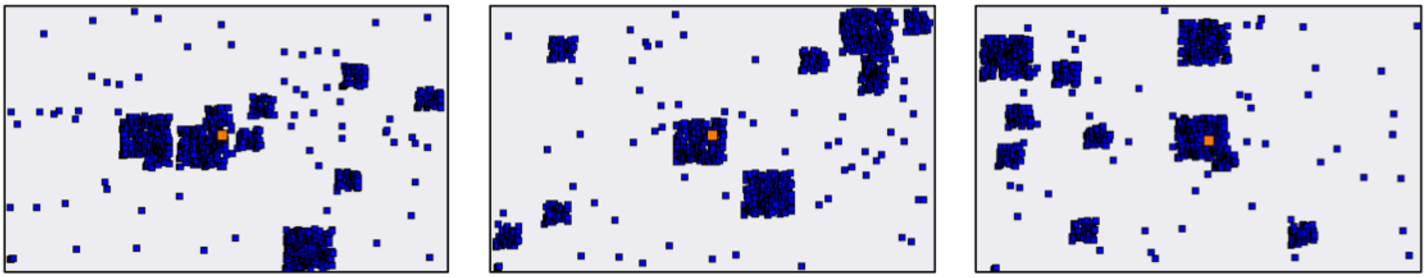


Figure 7.16 – The three different areas used in the simulations

Next to that, the following model settings are used:

- The smallest unit of distance used is [redacted] meters, while a single time step in the simulation represents one minute.
- A handling time of one minute per roll container is assumed, as well as a fixed pickup time of two minutes per stop.
- The limit for exceeding the time window during replanning is set to 30 minutes.

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[4] A capacity of zero means that only mailboxes and mail service customers without roll containers can be collected by this vehicles.

- For all experiments discussed, the first planning strategy is used (assigning vehicles to customers). Next to that, both customers as well as vehicles are sorted from smallest to largest during planning and replanning. The reason for using these settings, is that the second planning strategy (assigning customers to vehicles) is not compatible with the used dataset. Using the second planning strategy while having mailboxes with a large time window and a volume of zero roll containers present in the dataset, will result in a large number of pickups representing mailboxes (multiple hundreds) being assigned to a single vehicle, which is not desirable. Furthermore, sorting vehicles and customers from large to small will likely result in very large numbers of customers being assigned to a single large truck.

7.4.5 Experiments

Using the aforementioned datasets and settings, a number of different experiments will be performed.

Combining divisions (base case)

The first experiment will investigate the effect of combining the pickups for both the mail service as well as the parcel service into a single planning. First, the customers of both divisions are simulated separately using only the vehicles they have at their disposal. Next, the result of both simulations are combined and compared to a simulation where all customers and all vehicles are used for collection. The total distance driven, the number of vehicles used, as well as the impact on customer satisfaction (based on how many customers are collected outside of their time window) are then discussed to evaluate the advantages and disadvantages of doing so.

Improving the planning accuracy

It was found that when a customer is sending its pre-shipping notification on a consistent basis throughout the day, it can be used to increase the planning accuracy. In order to quantify the impact of this improved accuracy on the actual collection process, the mean planning difference as well as the standard deviation for all customers using roll containers is changed to the values discussed in Section 7.4.2. This assumes a situation where all customers using roll containers use these to ship parcels, and that their pre-shipping notifications are send in such a way that the same accuracy as discussed in Section 6.4 can be achieved.

Back-up vehicles

The simulation model has the option to either remove vehicles that do not have any pickups assigned to them after the first planning run, or to keep them to be used in replanning if applicable. The previous experiments removed the unused vehicles as this represents the current case the closest (there are currently no vehicles standing-by during collection). However, having vehicles present at the depot to be used in case replanning is required might be beneficial to the performance of the collection process. The simulation will be run, now with back-up vehicles, for both the current as well as the improved planning accuracy.

Additional vehicle

The previous experiments made use of the vehicles that are commonly used by either the mail or parcel division. While these vehicles have different capacities, it might be beneficiary to include another vehicle with a capacity currently not offered. Different vehicles will be added to the simulation model and the model will then again be run for both the current as well as improved planning accuracy.

7.5 Results

This section will address the results of the different experiments discussed in the previous section. While this section will focus on the most important results, the full results can be found in Appendix VI.

7.5.1 Combining divisions

When combining both divisions, large improvements can gained in both the total travel distance as well as the number of vehicles used. This however was to be expected. When operating as two separate divisions, it is very well possible that two pickups in close proximity to each other are collected using two different vehicles while the volume might be low enough to be combined into one vehicle. With a reduction in the required number of vehicles, the total distance is reduced as well, while the distance per vehicle is increased slightly (4% on average).

One might argue that while the total number of vehicles decreases, it might be possible that a large number of high capacity vehicles of the parcel division is used instead of a small number of lower capacity vehicles. This should however not be the case as the planning strategy was set to sort vehicles from low capacity to high capacity before assigning customers to vehicles. This is confirmed when looking at the vehicle split shown in Figure 7.17. The number of vehicles used decreases for all vehicle types, with the vehicle of capacity six having a larger share in the combined planning. This should also come as no surprise. While the parcel division should solely be used for large customers, it was found that a large number of parcel division customers ship volumes smaller than six roll containers.

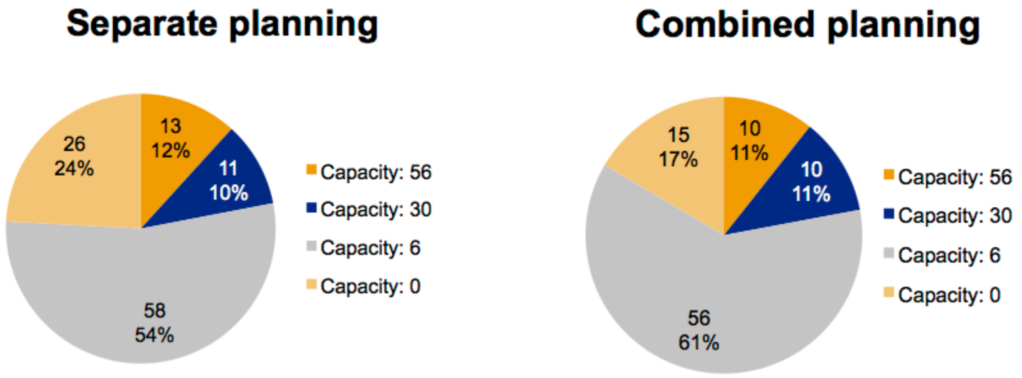

Figure 7.17 – Average vehicle use per capacity

The only downside to combining the planning is the impact on the customer satisfaction. After combining the planning, small increases are found for the number of pickups outside of the time window, the average time exceeding the time window, and the maximum time exceeding the time window. While difference are only small, it was to be expected as having a more efficient planning means less room for error. Since there is still a lot of uncertainty when it comes to what volume customer actually present for collection, it is no surprise that having less room for error means a decrease in punctuality. Table 7.12 gives an overview of the most important results of the experiment.

	Difference Total distance	**Difference Vehicles planned**	**Difference Vehicles used**	**Pickups not in window (excluding mailboxes)**	**Average time exceeding time window (min)**	**Max time exceeding time window (min)**
Area 1	***-14%***	***-15%***	***-22%***	From ***4,8*** to ***8***	From ***9,4*** to ***9,4***	***15,7*** to ***21,9***
Area 2	***-17%***	***-13%***	***-18%***	From ***6,7*** to ***8,8***	From ***11,1*** to ***11,7***	***20,3*** to ***27,9***
Area 3	***-15%***	***-8%***	***-15%***	From ***8,2*** to ***7,1***	From ***10,7*** to ***10,5***	***20,0*** to ***24,8***
Average	***-15,3%***	***-12%***	***-18,3%***	From ***6,6*** to ***8,0***	From ***10,4*** to ***10,5***	***18,7*** to ***24,9***

Table 7.12 - Separate planning versus Combined planning

7.5.2 Improve planning accuracy

The next experiment looks at the effect of increasing the planning accuracy. Looking at the main results shown in Table 7.13, it becomes clear that increasing the planning accuracy mostly has effect on the number of vehicles used. As can be expected, increasing the accuracy means being able to assign more customers to a single vehicle during planning. The results show that not only is number of vehicles actually used reduced, the effect is larger on the number of vehicles used in planning. During the simulation, a number of vehicles is assigned customers during the first planning run, this number is shown as "Vehicles planned". During the simulation as customers and routes are replanned, it is possible that fewer vehicles are actually used during execution. (shown as "Vehicles used"). The vehicles that were planned but not actually used, would have been vehicles waiting to drive to their first assigned customer, but having their customers reassigned to other vehicles before leaving the depot. Having the number of vehicles planned decrease stronger than the number of vehicles used (thus reducing the difference between vehicles planned and vehicles used) has a positive effect on the collection operation as less vehicles (and drivers) are prepared for collection but not actually used.

The increased accuracy has little impact on the total distance travelled. While less vehicles are used, the distance per vehicles is increased as more pickups can now be combined in a route.

As might however be expected, further increasing the planning efficiency has a negative effect on the punctuality for the same reasons mentioned before. Given a total number of customers of [redacted], having the number of pickups outside of the time window increase to close to 5% of total customers might not be acceptable. The effect on the time with which the time window is exceed is limited. However, this is also due to the simulation having a soft limit of 30 minutes when replanning customers, meaning a customer is not assigned to the nearest vehicle if it means exceeding the time window by more than 30 minutes. Instead, the next vehicle closest by is tried.

	Difference Total distance	**Difference Vehicles planned**	**Difference Vehicles used**	**Pickups not in window (excluding mailboxes)**	**Average time exceeding time window (min)**	**Max time exceeding time window (min)**
Area 1	-2%	-12%	-5%	From 8 to 16,6	From 9,4 to 10,7	21,9 to 26,4
Area 2	4%	-6%	-1%	From 8,8 to 15,2	From 11,7 to 12,7	27,9 to 27,0
Area 3	-0%	-10%	-4%	From 7,1 to 24,5	From 10,5 to 12,0	24,8 to 27,2
Average	1%	-9,3%	-3,3%	From 8,0 to 18,8	From 10,5 to 11,8	24,9 to 26,9

Table 7.13 – Current accuracy versus increased accuracy (using combined planning and first prediction approach)

The possible negative effect on the customer agreements was already discussed at length in Section 6.3 and thus appears to be confirmed. As was discussed in the aforementioned section, an alternative could be to apply the prediction model with a safer assumption for the number of parcels per roll container, effectively increasing the expected number of roll containers. This alternative prediction is again compared to the combined planning using the current accuracy. Table 7.14 shows the main results.

	Difference Total distance	**Difference Vehicles planned**	**Difference Vehicles used**	**Pickups not in window (excluding mailboxes)**	**Average time exceeding time window (min)**	**Max time exceeding time window (min)**
Area 1	7%	2%	10%	From 8 to 7,8	From 9,4 to 6,9	21,9 to 14,4
Area 2	10%	1%	7%	From 8,8 to 6,3	From 11,7 to 10,0	27,9 to 19,9
Area 3	8%	-4%	5%	From 7,1 to 2	From 10,5 to 2,9	24,8 to 5,3
Average	8,3%	-0,3%	7,3%	From 8,0 to 5,4	From 10,5 to 6,6	24,9 to 13,2

Table 7.14 – Current accuracy versus increased accuracy (using combined planning and second prediction approach)

Increasing the expected number of roll containers has a negative effect on the number of vehicles used as well as the total distance driven compared to the combined planning using the current accuracy. When looking at the characteristics of the second prediction approach as shown in Table 6.7, it does appear that the increase in accuracy is outweighed by the high bias.

The upside of using the second prediction approach is found in the punctuality towards the customers. As can be expect, overestimating the customer volume combined with a higher accuracy results in strong improvements in the number of pickups outside of the time window, as well as the corresponding times. Next to that, the increased accuracy still means that the difference between vehicles planned and vehicles used is strongly reduced, resulting in operational advantages.

While using the second prediction approach still performs better on all fronts than the current state of planning separately, it does not appear to be the ideal solution.

7.5.3 Back-up vehicles

As mentioned before, the simulation model has the option to either discard or keep vehicles that are generated but not used in the initial planning. While the previous experiments discarded the vehicles after planning, this experiment will investigate the impact of keeping the vehicles after planning. This is done using both the current planning accuracy as well as the planning accuracy when using the first prediction model approach. Table 7.15 shows the results for the current accuracy, while Table 7.16 shows the results for the improved accuracy.

	Difference Total distance	**Difference Vehicles planned**	**Difference Vehicles used**	**Pickups not in window (excluding mailboxes)**	**Average time exceeding time window (min)**	**Max time exceeding time window (min)**
Area 1	***-3%***	***45%***	***0%***	From ***8*** to ***10,8***	From ***9,4*** to ***9,1***	***21,9*** to ***24,3***
Area 2	***1%***	***32%***	***2%***	From ***8,8*** to ***7,6***	From ***11,7*** to ***10,7***	***27,9*** to ***20,9***
Area 3	***-3%***	***29%***	***-2%***	From ***7,1*** to ***14,7***	From ***10,5*** to ***11,4***	***24,8*** to ***24,2***
Average	***-2,0%***	***35,3%***	***0%***	From ***8,0*** to ***11,0***	From ***10,5*** to ***10,4***	***24,9*** to ***23,1***

Table 7.15 – Difference when using back-up vehicles (using combined planning and current accuracy)

	Difference Total distance	**Difference Vehicles planned**	**Difference Vehicles used**	**Pickups not in window (excluding mailboxes)**	**Average time exceeding time window (min)**	**Max time exceeding time window (min)**
Area 1	***1%***	***35%***	***2%***	From ***16,6*** to ***13,8***	From ***10,7*** to ***10,0***	***26,4*** to ***25,7***
Area 2	***1%***	***40%***	***3%***	From ***15,2*** to ***14***	From ***12,7*** to ***11,7***	***27,0*** to ***27,4***
Area 3	***-2%***	***21%***	***-2%***	From ***15,6*** to ***14,5***	From ***12*** to ***13***	***27,2*** to ***27,5***
Average	***0%***	***32%***	***1%***	From ***15,8*** to ***14,1***	From ***11,8*** to ***11,6***	***26,9*** to ***26,6***

Table 7.16 – Difference when using back-up vehicles (using combined planning and first prediction approach accuracy)

Looking at the results, it is clear that the impact on most parameters is close to non. The only strong difference is the number of vehicles that is planned. This is to be expected as the model has the freedom to assign and reassign customers to more vehicles. However, this is not translated to any more vehicles being used during execution, which is surprising. While having more vehicles seemed beneficiary during planning (as apparently, using more vehicles seems to be profitable during planning as more vehicles are assigned customers), it is not translated into actual benefits.

In reality however, having additional vehicles standing by will result into operational cost in the form of paying a fee for drivers to standby. As a result, having additional vehicles standing-by does not seem to be beneficial.

7.5.4 Additional vehicles

Finally, the impact of adding additional vehicles with a different capacity is investigated. Two different options for an additional vehicle capacity are considered:

- A vehicle of capacity 15, as this would fill the largest jump in capacity currently present with the vehicles.
- A vehicle of capacity 3, as the large majority of pickups have an expected volume of equal to or less than 3 roll containers.

The different vehicles are simulated for the same three areas as used before, and by applying either the current planning accuracy, or the one achieved by using the first approach of the prediction model.

15 roll container capacity

Table 7.17 gives an updated view of the vehicle pool, showing the characteristics of the added vehicle.

Vehicle	Vehicle 1	Vehicle 2	***Vehicle 3***	Vehicle 4	Vehicle 5
Capacity (RC)	0	6	***15***	30	56
Division	Mail	Mail	***Additional***	Parcel	Parcel
Average speed	40	40	***40***	40	40

Table 7.17 – Updated vehicle set

The vehicle is added to the simulation model and the simulation executed for both the current as well as the improved accuracy. The results of the simulation runs for both accuracies can be found in Table 7.18 and Table 7.19 respectively.

	Difference Total distance	**Difference Vehicles planned**	**Difference Vehicles used**	**Pickups not in window (excluding mailboxes)**	**Average time exceeding time window (min)**	**Max time exceeding time window (min)**
Area 1	***1%***	***5%***	***6%***	From ***8*** to ***10,9***	From ***9,4*** to ***9,1***	***21,9*** to ***20,5***
Area 2	***4%***	***7%***	***3%***	From ***8,8*** to ***11,3***	From ***11,7*** to ***10,7***	***27,9*** to ***26,4***
Area 3	***2%***	***1%***	***1%***	From ***7,1*** to ***7,8***	From ***10,5*** to ***10,3***	***24,8*** to ***23,1***
Average	***2,3%***	***4,3%***	***3,3%***	From ***8,0*** to ***10,0***	From ***10,5*** to ***10,3***	***24,9*** to ***23,3***

Table 7.18 – Difference when adding additional vehicle (current planning accuracy)

	Difference Total distance	**Difference Vehicles planned**	**Difference Vehicles used**	**Pickups not in window (excluding mailboxes)**	**Average time exceeding time window (min)**	**Max time exceeding time window (min)**
Area 1	***2%***	***4%***	***5%***	From ***16,6*** to ***16,9***	From ***10,7*** to ***9,5***	***26,4*** to ***25,4***
Area 2	***2%***	***2%***	***3%***	From ***15,2*** to ***14,3***	From ***12,7*** to ***12,3***	***27,0*** to ***26,7***
Area 3	***2%***	***2%***	***2%***	From ***15,6*** to ***11,5***	From ***12*** to ***10,5***	***27,2*** to ***24,8***
Average	***2%***	***3,7%***	***3,3%***	From ***15,8*** to ***14,3***	From ***11,8*** to ***10,8***	***26,9*** to ***25,6***

Table 7.19 – Difference when adding additional vehicle (higher prediction planning accuracy)

The results do not immediately show whether or not the addition of the vehicle has a positive effect on the collection process. There is an increase of total distance as well as the number of vehicles used, which is to be expected as vehicles are sorted on size from small to large during planning. As a result, more vehicles are used resulting in an increase in total distance as well. In terms of punctuality, it must be noted that the effect on the total number of pickups outside of the time window appears negative for the case of the current planning accuracy, while it is positive for the case of the increased planning accuracy. One explanation could be that having smaller vehicles means that –under the assumption that planned vehicle fill rate will remain equal- there is less absolute free space to be used in case of a planning error. For example, if all vehicles are on average planned to 90% of capacity, a vehicle with a capacity

of 10 roll container will have one free space available, while a vehicle with a capacity of 20 roll containers will have double that free space.
On the other hand, if the planning accuracy is higher, but the bias towards overestimating the collection volume lower, having smaller vehicles can be beneficial for the punctuality. The reason for this is that a smaller vehicle will typically have fewer customers assigned to it. When it is just as likely to overestimate the customer volume as it is to underestimate it, there will be instances where a vehicle will see a number of customers presenting more volume than expected, this means a longer handling time and a later arrival at the next customer. The total increase in handling time will grow the more customers are handled. As a result, if the number of customers is large enough, the last customer might not be served within its time window. This risk is lower if fewer customers are assigned to a vehicle.

Looking at how the customers are distributed over the different vehicles (Figure 7.18) however gives some more insight in the benefit of adding an additional vehicle. Adding the vehicle means an increase in the use of smaller vehicles, and the reduction of some bigger vehicles (see Table 7.20). The total vehicle capacity after adding the vehicle is reduced by 128 roll containers, indicating that the fill rate per vehicle has increased. However, this does not necessarily translate to a reduction in cost as larger vehicles will have lower per roll container cost due to economies of scale. Further investigation will be required to derive a conclusion on the topic.

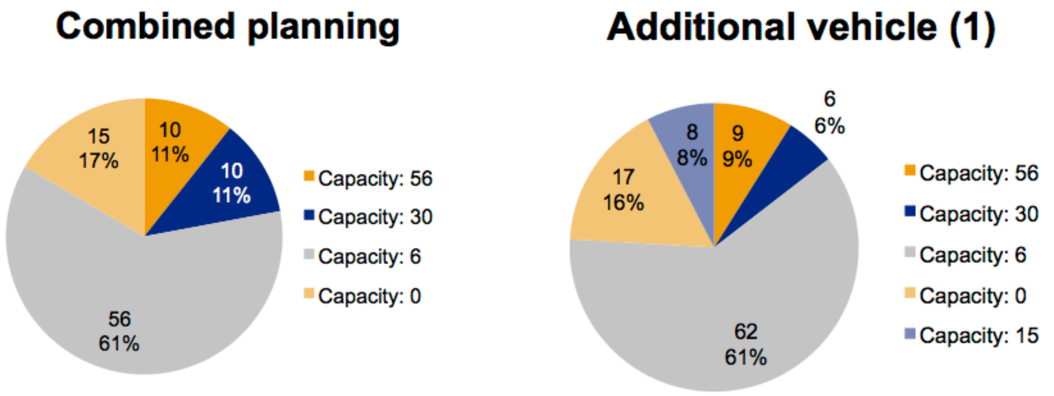

Figure 7.18 – Average vehicle use per capacity with an additional vehicle (1)

Vehicle	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4	Vehicle 5
Capacity	0	6	15	30	56
Difference in use	+2	+6	+8	-2	-4

Table 7.20 – Changes in the number of vehicles used per type

3 roll container capacity

Again, Table 7.21 gives an updated overview of the total vehicle pool. The simulation is performed in the same fashion as explained for the previous vehicle addition. The results are shown in Table 7.22 for the regular planning accuracy, and in Table 7.23 for the increased accuracy following from the prediction model.

Vehicle	Vehicle 1	***Vehicle 2***	Vehicle 3	Vehicle 4	Vehicle 5
Capacity (RC)	0	***3***	6	30	56
Division	Mail	***Additional***	Mail	Parcel	Parcel
Average speed	40	***40***	40	40	40

Table 7.21 – Updated vehicle set

	Difference Total	**Difference Vehicles**	**Difference Vehicles used**	**Pickups not in window**	**Average time exceeding time**	**Max time exceeding time**

	distance	**planned**		**(excluding mailboxes)**	**window (min)**	**window (min)**
Area 1	*1%*	*25%*	*15%*	From *8* to *8,9*	From *9,4* to *9,4*	*21,9* to *21,4*
Area 2	*7%*	*27%*	*14%*	From *8,8* to *9,7*	From *11,7* to *10,1*	*27,9* to *22,3*
Area 3	*4%*	*18%*	*13%*	From *7,1* to *11*	From *10,5* to *11,7*	*24,8* to *26,6*
Average	*4%*	*23,3%*	*14%*	From *8,0* to *9,9*	From *10,5* to *10,4*	*24,9* to *23,4*

Table 7.22 - Difference when adding additional vehicle (current planning accuracy)

	Difference Total distance	**Difference Vehicles planned**	**Difference Vehicles used**	**Pickups not in window (excluding mailboxes)**	**Average time exceeding time window (min)**	**Max time exceeding time window (min)**
Area 1	*12%*	*30%*	*32%*	From *16,6* to *8,9*	From *10,7* to *11,7*	*26,4* to *23,4*
Area 2	*15%*	*31%*	*30%*	From *15,2* to *16,4*	From *12,7* to *13,9*	*27,0* to *27,2*
Area 3	*19%*	*35%*	*33%*	From *15,6* to *14,4*	From *12* to *13,6*	*27,2* to *26,6*
Average	*15,3%*	*32%*	*31,7%*	From *15,8* to *13,2*	From *11,8* to *13,1*	*26,9* to *25,7*

Table 7.23 – Difference when adding additional vehicle (higher prediction planning accuracy)

The results are in line with what was found with the previous vehicle addition. In general, there is an increase in the number of vehicles used as well as the total distance travelled. Again, the addition of the vehicle appears to have a positive effect on punctuality when the planning accuracy is high, while the opposite is true for the case of the current planning accuracy.

Figure 7.19 as well as Table 7.24 show what impact the addition of the vehicle has on the distribution of the customers over the vehicles, as well as the absolute change in number of vehicles. The addition of the vehicle results in an increase in total vehicle capacity of 12 roll containers, which can almost be neglected. Generally speaking, it can be concluded that each vehicle with a capacity of 6 roll containers is now replaced by two vehicles of 3 roll containers. Given that the impact on punctuality is small, it is highly unlikely that using a smaller vehicle type will be beneficial as the per roll container cost of a small vehicle will most likely be higher than a larger vehicle.

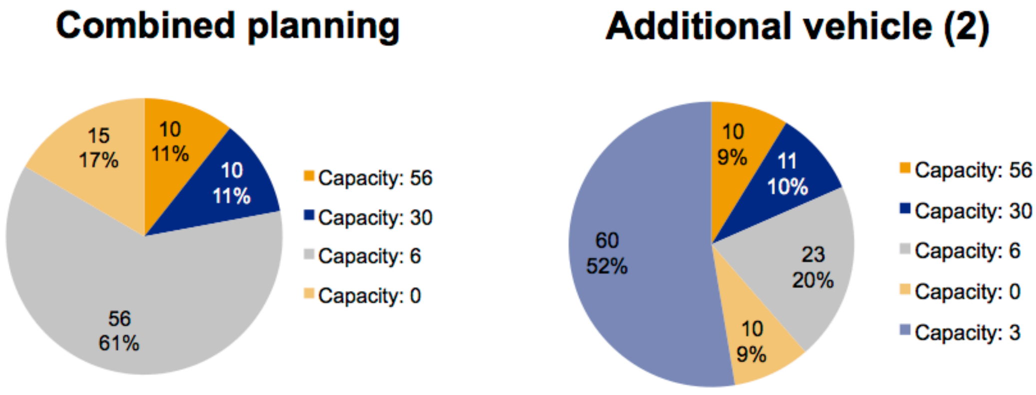

Figure 7.19 – Average vehicle use per capacity with an additional vehicle (2)

Vehicle	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4	Vehicle 5
Capacity	0	3	6	30	56
Difference in use	-5	+60	-33	+1	0

Table 7.24 - Changes in the number of vehicles used per type

7.6 Conclusion on simulation results

Based on the different experiments performed with the simulation model, a number of conclusions can be drawn:

- **Combining the planning of both divisions is likely to improve overall collection process performance.** While the impact on punctuality is small, the reduction of total distance driven as well as the number of vehicles used is large. As these are the main cost drivers for the collection process, it is likely that combining the planning will reduce total cost.
- **Applying a prediction model to improve accuracy could benefit cost, but might negatively impact punctuality.** Having the planning as accurate as possible showed to help reduce the number of vehicles needed, which could reduce collection cost. However, having vehicles planned as efficiently as possible while not having a strong bias for [redacted] collection volume leaves little room for error when customers turnout to have a higher collection volume than expected. On the other hand, by applying the "safer" approach to using the prediction model, the punctuality could be strongly improved. This was however at the expense of efficiency.
- **A balance between efficient planning and customer satisfaction should be found.** As was shown by the previous point, a balance should be found between having an efficient collection process that is still punctual. Further investigation is however required as to which way is best to achieve this balance. For example, a tighter time window could be used during planning than was agreed upon with the customer, forcing the model to leave room for error. In a similar fashion, the bias of overestimating the collection volume could be adjusted to build in room for error.
- **Having back-up vehicles available does not improve collection performance**. The simulation model indicates that having vehicles available at the depot to be used when replanning is required, does not improve the collection performance.
- **Adding vehicles could be beneficial, but further investigation is required.** While it is unlikely that adding a vehicle smaller than six roll containers is beneficial for the collection performance, it is possible that adding a medium sized vehicle will decrease collection cost as the simulation indicates that doing so would slightly increase the average vehicle fill rate. Further investigation into the cost related to such a vehicle is however required.

7.7 Remarks on model assumptions and limitations

While the simulation model makes it possible to test a large number of different collection configurations and settings in a relatively short time (a few seconds instead of a few hours when using the current planning system), there are a number of limitations to the model due to the assumptions made. When it comes to the customer set used in the simulation runs, Section 7.4 already addressed the assumptions at length. Instead, this section will focus on the assumption and limitation of the model itself.

Constant speed and handling time

The model makes use of a constant speed as well as handling time for each vehicle and simulation run. In practice however, there can be variations in both.

Traffic jams and other obstructions while driving can negatively impact the average speed that can be achieved during collection. Next to that, it can be assumed that the larger the vehicle, the lower the average speed might be. While it is not difficult to add a distribution to the vehicle speed in the model, it was deemed unnecessary given the scope of the research and the lack of information regarding average vehicle speeds.

Regarding the handling time, it can again be argued that adding a distribution for this parameter would increase the accuracy of the model. Not only will there be a difference between pickups, but there might also be a difference in speed between different collection drivers. Next to that, not every collection customer is equally as easy to reach. While it is possible to park the vehicle right in front of the customer, sometimes it might be necessary for the collection drive to walk a certain distance before reaching the customer, thus increasing the handling time. Again, given the scope of the research and lack of information, adding more accurate handling time to the model was not found to be needed.

Distance between customers

Another limitation to the model is the way the distance (and thus the travel time) between customers is determined. The model simply assigns an X and Y coordinate to each customer. Based on these coordinates, the travel distance is determined as the straight line distance between the customer and the current location of for example a vehicle. Doing so makes it possible to quickly determine the distance between two location. Making use of more accurate information, for example using the actual road network, would mean having a distance look-up table with $(p+1)^2-p$ elements, with p being the number of different pickup locations (or half of the elements if the travel time is assumed to be independent of the direction). For the used datasets, this would mean over a million elements which need to be recalculated every time a new dataset is generated. While it is worth investigating the impact of this assumption, having another approach would defeat the purpose of the simulation model (to quickly test different collection setups).

Single depot

The model assumes the use of a single depot to which all collected items are shipped. This assumption can be made when simulating a region such as Zwolle, where the parcel depot and the mail depot are just a few kilometers separated from each other. However, when applying it to another region, the model could require the addition of a second depot to which items can be shipped.

Application of only a single planning strategy

While the model features a number of different strategy settings, the decision was made to only apply a single strategy for the experiments. While the other strategies are tested throughout the building of the model and also used in verification, the choice is made to not apply the other settings to the experiments. This is in part due to the incompatibility of some options with the dataset, but also since the goal of the model is not to find the preferred planning method, but to make a fair comparison between different collection arrangements under a constant planning strategy.

While there are clear limitations to the simulation model as used for this research, it is worth reiterating that the goal of the model is to compare different situation based on the simulation results. As the assumptions are the same for each of these situations, a comparison would still be valuable. This would have been different incase the simulation results would have been compared to the results of the current situation at PostNL as this would have been an unfair comparison.

8 Implementation

Based on the previous Chapters, a number of improvements in the way the collection process should be organized is brought forward. These can be summarized as having a collection process that is both organized company wide, offering flexibility to customers in terms of collection volume, and having information available regarding collection volume on which collection runs can be dynamically planned. This chapter will address which challenges must be overcome to implement such an improved collection process. The chapter will focus on the implantation from an operational perspective on the one hand, and a commercial perspective on the other hand. While the former will focus on the internal challenges, the latter will focus on what kind of agreements need to be made with the customer to make such an approach to collection feasible.

8.1 Operational perspective

Implementation from an internal perspective should focus mainly on applying the revised functions as discussed in Chapter 5 into practice. The main changes between these functions and the current functions as discussed in Chapter 3 lay with the following points:

- A centralized dynamic planning process.
- Improved measuring and evaluation of processes.

Each of these points will be addressed in this section.

8.1.1 Centralized and dynamic planning

The main challenge identified during this research was the difference between the fluctuating collection volume presented by the customer versus the constant planning volume on which the collection routes were based, resulting in an inefficient collection process. The main changes that are proposed to improve this, is to have a centralized planning department that does not work with fixed collection volumes, but has an input of tasks that changes daily, based on available information.

Combining the planning departments

The first step in achieving this, is combining the planning department from the mail division and the parcel division. During the research, it was found that whereas there are large differences in the way collection is planned and measured, they essentially start with the same tasks; a certain volume (expressed in a number of load devices) should be collected at a certain location, within a certain time frame and be delivered to a certain destination. In terms of resources, both divisions also have similar capabilities. Both have a fleet of vehicles with different capacities as well as the option to purchase capacity from subcontractors. When combining both planning departments, a decision has to be made as to which planning system is used for all future collection tasks. While the parcel division currently works mostly based on experience, the mail division uses a planning system that uses algorithms to solve a vehicle routing problem that is derived from the different collection tasks. The former approach is quicker whereas the latter should result in a more efficient collection route. Next to that, planning vehicles manually based on experience is not feasible for the number of tasks that the mail division has to plan compared to the number of tasks for which the parcel division is responsible. As a result, the planning system used by the mail division would be better suited to plan all collection tasks in a centralized way. Doing so would involve extending the planning system to take into account not only the tasks currently planned by the parcel division, but also a number of other factors. These include the characteristics of the vehicles used by the parcel division (price per kilometer, driver wage per hour, etc.) as well as the PostNL locations used by the parcel division (i.e. parcel depots). Some discussion might occur when it comes to determining the characteristics of the vehicles of the parcel division. It is important that these are comparable to the characteristics of the current vehicles present in the mail division planning system. For example, when determining the per kilometer price of one of the newly added vehicles, the same components must be included in the price as was done for the vehicles already present in the mail planning system (such as whether or not to include the costs related to wear on the tires). However, since all cost components are already known by PostNL, it should in theory be possible to determine. After successfully integrating the tasks and resources of the parcel division into the planning system of the mail division, all collection routes can be reevaluated, with the goal of achieving the improvements that were found in Section 7.5.1.

Dynamic planning of volumes

The next important step lays in making the planning process dynamic. Currently, it is only necessary to plan routes when a new task is added. In a future state, planning of routes should occur on a daily basis. When discussing dynamic planning of routes, a distinction can be made between planning before starting a route and planning during the execution of a route. The most important dimensions in which these forms of planning differ is the amount of information required and the speed with which planning should occur (see Figure 8.1). The current planning process requires little information. Customers indicate a volume that needs to be collected on a daily basis. Based on this volume, routes are planned. As these volumes do generally not change, there is little planning speed required. When dynamically planning routes on a daily basis before execution, more information is required regarding the collection volumes. Possible information sources addressed in this research were the pre-shipping notifications and the acceptation scans. While it is possible to further investigate the use of these information sources, an alternative would be to generate new sources of information. These could for example include customers proactively indicating expected collection volumes (which will be discussed in more detail in the next section). Next to requiring more information, it is also necessary to be able to quickly plan collection routes. As it is recommended to plan routes on a daily basis, it is per definition required to perform the planning process within 24 hours. However, the closer the routes are planned to the actual collection time, the more accurate the information will be as more of the collection volume will be known. This should be taken into account when deciding on which planning system to use and how to use it.

The next step would be to perform dynamic planning during the execution of the collection routes as was also done when applying the simulation model. As more and more customers are collected, more information becomes available on the actual collection volumes and thus remaining capacity in the collection vehicles. This information can be used to replan more efficient routes for the remaining customers that still require collection. Next to that, it makes it possible to deal with unexpected occurrences such as exceeding vehicle capacity or a vehicle breakdown as efficiently as possible. Having dynamic planning during execution does not only require information to flow from the customer to the planning department and in turn to the driver, but also the other way around.

Finally, something to take into consideration is that routes driven by the mail division occurs in two waves; a morning wave where mail is delivered to customers (not addressed in this research) and an evening wave in which mail and parcels are collected at customers. For the parcel division, routes are typically a lot longer and do not have a start and an ending as clear as with the mail division. This makes the boundary between dynamic planning before execution and during execution a lot less clear.

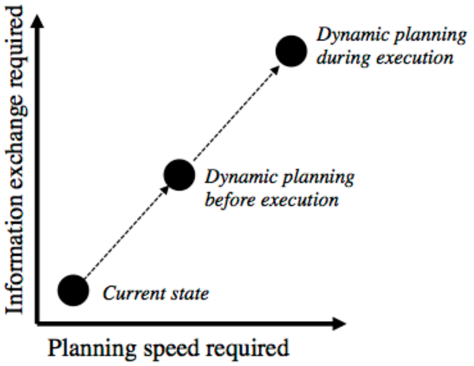

Figure 8.1 – Stages of dynamic planning

Impact on the driver

Having routes planned dynamically has great impact on the collection drivers actually executing the routes. Currently, routes are mostly known in advance with some small changes possibly being made last minute. After starting, the route will almost never change[5]. This means that the drivers know in advance how long their shift will last and where they need to drive to. Better still, there currently are constraints to the minimum and maximum length of a route. On the one hand, a driver should make a minimum number of hours to insure they receive enough wage in a month, while on the other hand, drivers can only be en-route for a certain number of hours. These requirements can limit the benefit of dynamically planning the collection routes. It is thus worth to further investigate if for example paying collection drivers a fixed wage regardless of the number of hours their route takes, is outweighed by the improved efficiency of dynamic planning.

8.1.2 Improved measuring and evaluation of processes

Another important improvement to be implemented is to continuously measure and evaluate the performance of the process. The most important parameter to measure is the actual collection volume that customers present. Not only can this be used to determine performance indicators such as the vehicle and order fill rate, it also indicates how accurate the information was on which the collection routes were planned.

Currently, collection drivers of the mail division are equipped with a computer terminal that shows their route and is used to indicate their position to the control room. By changing the software on their terminal to include the option to register actual collection volumes, it should be possible to accurately measure this. This can be done by having it be a part of the process at a customer when picking up collection volume. Important to consider is the incentive for drivers to register the collection volume accurately. For example, if it is easier for a driver to indicate that the collection volume was as planned then to register a deviation from planning, one can expect the measurements to be inaccurate as drivers might want to quickly got through the collection process at the customer.

Based on the measurements, the performance of the collection process can be measured and changes can be made to the collection process accordingly.

8.2 Commercial perspective

Next to an operational perspective, the commercial aspect of implementing changes to the collection process should also be considered. This commercial perspective mainly involves the agreements that are made between PostNL and the customers. The main questions to be answered include:

- What is agreed with the customer?
- What information is required from the customers?
- How is the customer charged for collection?

Currently, agreements with the customer regarding collection mostly involve setting a collection volume, a load device to be used and a time window. These factors directly influence the price charged for collection. This price is set when the customer and PostNL first agree to use collection and is based on the expected collection volume. As the collection price is often included in the price per parcel that is shipped, it is beneficial for a customer to overestimate the collection volume as this means that the per parcel price that is actually

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[5] It is possible to send a message to the terminal of the collection driver to include another pickup into the route. This is currently however only done if absolutely necessary.

charged, will be lower. This is expected to be one of the reasons for the inaccuracy between planned and actual volume.
Next to that, the research brought forward both the wish from the customer to be flexible in collection volume, as well as the opportunity to improve the collection process efficiency by dynamically planning the routes. Doing so would however mean that a new way is required in which the collection volume is included in the prices.
It is thus important to determine how the agreement with the customer can be made so that the customer is charged for what is actually collected as opposed to what is expected.

An option would be to treat collection in the same way as distribution, and charge the customer a fixed fee for each parcel that is collected, independent of the total volume that is collected. In this case, customers would simply indicate they want to make use of collection. Although doing so will ensure fair pricing, it does mean that large customers of PostNL will end up paying more per collected parcel then they currently do, while smaller customers end up paying less than they currently do. Given that the larger customers of PostNL make up for the majority of revenue, this is not a desirable approach. Next to that, it removes any indication PostNL has as to what volume will be collected at the customer. Finally, by charging customers per parcel instead of per load device, there is no incentive for customers to efficiently fill the load devices.

An alternative would be to charge customers for each load device that is collected. By having customers purchase a number of load devices that is guaranteed to be collected, they are motivated to only purchase what is necessary. It is then up to PostNL to determine if they want to use this number of load devices in their planning process, or deviate from this if their information sources (such as pre-shipping notifications) indicate that it is preferable to do so. While this might seem positive from the perspective of PostNL, it requires a customer to change their collection order on a daily basis as not to overpay. Given that customers indicated that the main reason for choosing PostNL to collect their mail and parcels as opposed to dropping it off themselves is the added convenience, it is expected that customers are not willing to do so. This is however all dependent on how difficult it is to do. They might be willing to do so if the process is easier than it is now.

The final option is closest to what was already addressed when discussing pre-shipping notifications; have customers pay for what they actually have collected, and make agreements regarding the way in which customers indicate the volume they expect. By agreeing that customers send pre-shipping notifications in a consistent way or by agreeing on another way by which the customer can easily inform PostNL about the actual collection volume, it is possible to offer customer flexibility while still being able to efficiently plan the collection.

9 Conclusion and Recommendations

The research set out to determine to which extent the current collection process of PostNL was performing as required by its customers and by PostNL itself. After analyzing the current collection process using the *Delft Systems Approach*, as well as performing a number of in-depth customer interviews, it was found that there was room for improvement in the current way of controlling and executing the collection process. While customers require flexibility from the collection process due to fluctuations in collection volume, PostNL currently uses fixed planning volumes that are not systematically updated. As a result, there is a large difference between planned and actual collection volume of [redacted]% for the parcel division, of which reliable performance information is available. It was shown that this difference on a customer level had a direct impact on the actual vehicle fill rate, which was found to be [redacted]% while a fill rate of [redacted]% was planned for. Next to that, there was a lack of control in the collection process. Due to a lack of information regarding actual collection volumes, a feedback loop is missing that evaluates and adjusts the expected collection volume for each customer. Finally, it was found that the separation between the mail and parcel division could possibly decrease the efficiency of the collection process. Based on these findings a number research questions were proposed, focusing on how the collection process should be controlled and executed. The main research question to be answered was:

How should the collection process be arranged, controlled and executed as to improve the process performance while taking into account the uncertainty in collection volume?

By again applying the *Delft Systems Approach*, it was found that the largest information source currently lacking to successfully control the collection process, is an indication of the actual volume a customer is having collected. By having this information available, the collection tasks can be updated on a frequent basis, helping to reduce the difference between planned and actual collection volume. By then measuring the actual collection volume during execution, the information regarding expected collection volumes can be checked and update, resulting in a feedback loop that is now missing.

Although currently not used, there is already information available that could help determine the expected collection volume. This information includes pre-shipping notifications. By using historical data it was shown that for a customer that sends these pre-shipping notifications consistently throughout the day, the planning accuracy could be improved by as much as [redacted]%. The downside to improving the planning accuracy is however the number of occurrences were the expected volume is exceeded by the actual volume, possibly resulting in exceeding vehicle capacity during collection.

A simulation model was proposed, build, and successfully verified in order to test the impact of this increase in planning accuracy, as well as different approaches to executing the collection process (for example combining the mail and parcel division as well as introducing additional vehicles) on the main cost drivers of the collection process; the number of kilometers driven and the number of vehicles used.

Based on four different experiments it was found that combining the mail and parcel division into a single planning department could reduce the number of kilometers and the number of vehicles used by [redacted]% and [redacted]% respectively. Next to that, by achieving a similar planning accuracy as was found when using the pre-shipping notifications, a further reduction in vehicles could be achieved. However, an increased accuracy indeed led to more customers being collected too late, showing the balance between efficiency and punctuality when uncertainty on collection volumes exists.

Based on the research, a number of recommendations can be made to PostNL that should either improve the collection process performance, or are worth further investigating:

- Currently, the mail division does not measure the volume that is collected at the customer. This not only makes it impossible to determine the performance of the collection process, it also means that it is not possible to have a feedback loop on the volume the customer expected to have collected. Given that collection drivers are equipped with a hand terminal, it should be possible to include measuring the collection volume in the process of picking up load devices at the customer. When doing so however, one must consider the way in which the driver enters the data, making sure there is no motivation to register an incorrect volume (for example because it is easier to do so).

- The process of registering a customer wish should be set up in such a way that there is no motivation to either over- or underestimate the volume a customer is expected to have collected. Next to that, a feedback loop should be implemented where the customer volumes are updated on a regular basis, based on information gathered during collection such as actual volumes (see the previous point).

- The simulation indicated that combining the planning of both the mail as well as the parcel division could have a large positive impact on the performance of the collection process. Given that a collection task looks the same for both of these departments, there appears to be a low barrier to combining them into a single planning run. It is thus recommended to consider combining the two planning departments in a single one.

- It is recommended that further investigation is performed into which sources of information can be used to gaining insight into the actual collection volume at the customer. While it was shown that using pre-shipping notifications can improve the planning accuracy, it does not necessarily have to be the best source of information. Next to that, the commercial implications of having the planned collection volumes change day to day should be addressed. Important questions to be answered are what agreements are made with the customer in terms of minimum and maximum collection volumes that can be collected, as well as in which way the customer is charged for collection. Finally, it might be worth considering given the customer a discount on the collection if they provide reliable information regarding actual collection volumes themselves.

While the presented research gives important insights into the performance of the current collection process of PostNL and offers a number of concrete improvements, there is still room for future research. Most important is the balance between efficiency and punctuality. The simulation model showed that it is possible to reduce the number of vehicles required for collection when improving the planning accuracy. However, trying to utilize the vehicles as much as possible means having little room for error when the collection volume of a customer exceeds expectations. Future research could focus on what is the best balance between these two. The two different approaches to using the prediction model based on pre-shipping notifications showed the two extremes. A next step could be to find an application where the benefits are maximized while minimizing the downsides.

Next to that, the simulation model used in this research presents a number of limitations and opportunities for future research. By investigating and subsequently implementing a more accurate way to represent the distance and drive time between the different customers, as well as the handling time at the customer, the accuracy of the model could be further improved. Also, while the model was extensively verified, it was not possible to validate the model, limiting the value of its outcomes. By either having the model represent the actual planning process or by testing the same planning process used in the simulation in practice, validation of the model should also be possible. Finally, the simulation model did not take into account the agreements with the drivers regarding minimum and maximum working hours. While these are not set in stone, it can be important to take these into account as well.

Finally, the unit of volume used in this research were the load devices used by the customers to ship postal items. Subsequent research could investigate the collection process on an item level (for example individual parcels) instead of a load device level. Doing so could for example mean looking at the level to which the load devices are actually filled. This can especially be interesting for customers that only have a single load device unit collected, as the effects could be the biggest in that case.

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I Scientific paper

Improving the control and execution of the mail and parcel collection process under uncertainty in collection volume

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Abstract – While the focus in shipping postal items is mostly on the distribution side by offering different delivery options to consumers, having a well performing collection process is a first important step in efficiently shipping a postal item to a consumer. This research addresses the current collection performance at a large mail, parcel, and e-commerce corporation, as well as possible improvements that can be made to the control and execution of this process. By applying the *Delft Systems Approach* to analyze the current process, it was found that there is a disconnect between the planned and actual volumes collected at customers of the company. This disconnect directly impacted the vehicle fill rate, which indicates inefficiencies in the current collection process. Subsequently a prediction model is proposed and successfully test for two customers that uses currently available information to reduce the difference between planned and actual volumes, thus improving the planning accuracy. Finally, a discrete time simulation model was used to show that while this improved planning accuracy has a positive effect on one of the main cost drivers of collection, it does negatively impact the punctuality.

I Introduction

With more and more people ordering online, the market for parcel delivery is ever growing. The different companies offering the service of shipping postal items are competing by offering an ever increasing number of delivery options, such as same-day deliver, delivery to a parcel point (either manned or unmanned), or evening delivery. However, the fulfillment process of postal items such as mail and parcels often starts with the collection of these items at the customer of the postal company (for example a webshop). While companies often focus on the delivery side, having a well performing collection process is a first important step in efficiently, quickly, and successfully shipping a parcel to a receiver. This paper investigates the collection performance at a large postal, parcel, and e-commerce corporation. The goal is to investigate the current performance and address in which way improvements can be made to the control and execution of this process.

II Method

In order to provide a structured analysis of the current collection process, the *Delft Systems Approach* is applied [1]. First, the primary function under investigation is defined, as shown in Figure 1. It concerns the process of transforming load devices (filled with for example parcels or mail items) into collected items. This function should meet certain requirements that are imposed by the environment in which it operates. In return, the function delivers a certain performance that should match the requirements as closely a possible.

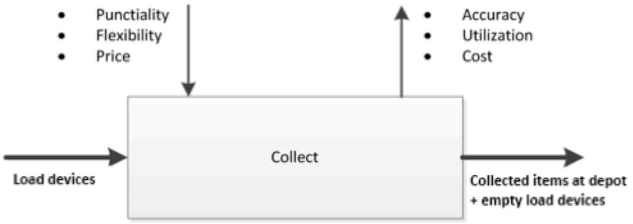

Figure 1 – The primary function

The root definition of this function is given as: *A system that utilizes the employees and other resources of PostNL to perform all the necessary handlings to move the item (such as a parcel), loaded and transported in a load device, from the shipper (such as a webshop) to the depot as efficiently as possible, while meeting the agreement with the shipper, with the goal of providing the shipper the convenience of not transporting the parcel to a depot themselves.*

While this overview provides an initial insight into the system under investigation, a further, more detailed description is required. Following the methodology of the *Delft Systems Approach*, an industrial system can be analyzed by addressing three different *aspects* of the system; the material flow, the order flow and the resource flow. In this case, the material flow represents the flow of items, the order flow the customer wish to have parcels collected, and the resource flow the use of different people, vehicles, and other means to execute the collection of parcels. To do so, a PROPER ("PROcess-PERformance") model of the collection process will be defined [1].

Figure 2 gives a high level overview of the system under investigation. A customer wish is transformed into a handled customer wish by the responsible departments. This transformation results in a task that is executed by the "collect" function. This function transforms a "load device" into "collected items & empty load devices". To do so, the collect function assigns resources to execute the function of "collection". The application of these resources are found in the "use" function, which transforms these "resources" into "used resources".

Above the three aspect, the control function is found. Since there are as well control functions within the different aspects, this control function is named "coordination control" as it coordinates the three aspects.

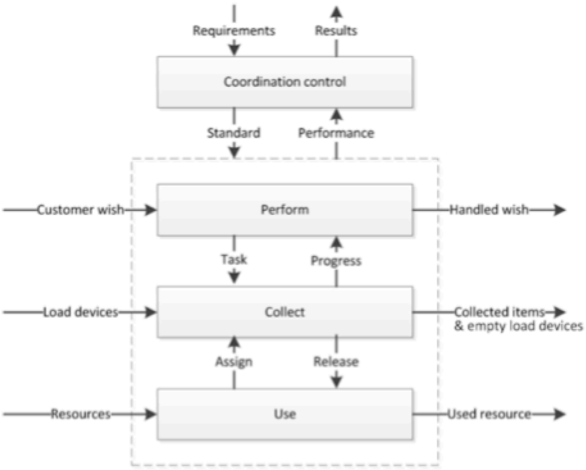

Figure 2 – PROPER model of the collection process

However, it must be noted that while the three processes run in parallel, they occur on a different timescale. While the customer wish is transformed in a handled wish roughly once a year, the collection process occurs daily. This means that the task that is set by the perform process is independent of the input of parcels.

Based on a total of nine in-depth interviews, customers of the postal company indicate that they notice strong fluctuations in the volume they ship. As a result, not having a collection task that matches this fluctuation is expected to lead to a difference between planned collection volume and actual collection volume (as will be discussed in the *results* section).

Prediction model

Given that there is currently a disconnect between the planned collection volumes and the fluctuating actual collection volumes, it is worth investigating a way to have the planned collection volumes matches more closely to the actual collection volumes by making a prediction or forecast of these volumes.

The volumes as they are collected every day is considered a time series as they are *a collection of observations made sequentially through time* [2]. A large number of techniques can be found in literature to forecast the future values of such time series. These range from simple techniques such as using a moving average to more advanced techniques such as exponential smoothing (see for example the Holt-Winters method [3]). However, these techniques rely on contributing the variation in the time series on the presence of a trend or seasonal behavior [2]. However, while there might be a long term trend in the ever increasing number of parcels people order online, the day-to-day volumes per customer do not appear to follow a specific trend. This became clear during the interviews were customers noticed the strong fluctuation in collection volume as well. As a result, instead of directly forecasting the collection volumes based on historic volumes, an alternative information source in the form of pre-shipping notifications is investigated for its predictive value when it comes to collection volumes. These pre-shipping notifications are generated by the customers of the postal company when sending a parcel and need to be received before collection takes place. As some customers send out notifications on a continues basis throughout the day, it can be used as an indication of the number of parcels and thus load devices the postal company can expect to collect. This approach is similar to the one utilized by Chambers & Eglese [4] where it was applied to predicting the demand for mail order catalogue fashion products.

By determining on a per-customer basis how the sending of pre-shipping notifications is distributed over the day, a prediction of the total number of pre-shipping notifications (and thus items) at the time of collection can be made. Figure 3 shows the distribution of pre-shipping notifications as they are send by a specific customer for each work day. The expected total number of notifications as predicted at time t, equals the number of pre-shipping notifications so far received at time t, multiplied by the percentage of notifications that is historically received at time t.

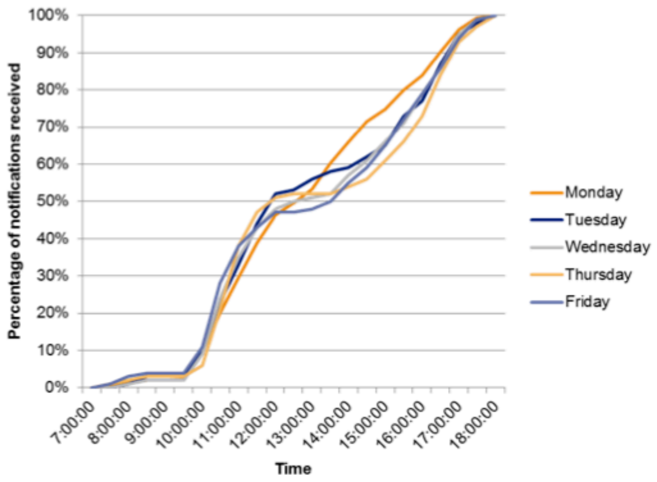

Figure 3 – Distribution of pre-shipping notifications

Under the assumption that the number of notifications equals the number of items that are collected, the total collection volume can be predicted by assuming an average number of items per load device. Having done so makes it possible to improve the accuracy with which collection volumes are planned.

Simulation model

In order to see if having more insight into the actual collection volumes on a customer level will positively impact the collection process performance, a discrete time simulation model is build. The process performance measures under investigation are the total number of kilometers travelled as well as the number of vehicles used for collection, as these two factors represent the main cost drivers for the collection run. Next to that, the punctuality of the collection (times collected outside of the time window) is also measured. By modeling the collection process and applying it to different sets of customers using different values for the planning accuracy, insight can be gained in the impact of these factors on the aforementioned cost drivers and punctuality. The simulation model is implemented using the Embarcadero Delphi programming language and developing environment. In addition, Tomas is used in order to model the discrete time simulation [5].

An important aspect of the simulation model is the construction of collection routes. Doing so means finding a solution to a variant of the *vehicle routing problem* that includes time window constraints (VRPTW) [6]. When trying to solve this problem to optimality, an exact algorithm such as *branch and cut* is typically used [7]. However, given the large computational time required to solve a VRPTW using an exact algorithm, a heuristic is used in the simulation model instead. Specifically, two variants of the *nearest neighbor algorithm* are implemented in the model as these can quickly find feasible routes for a large dataset and are simple to implement in the simulation model [8]. The first is a parallel route building heuristic where different routes are build up simultaneously, while the second one is a sequential one where a vehicle route is finished before building the next one [9].

III Results

Current state performance

The order performance of the current collection process is quantified by looking at the collection orders performed by the parcel division of the postal company under investigation, as this division keeps an accurate database of previous planned and actual collection volumes. In the month of June 2016, a total of [redacted] transport orders from customer to parcel depot were found. Each of these orders represents a pick-up at a customer.

An average order size of [redacted] roll containers was found. The average realized pickup size was however found to be a lot lower at [redacted] roll containers, resulting in an order fill rate of [redacted]. However, as shown in Figure 4, there are also a number of instances found where the picked-up volume exceeds the planned volume. On average, the absolute deviation between the planned and the picked-up volume is found to be [redacted] equivalent roll containers, meaning there is on average a [redacted] error between the planned and the collected volume (see Table 1).

Number of orders	[redacted]
Average order size (roll containers)	[redacted]
Average realization (roll container)	[redacted]
Average order fill rate	[redacted]
Average absolute deviation (roll container)	[redacted]

Table 1 – Current collection performance

[redacted]

Figure 4 - Categorization of planned volume vs. realized volume

Closely related to the order accuracy is the vehicle fill rate. The vehicle fill rate describes to which extend a vehicle is utilized during transport. By combining the data regarding the planned and actual collection volumes with the route compositions (i.e. how pickups are combined in routes), it is possible to quantify the vehicle fill rate. There are however different options in how to define the vehicle fill rate [10]. Here, two options are addressed. The first one gives the average vehicle fill rate over a complete trip, while the second option measures the vehicle fill rate at each stop where a certain part of the volume is unloaded. Table 2 shows the results for the first option, while Table 3 does so for the second.

Number of trips	[redacted]
Avg. planned veh. fill rate (option 1)	[redacted]
Avg. actual veh. fill rate (option 1)	[redacted]

Table 2 – Vehicle fill rate (option 1)

Number of stops	[redacted]
Avg. planned veh. fill rate (option 2)	[redacted]
Avg. actual veh. fill rate (option 2)	[redacted]

Table 3 – Vehicle fill rate (option 2)

As is shown in the tables, there is a large difference between the planned vehicle fill rate (which is the achieved fill rate in the case that the realized volumes matched the planned volumes for all pickups in the trip) and the actual vehicle fill rate, showing the impact on the order accuracy on the vehicle fill rate.

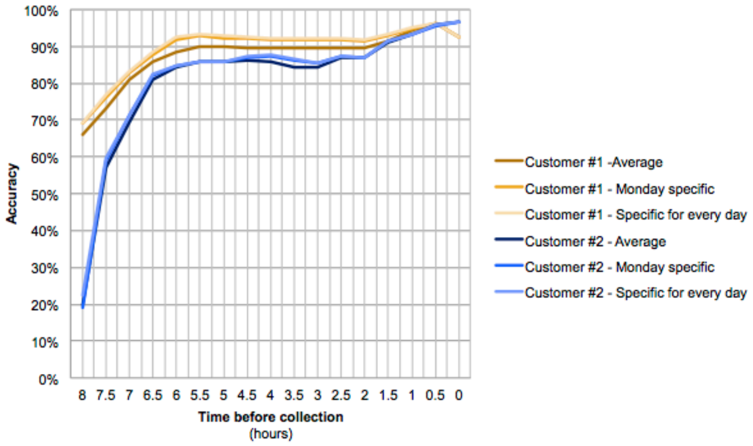

Figure 5 - Accuracy of the prediction (notifications to parcels) as a function of the time

Applying the prediction model

The before discussed prediction model is applied to two different customers that were found to send pre-shipping notifications continuously throughout the day on a consistent basis. One variable that is not yet discussed extensively, is the time *t* at which the prediction is made. It goes without saying the closer time *t* is to the collection time, the more accurate the prediction of the total number of pre-shipping notifications. Figure 5 shows the accuracy of the prediction as a function of the time (in this case, the number of hours before collection occurs). Furthermore, a distinction is made between using a distribution independent of the day, a specific distribution for Mondays vs. every other day, and a distribution dependent on the day.

As expected, the accuracy will become higher the closer before collection one measures. However, at roughly five hours before collection, the accuracy is already greater than 80%, which means that it should be operationally feasible to take the prediction into account when planning vehicles. Furthermore, the accuracy of the prediction increases as the distribution is more specific, as one would expected.

Figure 6 and Table 4 show one of the possible results for the first customer under investigation. In this case, the time of measuring the pre-notifications is set at 16:00, or 4 hours before collection. The number of parcels per roll container is varied and set at the value resulting in the smallest average deviation between predicted and realized.

[redacted]

Figure 6 – Prediction model applied to customer #1

	Prediction – 36 parcels/RC
Difference planned/predicted vs. realized volume	[redacted]
	[redacted]
Occurrences of exceeding planned/predicted capacity	[redacted]
	[redacted]
Required number of RCs	[redacted]
	[redacted]
Average order fill rate	[redacted]

Table 4 – Results of the prediction model

The results show that using the prediction model for this measuring time makes it possible to improve the planning accuracy by 67%, resulting in a reduction of transport capacity to be purchased of 49 roll containers. Furthermore the number of times the customer is possibility confronted with insufficient vehicle capacity is reduced by one occurrence.

It is however worth noting that it turns out that the performance of *customer 1* is not typical. The customer is experiencing strong growth, resulting in underestimated planning volumes in the month of July (which is atypical compared to what was found with other customers). As a result, the reduction in the required number of roll containers is limited as the number that was planned with was already low. Furthermore, while the number of occurrences of exceeding the planned/predicted volume decreased, it is still higher than desirable.

The results for the second customer are shown in Figure 7 and Table 5, but now using two different values for the average number of parcels per roll container. For this customer the measurement is performed at 15:00, or 3 hours before collection.

The first prediction uses 74 parcels per roll container and results in the lowest difference between predicted and realized volumes. However, when doing so, the number of occurrences of customers presenting more volume than planned/predicted sharply increases (from 2 to 11 occurrences). This is no surprise given that when trying to plan as closely to the expected volumes as possible, the chance of the actual volumes to slightly exceed the planned volume is higher than when planned volumes are typically overestimated (as currently is the case).

When striving to keep the number of occurrences at the same level as currently is the case, the best results are achieved when using 50 parcels per roll container in the prediction model. In this case it is still possible to improve the accuracy by 44,5% and reduce the number of roll containers by 23%.

[redacted]

Figure 7 - Prediction model applied to customer #2

	Prediction (1) – 74 parcels/RC	Prediction (2) – 50 parcels/RC
Difference planned/predicted vs. realized volume	[redacted]	[redacted]
Occurrences of exceeding planned/predicted capacity	[redacted]	[redacted]
Required number of RCs	[redacted]	[redacted]
Average order fill rate	[redacted]	[redacted]

Table 5 – Results of the prediction model

Applying the simulation model

The simulation model is applied to three randomly generated collection regions that are filled with different kinds of pick-ups. These range from for example mailboxes (low volumes and no time window) to collection at customers of either the parcel or the mail division. The characteristics of the generate dataset in terms of the distribution of pickups over the region, the actual volumes, the time windows, and the total number of pick-ups for each kind, are in line with those found in a current collection region.

In order to test the impact of planning accuracy, three different scenarios will be simulated. The first one will be the base scenario using the current planning difference as well as the current bias to overestimating the collection volumes as found for the parcel and mail division. The next scenario will use the planning difference and bias as found when applying the first instance of the prediction model to *customer 2* (using 74 parcels/rc) and apply it to all pickups (thus assuming a scenario where the prediction model can be applied to all pickups in a similar fashion as with *customer 2*). The final scenario will use the second instance of the prediction model as applied to *customer 2* (using 50 parcels/rc). The reason for choosing *customer 2* over *customer 1*, is that the behavior found for *customer 2* matches more closely with the behavior typically found at collection customers. In all instances, the planning difference is modeled as a normal distribution and the simulation will be run for two weeks of collections. Table 6 gives an overview of the values as used for the different scenarios.

Table 7 and Table 8 show the result when comparing the result of the base scenario with the scenario where the accuracy achieved with the first instance of the prediction model for *customer 2* is applied to all pick-ups.

	Mean planning difference	Planning difference SD	Bias
Collection parcel division	[redacted]	[redacted]	[redacted]
Collection mail division	[redacted]	[redacted]	[redacted]
Prediction model (1)	[redacted]	[redacted]	[redacted]
Prediction model (2)	[redacted]	[redacted]	[redacted]

Table 6 – Planning difference for different kinds of pick-ups and scenarios

	Diff. Total distance	**Diff. Vehicles planned**	**Diff. Vehicles used**
Area 1	***-2%***	***-12%***	***-5%***
Area 2	***4%***	***-6%***	***-1%***
Area 3	***-0%***	***-10%***	***-4%***
Average	***1%***	***-9,3%***	***-3,3%***

Table 7 – Current accuracy versus increased accuracy using first prediction approach (1)

	Pickups not in window (excluding mailboxes)	**Average time exceeding time window (min)**	**Max time exceeding time window (min)**
Area 1	From ***8*** to ***16,6***	From ***9,4*** to ***10,7***	***21,9*** to ***26,4***
Area 2	From ***8,8*** to ***15,2***	From ***11,7*** to ***12,7***	***27,9*** to ***27,0***
Area 3	From ***7,1*** to ***24,5***	From ***10,5*** to ***12,0***	***24,8*** to ***27,2***
Average	From ***8,0*** to ***18,8***	From ***10,5*** to ***11,8***	***24,9*** to ***26,9***

Table 8 – Current accuracy versus increased accuracy using first prediction approach (2)

It becomes clear that increasing the planning accuracy mostly has effect on the number of vehicles used. As can be expected, increasing the accuracy means being able to assign more customers to a single vehicle during planning. The results show that not only is the number of vehicles actually used reduced, the effect is actually larger on the number of vehicles used in planning. During the simulation, a number of vehicles is assigned to customers during the first planning run, this number is shown as "Vehicles planned". During the simulation as customers and routes are replanned, it is possible that fewer vehicles are actually used during execution. (shown as "Vehicles used"). The vehicles that were planned but not actually used, would have been vehicles waiting to drive to their first assigned customer, but having their customers reassigned to other vehicles before leaving the depot. Having the number of vehicles planned decrease stronger than the number of vehicles used (thus reducing the difference between vehicles planned and vehicles used) has a positive effect on the collection operation as less vehicles (and drivers) are prepared for collection but not actually used. The increased accuracy sees little impact on the total distance travelled. While less vehicles are used, the distance per vehicles is increased as more pickups can now be combined in a route. As might however be expected, further increasing the planning efficiency has a negative effect on the punctuality.

Table 9 and Table 10 show the result when comparing the result of the base scenario with the scenario where the accuracy achieved with the second instance of the prediction model for *customer 2* is applied to all pick-ups.

	Diff. Total distance	**Diff. Vehicles planned**	**Diff. Vehicles used**
Area 1	***7%***	***2%***	***10%***
Area 2	***10%***	***1%***	***7%***
Area 3	***8%***	***-4%***	***5%***
Average	***8,3%***	***-0,3%***	***7,3%***

Table 9 – Current accuracy versus increased accuracy using second prediction approach (1)

	Pickups not in window (excluding mailboxes)	**Average time exceeding time window (min)**	**Max time exceeding time window (min)**
Area 1	From ***8*** to ***7,8***	From ***9,4*** to ***6,9***	***21,9*** to ***14,4***
Area 2	From ***8,8*** to ***6,3***	From ***11,7*** to ***10,0***	***27,9*** to ***19,9***
Area 3	From ***7,1*** to ***2***	From ***10,5*** to ***2,9***	***24,8*** to ***5,3***
Average	From ***8,0*** to ***5,4***	From ***10,5*** to ***6,6***	***24,9*** to ***13,2***

Table 10 – Current accuracy versus increased accuracy using second prediction approach (2)

Decreasing the number of items per load device (and thus increasing the expected number of roll containers) as was done for the second instance of the prediction model for *customer 2*, has a negative effect on the number of vehicles used as well as the total distance driven compared to the base scenario. When looking at the characteristics of the second prediction approach as shown in Table 6, it does appears that the increase in accuracy is outweighed by the high bias.

The upside of using the second prediction approach is found in the punctuality towards the customers. As can be expected, overestimating the customer volume combined with a higher accuracy results in strong improvements in the number of pickups outside of the time window, as well as the corresponding times. Next to that, the increased accuracy still means that the difference between vehicles planned and vehicles used is strongly reduced, resulting in operational advantages.

IV Discussion

Looking at the current collection process performance, it became clear that the difference between planned collection volumes and actual collection volumes negatively impacted an important indicator of the efficiency of the process; the vehicle fill rate. Having a low vehicle fill rate could mean having an unnecessarily high number of vehicles performing pickups, resulting in high cost. It was found that by using pre-shipping notifications to predict collection volumes, the planning accuracy could be improved. Subsequently applying this increased planning accuracy using a simulation model, showed a positive impact on one of the main cost drivers of the collection process. Having the planning as accurate as possible helped reduce the number of vehicles needed, which could reduce collection cost. However, having vehicles planned as efficiently as possible while not having a strong bias for overestimating collection volume leaves little room for error when customers turnout to have a higher collection volume than expected, resulting in more customer being collected outside of the agreed upon time window. On the other hand, by applying the "safer" approach to using the prediction model, the punctuality could be strongly improved. This was however at the expense of efficiency. Further investigation is thus required as to how best achieve this balance between efficiency and punctuality.

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II Appendix

Table II.1 below shows the results of the prediction model applied to customer #2 for different values of the number of parcels per roll container. As can be seen, the lowest absolute deviation is achieved by assuming 74 parcels per roll container. The lowest absolute deviation, given that the number of times the actual volume exceeds the prediction volume remains at 2, is found for 50 parcels per roll containers.

Parcels/RC	Abs deviation	RC reduction	Exceeding prediction
1	[redacted]	[redacted]	[redacted]
2	[redacted]	[redacted]	[redacted]
3	[redacted]	[redacted]	[redacted]
4	[redacted]	[redacted]	[redacted]
5	[redacted]	[redacted]	[redacted]
6	[redacted]	[redacted]	[redacted]
7	[redacted]	[redacted]	[redacted]
8	[redacted]	[redacted]	[redacted]
9	[redacted]	[redacted]	[redacted]
10	[redacted]	[redacted]	[redacted]
11	[redacted]	[redacted]	[redacted]
12	[redacted]	[redacted]	[redacted]
13	[redacted]	[redacted]	[redacted]
14	[redacted]	[redacted]	[redacted]
15	[redacted]	[redacted]	[redacted]
16	[redacted]	[redacted]	[redacted]
17	[redacted]	[redacted]	[redacted]
18	[redacted]	[redacted]	[redacted]
19	[redacted]	[redacted]	[redacted]
20	[redacted]	[redacted]	[redacted]
21	[redacted]	[redacted]	[redacted]
22	[redacted]	[redacted]	[redacted]
23	[redacted]	[redacted]	[redacted]
24	[redacted]	[redacted]	[redacted]
25	[redacted]	[redacted]	[redacted]
26	[redacted]	[redacted]	[redacted]
27	[redacted]	[redacted]	[redacted]
28	[redacted]	[redacted]	[redacted]
29	[redacted]	[redacted]	[redacted]
30	[redacted]	[redacted]	[redacted]
31	[redacted]	[redacted]	[redacted]
32	[redacted]	[redacted]	[redacted]
33	[redacted]	[redacted]	[redacted]
34	[redacted]	[redacted]	[redacted]
35	[redacted]	[redacted]	[redacted]
36	[redacted]	[redacted]	[redacted]
37	[redacted]	[redacted]	[redacted]
38	[redacted]	[redacted]	[redacted]
39	[redacted]	[redacted]	[redacted]
40	[redacted]	[redacted]	[redacted]
41	[redacted]	[redacted]	[redacted]
42	[redacted]	[redacted]	[redacted]
43	[redacted]	[redacted]	[redacted]
44	[redacted]	[redacted]	[redacted]
45	[redacted]	[redacted]	[redacted]
46	[redacted]	[redacted]	[redacted]
47	[redacted]	[redacted]	[redacted]
48	[redacted]	[redacted]	[redacted]
49	[redacted]	[redacted]	[redacted]
50	[redacted]	[redacted]	[redacted]
51	[redacted]	[redacted]	[redacted]
52	[redacted]	[redacted]	[redacted]

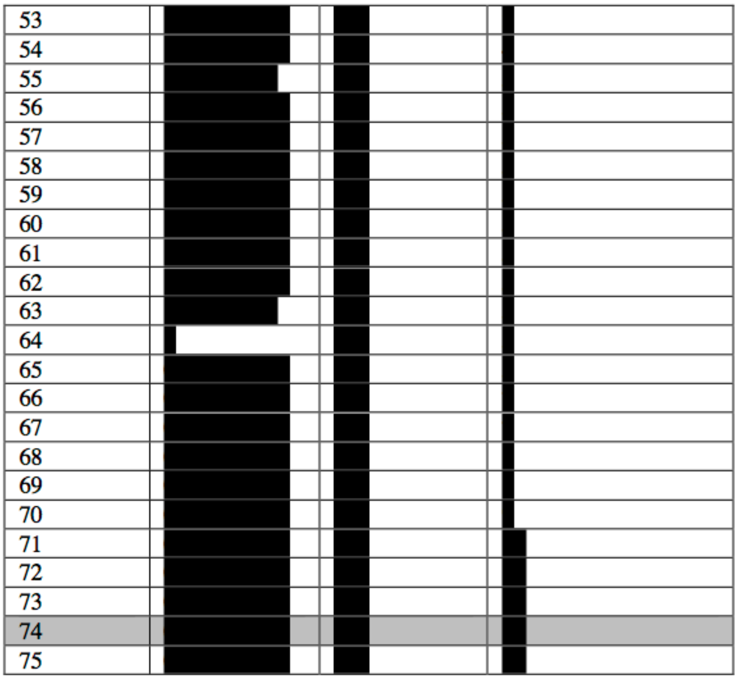


Table II.1 – Results of the prediction model for customer #2 for different values of parcels/roll container.

III Using acceptation scans to predict volume

As mentioned in Section 6.2.2 of the main report, there is an alternative to pre-shipping notification that can be used to predict volumes for retail locations; acceptation scans. This appendix will follow a similar approach to Section 6.3 to determine to which extended acceptation scans are suitable to predict collection volumes for retail locations. The approach is applied to the retail locations in the sample discussed in Section 6.1 as the actual collection volumes are required to determine the accuracy of the prediction.

III.i. Calculation steps

The calculations steps to translate a number of received acceptation scans to an expected number of load devices is similar to those presented in Section 6.3. However, as an acceptation scan always represents a physical parcel being present, there is no need to have a calculation step that translate the information of a parcel to a physical parcel actually being collected. Figure III.1 gives an overview of the calculation steps.

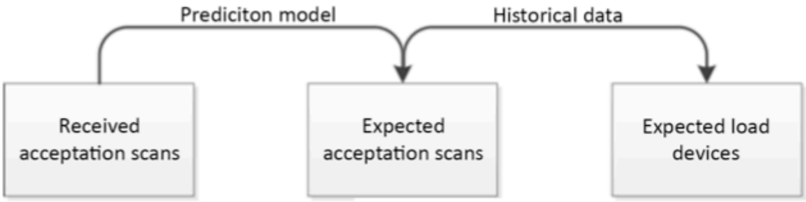


Figure III.1 – Calculation steps from acceptation scans to load device

III.i..1 Received acceptation scans to expected acceptation scans

The translation from received acceptation scans to expected acceptation scans follows the same approach as with the pre-shipping notifications; for each retail location, the distribution of received acceptation scans throughout the day, for each day of the week, is determined based on historic data. By doing so, an estimation can be made how many more acceptation scans are expected to arrive that day. For example, if there are **25 acceptation scans** received at **14:00 hours** on a **Monday**, and the specific retail location typically has **50%** of its total acceptation scans made **before 14:00**, the expected number of scans at the end of the day is **50**.

There are however two factors at play that make this approach more difficult compared to applying this approach to pre-shipping notifications:

- During the distribution of parcels, the delivery drivers sometimes stop at retail locations and pick-up a number of parcels that need to be collected. This is done because the distribution driver often stops at a retail location anyway since some consumers have parcels delivered at a retail location instead of their home. It is however unclear how many parcels are collected in this manner. It can happen that a parcel that had its acceptation scan is already collected by a distribution driver. As a result, it may occur that the number of parcels being collected is lower than the expected number of parcels based on the acceptation scans.
- In the approach using pre-shipping notifications, it was found that for the customers under investigation, the pre-shipping notifications where made throughout the day and stopped after the collection time had passed. Next to that, pre-shipping notifications were only received at days at which collection occurs (so typically not in the weekends). This made it easy to determine which day the parcel for which the pre-shipping notification was received, would be collected. With collection at a retail

location this is more difficult. Retail locations are often open in the weekends as well, and acceptation scans are also received after the collection time for that day (which is on average at 18:00 hours). As a result, the following rule set is applied to attribute acceptation scans to a certain day:

- Parcels receiving an acceptation scan past 18:00 are attributed to the next day.
- Parcels receiving an acceptation scan on Friday past 18:00 hours, on Saturday or on Sunday, are attributed to the next Monday.

III.i..2 Expected acceptation scans to expected load devices

The second step is to translate the number of acceptation scans (and thus the number of expected parcels) to an expected number of load devices. Just as with the pre-shipping notifications, this appears to be difficult to determine. Worse still, when collecting a regular customer, one can expect a certain average number of parcels per load devices as the products being shipped often show some form of uniformity. For example, a webshop selling beanbags can on average fit less parcels in a roll container than a webshop selling mobile phones can. However, a retail location can receive a wide variety of parcels of different sizes. Furthermore, a number of parcels collected at a retail location are so called *mailbox parcels* ("brievenbuspakketjes"). As the name suggest, whenever a parcel is small enough to fit through a mailbox, it can be send as a mailbox parcel at a reduced tariff. These parcels are shipped and delivered via the mail network just as every regular piece of mail. There is of course a large difference in average size between a mailbox and a regular parcel. As was the case with pre-shipping notifications, the number of parcels per load devices is thus kept as a variable.

III.i. Results

The aforementioned approach is applied to [redacted] retail location in the region of Zwolle. These retail locations are selected based on the fact that they have only a single scheduled collection per day and that the actual collection volumes were completely measured. While the results are determined for all [redacted] retail locations, some specific results are only shown for the three retail locations with the largest planned collection volumes (as the impact for these retail location is expected to be the largest).

Based on acceptation scans in the months July, August and September, the average distribution of acceptation scans per day of the week for all [redacted] retail locations are determined. Figure III.2 shows these distributions for the three retail locations mentioned before that are addressed in more detail. Interesting to note is that the distribution for the Monday indeed includes a large number of acceptation scans incurred over the weekend (resulting in for example already more than 30% of the scans for retail location #1 at the start of the day). Next to that, the distribution on Monday for retail location #1 and #2 remains constant till 13:00 hours while the percentage of acceptation scans for retail location #3 start climbing at 09:00 hours. This is however expected as retail location #1 and #2 are closed on Monday mornings, while retail location #3 opens at the same time every weekday.

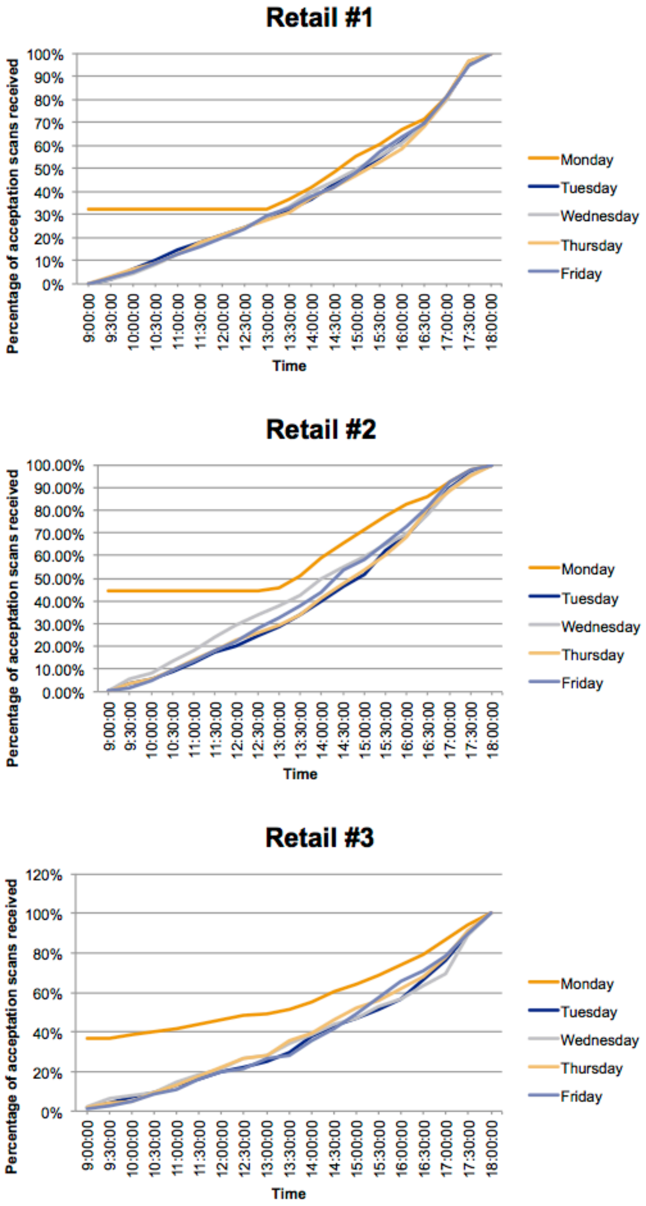


Figure III.2 - Acceptation scans as received throughout the day *(per day average over two months)*.

The average number of parcels per roll container for the [redacted] retail locations was found to be **42 parcels** per roll container. As can however be seen in Figure III.3, the distribution is more uniform than was found with the two customers investigated in Section 6.3, making it more difficult to accurately predict the number of roll containers.

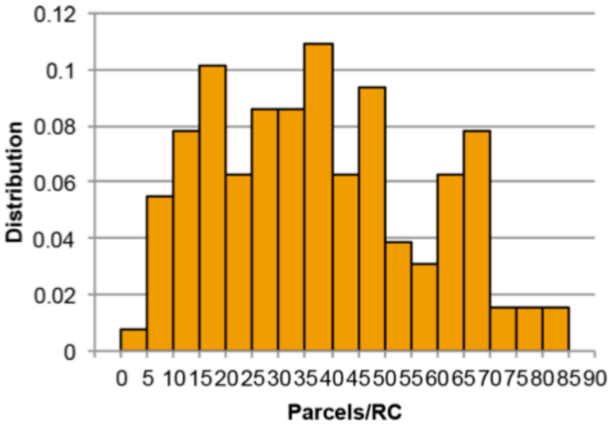


Figure III.3 – Distribution of parcels per roll container for retail locations

When using a measuring time of **14:00 hours** (or 4 hours before collection) and an average number of parcels per load devices of **42 parcels per roll container**, results are mixed. While the average accuracy is improved for Tuesday to Thursday, the results for Monday and Friday are worse than the planning volumes currently used. Worse so that the average accuracy over the whole week is lower than when using the planned collection volumes. This is a first indication that assigning the acceptation scans (and the parcels that belong to them) to collection pick-ups proves difficult, especially for days close to the weekend.

When trying to optimize the accuracy by adjusting the number of parcels per roll container, the highest accuracy is achieved by taking **60 parcels per roll containers**. By increasing the expected number of parcels per roll container, the predicted number of roll containers will decrease. The fact that an increase in parcels per roll container helps to improve accuracy indicates that there are indeed less parcels than expected due to the additional collection by the distribution drivers.
However, when looking again at the number of occurrences where the planned/predicted volumes are exceeded, there is a sharp increase when using the predicted volume instead of the planned volumes. Better still, when using the average number of parcels per roll container, the accuracy decreases (from [redacted] RC to [redacted] RC) while the number of times the planned/predicted volume is exceeded increases (from [redacted] to [redacted] occurrences). Table III.1 gives an overview of the performance of the prediction model when using either 42 or 60 parcels per roll container.

	Mon.	**Tues.**	**Wed.**	**Thur.**	**Fri.**	***Average***
Difference planned vs. realized volume	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Occurrences of exceeding planned capacity	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Difference predicted vs. realized volume (42 par/RC)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Occurrences of exceeding predicted capacity (42 par/RC)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Difference predicted vs. realized volume (60 par/RC)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Occurrences of exceeding predicted capacity (60 par/RC)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table III.1 – Prediction model performance per day for different parameters

Taking a closer look at the three customers and their day to day performance as shown in Figure III.4, it becomes clear that while using the average number of parcels per roll container shows a good prediction for the Tuesday, Wednesday, and Thursday, the prediction greatly overestimates the volume for the Monday and Friday. By increasing the number of parcels per roll container, the predicted volumes decrease overall, making the prediction for Monday and Friday more accurate, but decreasing the accuracy for the other days. An overview of the planning accuracy and the number of times the planning/predicted volume was exceeded is given in Table III.2.

42 parcels/RC:

[redacted]

60 parcels/RC:

[redacted]

Figure III.4 – Results for the three largest retail locations

	Retail #1	**Retail #2**	**Retail #3**
Average difference currently planned vs. realized volume	[redacted]	[redacted]	[redacted]
Occurrences of exceeding planned capacity	[redacted]	[redacted]	[redacted]
Average difference predicted vs. realized volume (42 par/RC)	[redacted]	[redacted]	[redacted]
Occurrences of exceeding predicted capacity (42 par/RC)	[redacted]	[redacted]	[redacted]
Average difference predicted vs. realized volume (60 par/RC)	[redacted]	[redacted]	[redacted]
Occurrences of exceeding predicted capacity (60 par/RC)	[redacted]	[redacted]	[redacted]

Table III.2 – Results for the three largest retail locations

While the sample of one week of data is too limited for a strong conclusion, it does becomes clear that the advantages found when planning based on pre-shipping notifications cannot be easily replicated for retail locations when using acceptation scans.
Some reasons for this were already mentioned, but to summarize:

- The used sample of only five days can be considered too small to find strong and conclusive results, compared to the data sample used for the pre-shipping notifications which was applied to multiple months of data.
- The additional collection of parcels performed by the distribution driver make it difficult to predict whether or not a parcel having had its acceptation scan will actually be collected that day by the collection driver.

- The large variety of parcel dimensions -also due to mailbox parcels- make it difficult to translate expected parcels to the measuring unit of roll containers.
- The performance of the current collection process for retail locations using the mail division is already better than the performance for the customers being collected by the parcel division, making it difficult to achieve similar improvements.
- A large number of pick-ups include collection orders of a single roll container. These orders are difficult to improve upon. While planned collection volume is often higher than the actual volume, a customer having a collection order for a single roll container can not have a lower realized volume. It might happen that the roll container is not used and a few parcels are collected separately, but whether a customer fills up a quarter, half or a full roll container, it will still be measured as the collection of a single roll container, and thus showing the planned volume as accurate. Addressing these customers and their collection performance requires looking at collection on a parcel level instead of a load device level, which lays outside of the scope of this research.

IV Detailed program description language

IV.i Classes:

```
CustomerClass = Class TomasElement
  Public
  PlanVolume, ActualVolume: Integer
  LocationX, LocationY: Integer
  TimeWindowStart, TimeWindowEnd: Real
  FixedToVehicle: Boolean
  DistToVeh: Real
  Published
  Constructor Create (CName:String)
  Destructor Destroy

AssignerClass = Class TomasElement
  Public
  AssignQ, AssignTempQ, VehicleIdleQ, VehicleBusyQ, VehicleTempQ: TomasQueue
  MyVehicle: VehicleClass
  MyCustomer: CustomerClass
  NextCustomer: CustomerClass
  Count: Integer
  Flag: Integer
  Published
  Constructor Create (AName:String)
  Destructor Destroy
  Procedure Process

VehicleClass = Class TomasElement
  Public
  MyCustomer: CustomerClass
  LocationX, LocationY, LocationXMEM, LocationYMEM, LocationXPLAN, LocationYPLAN:
                                                                          Integer
  TaskQ: TomasQueue
  Capacity, FreeCapacity, FreePlanCapacity, FreeCapacityMEM: Integer
  Drivetime: Real
  DistNextCus: Real
  IdleTime, IdleTimePlan: Real
  Speed: Real
  VehicleControl: Integer
  CustomersCollected: Integer
  Published
  Constructor Create (VName:String)
  Destructor Destroy
  Procedure Process
```

IV.i Processes

AssignerClass process

```
Start of process
Sort customers & vehicles
If  sort customers = true begin
  For I = 0 to Nr of customers – 1 begin
      MyCustomer = First element in AssignQ
      Move MyCustomer to AssignTempQ sorted on volume
      Move MyCustomer to AssignQ sorted on end of time window
```

```
  End
End

For I = 0 to Nr of customers – 1 begin
  MyVehicle = First element in VehicleIdleQ
  Move MyVehicle to VehicleTempQ
  Move MyVehicle to VehicleIdleQ sorted on capacity
End

First round of planning
MyVehicle = first element in VehicleIdleQ

Repeat while not all customers are assigned to a vehicle
While AssignQ length >0 do begin

  If using first planning strategy
  If plan strategy = plan vehicles to customer begin
      MyCustomer = First element in AssignQ
      For I = 0 to Nr of vehilces – 1 begin
          MyVehicle = First element in VehicleIdleQ
          Move MyVehicle to VehicleTempQ
          Move MyVehicle to VehicleIdleQ sorted on distance to MyCustomer
      End
      Flag=0
      MyVehicle = first element in VehicleIdleQ
      While Flag =0 do begin
          If MyVehicle can reach MyCustomer before MyCustomer.TimeWindowEnd
                                  and MyVehicle.FreeCapacity >= MyCustomer.PlanVolume  begin
              Flag =1
              Move MyCustomer to TaskQ of MyVehicle
              MyVehicle.PlanLocation = MyCustomer.Location
              MyVehicle .PlanFreeCapacity = MyVehicle.PlanFreeCapacity - MyCustomer.PlanVolume
              MyVehicle.IdleTime = Max(MyVehicle.IdleTime + Drivetime to MyCustomer + Handlingtime
                      at MyCustomer , MyCustomer.TimeWindowStart + Handlingtime at MyCustomer)
          End
          Else begin
              MyVehicle = MyVehicle.Successor(VehicleIdleQ)
          End
      End
  End

  If using second planning strategy
  If plan strategy = plan customers to vehicle begin
      For I = 0 to Customers in AssignQ – 1 begin
          MyCustomer = First element in AssignQ
          Move MyCustomer to AssignTempQ sorted on distance to planned location of MyVehicle
          Move MyCustomer to AssignQ sorted on start of time window
      End

      MyCustomer = First element in AssignQ
      While not (MyCustomer = Nil) do begin
          If MyVehicle can reach MyCustomer before MyCustomer.TimeWindowEnd and
                                          MyVehicle.FreeCapacity >= MyCustomer.PlanVolume  begin
              MyVehicle.PlanLocation = MyCustomer.Location
              MyVehicle .PlanFreeCapacity = MyVehicle.PlanFreeCapacity - MyCustomer.PlanVolume
              MyVehicle.IdleTime = Max(MyVehicle.IdleTime + Drivetime to MyCustomer + Handlingtime
                      at MyCustomer , MyCustomer.TimeWindowStart + Handlingtime at MyCustomer)
              Move MyCustomer from AssignQ to MyVehicle.TaskQ
              For I = 0 to Customers in AssignQ – 1 begin
                  MyCustomer = First element in AssignQ
                  Move MyCustomer to AssignTempQ sorted on distance to planned location of
                                                                              MyVehicle
                  Move MyCustomer to AssignQ sorted on start of time window
              End
              MyCustomer = First element in AssignQ
          End
          Else begin
```

```
              MyCustomer = MyCustomer.Successor(AssignQ);
          End
  End
  MyVehicle:=MyVehicle.Successor(VehicleIdleQ)
End

Delete unused vehicles if applicable
If delete unused vehicles = true begin
  MyVehicle = First element in VehicleIdleQ
  While not (MyVehicle = Nil) begin
      If first element in MyVehicle.TaskQ = Nil begin
          MyVehicle.TaskQ.Destroy
          MyVehicle.Destroy
          MyVehicle = First element in VehicleIdleQ
      Else begin
          MyVehicle = MyVehicle.Successor(VehicleIdleQ)
      End
  End
End

Reset and start vehicles
For I = 0 to Vehicles in VehicleIdleQ – 1 begin
  MyVehicle = First element in VehicleIdleQ
  MyVehicle.PlanLocation = (0,0)
  MyVehicle.IdleTime = 0
  MyVehicle.PlanFreeCapacity = MyVehicle.Capacity
  Move MyVehicle to VehicleBusyQ
  Start MyVehicle at TNow
End

During execution
While true begin

Wait until customers need to be replanned
  While AssignQ is empty do standby

Remove tasks from vehicles
  For I = 0 to Vehicles in VehicleBusyQ – 1 begin
      MyVehicle = First element in VehicleBusyQ
      Move MyVehicle to VehicleIdleQ
      MyVehicle.IdleTime = Max(MyVehicle.IdleTime, TNow)
      Save MyVehicle.PlanLocation
      Save MyVehicle.IdleTime
      Save MyVehicle.PlanFreeCapacity
      For J = 0 to Customers in MyVehicle.TaskQ – 1 begin
          MyCustomer = Last element in MyVehicle.TaskQ
          If MyCustomer is not fixed to MyVehicle begin
              Move MyCustomer to AssignQ sorted on end of time window
          End
      End
  End

 Sort customers & vehicles
  If  sort customers = true begin
      For I = 0 to Nr of customers – 1 begin
          MyCustomer = First element in AssignQ
          Move MyCustomer to AssignTempQ sorted on volume
          Move MyCustomer to AssignQ sorted on end of time window
      End
  End

  For I = 0 to Nr of customers – 1 begin
      MyVehicle = First element in VehicleIdleQ
      Move MyVehicle to VehicleTempQ
      Move MyVehicle to VehicleIdleQ sorted on capacity
  End
```

```
Replan vehicles
MyVehicle = first element in VehicleIdleQ

While AssignQ length >0 do begin

    If using first planning strategy
    If replan strategy = replan vehicles to customer begin

        MyCustomer = First element in AssignQ

        For I = 0 to Nr of vehilces – 1 begin
            MyVehicle = First element in VehicleIdleQ
            Move MyVehicle to VehicleTempQ sorted on Idle time
            Move MyVehicle to VehicleIdleQ sorted on distance to MyCustomer
        End

        If replan as much customer volumes as possible begin
            Flag=0
            MyVehicle = first element in VehicleIdleQ
            While Flag =0 do begin
                If  MyVehicle.FreeCapacity > 0 and MyVehicle can reach MyCustomer in time given
                                                              the limit of exceeding time window begin
                    Flag =1
                    Move MyCustomer to TaskQ of MyVehicle
                    MyVehicle.PlanLocation = MyCustomer.Location
                    MyVehicle .PlanFreeCapacity = MyVehicle.PlanFreeCapacity -
                                                                    MyCustomer.PlanVolume
                    MyVehicle.IdleTime = Max(MyVehicle.IdleTime + Drivetime to MyCustomer +
                                             Handlingtime at MyCustomer ,
                                             MyCustomer.TimeWindowStart + Handlingtime at
                                             MyCustomer)
                End
                Else begin
                    MyVehicle = MyVehicle.Successor(VehicleIdleQ)
                End
            End
        End

        If replan total customer volumes begin
            Flag=0
            MyVehicle = first element in VehicleIdleQ
            While Flag =0 do begin
                If  MyVehicle.FreeCapacity >= MyCustomer.PlanVolume  and MyVehicle can reach
                                  MyCustomer in time given the limit of exceeding time window begin
                    Flag =1
                    Move MyCustomer to TaskQ of MyVehicle
                    MyVehicle.PlanLocation = MyCustomer.Location
                    MyVehicle .PlanFreeCapacity = MyVehicle.PlanFreeCapacity -
                                                             MyCustomer.PlanVolume
                    MyVehicle.IdleTime = Max(MyVehicle.IdleTime + Drivetime to MyCustomer +
                                             Handlingtime at MyCustomer ,
                                             MyCustomer.TimeWindowStart + Handlingtime at
                                             MyCustomer)
                End
                Else begin
                    MyVehicle = MyVehicle.Successor(VehicleIdleQ)
                End
            End
        End


    End

    If using second planning strategy
    If replan strategy = replan customers to vehicle begin

        For I = 0 to Customers in AssignQ – 1 begin
```

```
              MyCustomer = First element in AssignQ
              Move MyCustomer to AssignTempQ sorted on distance to planned location of MyVehicle
              Move MyCustomer to AssignQ sorted on end of time window
          End

          If replan as much customer volumes as possible begin
              MyCustomer = First element in AssignQ
              While not (MyCustomer = Nil) begin
                  If  MyVehicle.FreeCapacity  > 0 and MyVehicle can reach MyCustomer in time given
                                                    the limit of exceeding time window begin
                      Move MyCustomer to TaskQ of MyVehicle
                      MyVehicle.PlanLocation = MyCustomer.Location
                      MyVehicle .PlanFreeCapacity = MyVehicle.PlanFreeCapacity -
                                                        MyCustomer.PlanVolume
                      MyVehicle.IdleTime = Max(MyVehicle.IdleTime + Drivetime to MyCustomer +
                                          Handlingtime at MyCustomer ,
                                          MyCustomer.TimeWindowStart + Handlingtime at
                                          MyCustomer)
                      For I = 0 to Customers in AssignQ – 1 begin
                          MyCustomer = First element in AssignQ
                          Move MyCustomer to AssignTempQ sorted on distance to planned location of
                                                                            MyVehicle
                          Move MyCustomer to AssignQ sorted on start of time window
                      End
                      MyCustomer = First element in AssignQ
                  End
                  Else begin
                      MyCustomer = MyCustomer.Successor(AssignQ)
                  End
              End
          End

          If replan total customer volume begin
              MyCustomer = First element in AssignQ
              While not (MyCustomer = Nil) begin
                  If  MyVehicle.FreeCapacity  >=  MyCustomer.PlanVolume and MyVehicle can reach
                                 MyCustomer in time given the limit of exceeding time window begin
                      Move MyCustomer to TaskQ of MyVehicle
                      MyVehicle.PlanLocation = MyCustomer.Location
                      MyVehicle .PlanFreeCapacity = MyVehicle.PlanFreeCapacity -
                                                            MyCustomer.PlanVolume
                      MyVehicle.IdleTime = Max(MyVehicle.IdleTime + Drivetime to MyCustomer +
                                          Handlingtime at MyCustomer ,
                                          MyCustomer.TimeWindowStart + Handlingtime at
                                          MyCustomer)
                      For I = 0 to Customers in AssignQ – 1 begin
                          MyCustomer = First element in AssignQ
                          Move MyCustomer to AssignTempQ sorted on distance to planned location of
                                                                            MyVehicle
                          Move MyCustomer to AssignQ sorted on start of time window
                      End
                      MyCustomer = First element in AssignQ
                  End
                  Else begin
                      MyCustomer = MyCustomer.Successor(AssignQ)
                  End
              End
          End
          MyVehicle = MyVehicle.Successor(VehicleIdleQ)
      End
  End

Reset the state of the vehicles
  For I = 0 to Vehicles in VehicleIdleQ – 1 begin
      MyVehicle = First element in VehicleIdleQ
      Restore MyVehicle.PlanLocation from save
      Restore MyVehicle.IdleTime from save
```

```
    Restore MyVehicle.PlanFreeCapacity from save
    Move MyVehicle to VehicleBusyQ
  End
End
```

VehicleClass process

```
While true begin

Wait until a customer needs to be collected by the vehicle
  While TaskQ is empty do standby

  MyCustomer = First element in TaskQ

  Drivetime = Distance to MyCustomer/speed

  Wait till start to drive and reevaluate first customer in TaskQ
  While Time window start of MyCustomer – Drivetime > TNow begin
      While TaskQ is empty do standby
      MyCustomer = First element in TaskQ
      Drivetime = Distance to MyCustomer/speed
  End

  Fix customer to vehicle and start driving
  MyCustomer is fixed to vehicle
  IdleTime = IdleTime +
              Max(DriveTime,MyCustomer.TimeWindowStart)+MyCustomer.PlanVolume*HandlingTime
  PlanLocation = Location of MyCustomer
  PlanFreeCapacity = PlanFreeCapacity-MyCustomer.PlanVolume
  Hold(Drivetime)

  At customer
  Location = MyCustomer.Location
  Hold(Max(MyCustomer.TimeWindowStart-TNow,0))
  IdleTime = TNow

  If Customer volume exceeds free capacity
  If MyCustomer.ActualVolume>FreeCapacity begin

      If VehicleControl = 0 begin
          MyCustomer.ActualVolume:=MyCustomer.ActualVolume-FreeCapacity
          MyCustomer.PlanVolume:=MyCustomer.ActualVolume
          Drivetime = Distance from MyCustomer to depot / speed
          IdleTime = IdleTime+Drivetime+FreeCapacity*HandlingTime+FixedHandlingTime
          PlanFreeCapacity = Capacity
          PlanLocation = (0,0)
          Move from Assigner.VehicleBusyQ to Assigner.VehicleIdleQ
          For I = 0 to Customers in TaskQ – 1 begin
              MyCustomer = First element in TaskQ
              Set MyCustomer not set to vehicle
              Move MyCustomer to Assigner.AssignQ sorted on start of time window
          End
          Hold(FreeCapacity*HandlingTime+FixedHandlingTime)
          Hold(Drivetime)
          Location = Location of Depot
          FreeCapacity = Capacity
          IdleTime = TNow;
      End

      If VehicleControl = 1 begin
          MyCustomer.PlanVolume = MyCustomer.ActualVolume
          IdleTime = TNow;
          PlanFreeCapacity = FreeCapacity
          Move from Assigner.VehicleBusyQ to Assigner.VehicleIdleQ
          For I = 0 to Customers in TaskQ – 1 begin
              MyCustomer = First element in TaskQ
              Set MyCustomer not set to vehicle
```

```
              Move MyCustomer to Assigner.AssignQ sorted on start of time window
          End
      End
  End
  If otherwise, perform regular collection
  Else begin
      Register if collected in Time window or not
      FreeCapacity= FreeCapacity – MyCustomer.ActualVolume
      PlanFreeCapacity=FreeCapacity
      IdleTime = IdleTime + MyCustomer.ActualVolume * HandlingTime + FixedHandlingTime
      Hold(MyCustomer.ActualVolume*HandlingTime+FixedHandlingTime)
      MyCustomer.Destroy;
  End
End
```

Initiate simulation button process

```
Assigner = Create element of AssignerClass
VehicleCount = 0
CustomerCount = 0
```

Start simulation button process

```
HandlingTime = Read user input
Start Assigner at TNow
Startsimulation
```

Add vehicles button process

```
For I = 0 to Number of vehicles to be generated – 1 begin
  MyVehicle = Create element of VehicleClass
  MyVehicle.Location = (0,0)
  MyVehicle.PlanLocation = (0,0)
  MyVehicle.Capacity = Read user input
  MyVehilce.PlanCapacity = MyVehicle.Capacity
  MyVehilce.IdleTime = 0
  MyVehicle.Speed = Read user input
  MyVehicle.VehicleControl = Read user input
  Move MyVehicle to Assinger.VehicleIdleQ
  VehicleCount = VehicleCount+1
End
```

Add customers uniformly button process

```
LocationDistribution = create Uniform distribution with user input
TimeDistribution = create Uniform distribution with user input
VolumeDistribution = create Uniform distribution with user input
VolumeDifferenceDistribution = create Normal distribution with user input
BaisDistribution = create Uniform distribution between 1 and 101

For I = 0 to Number of customers to be generated – 1 begin
  MyCustomer = Create element of CustomerClass
  MyCustomer.Location = Round(LocationDistribution sample)
  MyCustomer.Actual = Trunc(VolumeDistribution sample)
  Calc1 = VolumeDifferenceDistribution.Sample
  Calc2 = Trunc(BaisDistribution.Sample)

  If Calc2 <=user input of percentage overestimating actual volume begin
      MyCustomer.PlanVolume=Round((MyCustomer.ActualVolume*-1)/(Calc1-1));
  End
  Else begin
      MyCustomer.PlanVolume=Round((MyCustomer.ActualVolume)/(Calc1+1));
  End

  MyCustomer.PlanVolume = Max(MyCustomer.PlanVolume,VolMin)
  MyCustomerPlanVolume = Min(MyCustomer.PlanVolume,VolMax)
  MyCustomer.TimeWindowStart = Round(TimeDistribution.Sample)
```

```
  MyCustomer.TimeWindowEnd = MyCustomer.TimeWindowStart + user input of time window length
  Move MyCustomer to Assigner.AssignQ sorted on TimeWindowStart
  CustomerCount = CustomerCount+1
End
```

Set cluster button process

```
CenterXDist = create Uniform distribution with user input
CenterYDist = create Uniform distribution with user input

CenterX = Round(CenterXDist.Sample)
CenterY = Round (CenterYDist.Sample)
```

Add customers in cluster button process

```
LocationDistribution = create Uniform distribution based on cluster as set
TimeDistribution = create Uniform distribution with user input
VolumeDistribution = create Uniform distribution with user input
VolumeDifferenceDistribution = create Normal distribution with user input
BaisDistribution = create Uniform distribution between 1 and 101

For I = 0 to Number of customers to be generated – 1 begin
  MyCustomer = Create element of CustomerClass
  MyCustomer.Location = Round(LocationDistribution sample)
  MyCustomer.Actual = Trunc(VolumeDistribution sample)
  Calc1 = VolumeDifferenceDistribution.Sample
  Calc2 = Trunc(BaisDistribution.Sample)

  If Calc2 <=user input of percentage overestimating actual volume begin
      MyCustomer.PlanVolume=Round((MyCustomer.ActualVolume*-1)/(Calc1-1));
  End
  Else begin
      MyCustomer.PlanVolume=Round((MyCustomer.ActualVolume)/(Calc1+1));
  End

  MyCustomer.PlanVolume = Max(MyCustomer.PlanVolume,VolMin)
  MyCustomerPlanVolume = Min(MyCustomer.PlanVolume,VolMax)
  MyCustomer.TimeWindowStart = Round(TimeDistribution.Sample)
  MyCustomer.TimeWindowEnd = MyCustomer.TimeWindowStart + user input of time window length
  Move MyCustomer to Assigner.AssignQ sorted on TimeWindowStart
  CustomerCount = CustomerCount+1
End
```

V Model verification

This appendix will address the model verification in more detail. The first subsection will address a small sample problem that is calculated both manually using Microsoft Excel to perform the distance and time calculations as well as by the simulation. The second subsection will investigate the model performance for extreme and boundary values. Finally, the third subsection will use the functionality of Tomas to check if the elements and queues are used as planned.

V.i Manual calculations

As explained in the main report, a set of 10 customers will be planned using both planning strategies (where the same strategy is used for planning and replanning), to a set of six vehicles. The customers are not sorted on size, and the vehicles are sorted largest to smallest. Table V.1 gives an overview of the customers while Table V.1 shows the vehicles used.

Customer	Location X	Location Y	Planned volume (RC)	Actual volume (RC)	Time window start (min)
0	0	13	1	1	300
1	76	44	1	2	363
2	73	87	1	2	423
3	29	93	3	2	512
4	73	73	1	1	413
5	28	80	5	3	480
6	54	55	2	4	437
7	64	20	2	4	508
8	23	14	1	1	410
9	35	48	1	1	411

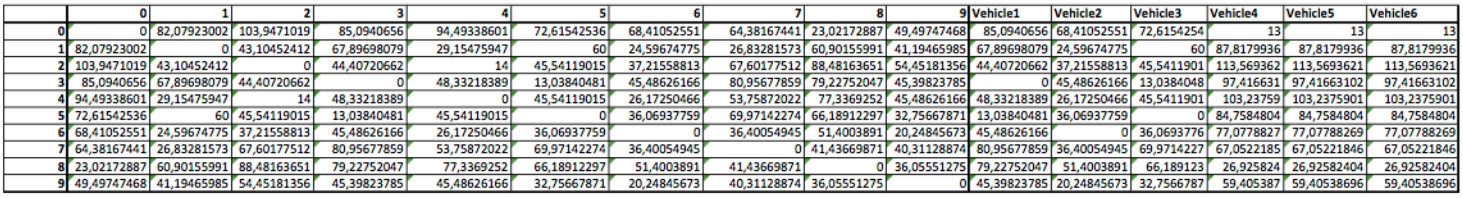
Table V.1 – Sample of customers

Vehicle	Capacity (RC)	Speed (km/h)
0-0	6	40
0-1	6	40
0-2	6	40
1-0	3	40
1-1	3	40
1-2	3	40

Table V.2 – Sample of vehicles

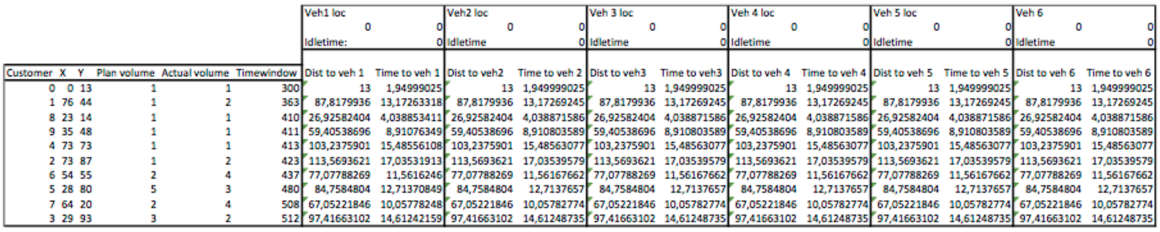
Calculation by hand

Hand calculations are performed using Microsoft Excel. A distance matrix is calculated (see Figure V.1) and the customers are sorted based on time window. Next, the distance between the customer and the vehicle, as well as the earliest possible arrival time at the customer for each vehicle is shown (Figure V.2).



	0	1	2	3	4	5	6	7	8	9	Vehicle1	Vehicle2	Vehicle3	Vehicle4	Vehicle5	Vehicle6
0	0	82,07923002	103,9471019	85,0940656	94,49338601	72,61542536	68,41052551	64,38167441	23,02172887	49,49747468	85,0940656	68,41052551	72,6154254	13	13	13
1	82,07923002	0	43,10452412	67,89698079	29,15475947	60	24,59674775	26,83281573	60,90155991	41,19465985	67,89698079	24,59674775	60	87,8179936	87,8179936	87,8179936
2	103,9471019	43,10452412	0	44,40720662	14	45,54119015	37,21558813	67,60177512	88,48163651	54,45181356	44,40720662	37,21558813	45,5411901	113,569362	113,5693621	113,5693621
3	85,0940656	67,89698079	44,40720662	0	48,33218389	13,03840481	45,48626166	80,95677859	79,22752047	45,39823785	0	45,48626166	13,0384048	97,416631	97,41663102	97,41663102
4	94,49338601	29,15475947	14	48,33218389	0	45,54119015	26,17250466	53,75872022	77,3369252	45,48626166	48,33218389	26,17250466	45,5411901	103,23759	103,2375901	103,2375901
5	72,61542536	60	45,54119015	13,03840481	45,54119015	0	36,06937759	69,97142274	66,18912297	32,75667871	13,03840481	36,06937759	0	84,7584804	84,7584804	84,7584804
6	68,41052551	24,59674775	37,21558813	45,48626166	26,17250466	36,06937759	0	36,40054945	51,4003891	20,24845673	45,48626166	0	36,0693776	77,0778827	77,07788269	77,07788269
7	64,38167441	26,83281573	67,60177512	80,95677859	53,75872022	69,97142274	36,40054945	0	41,43669871	40,31128874	80,95677859	36,40054945	69,9714227	67,0522185	67,05221846	67,05221846
8	23,02172887	60,90155991	88,48163651	79,22752047	77,3369252	66,18912297	51,4003891	41,43669871	0	36,05551275	79,22752047	51,4003891	66,189123	26,925824	26,92582404	26,92582404
9	49,49747468	41,19465985	54,45181356	45,39823785	45,48626166	32,75667871	20,24845673	40,31128874	36,05551275	0	45,39823785	20,24845673	32,7566787	59,405387	59,40538696	59,40538696

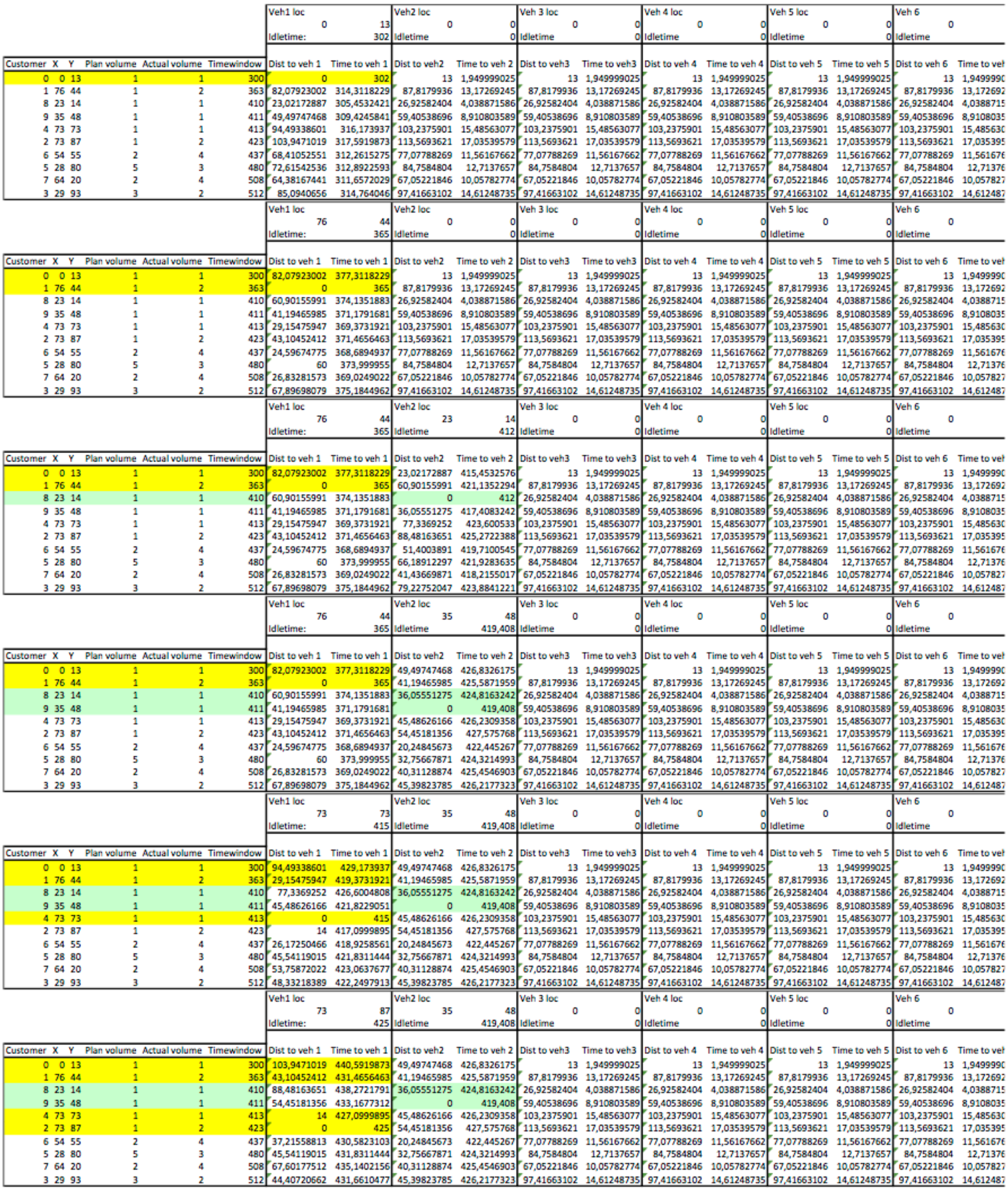
Figure V.1 – Distance matrix



						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						0	0	0	0	0	0	0	0	0	0	0	0
						Idletime:	0	Idletime	0	Idletime	0	Idletime	0	Idletime	0	Idletime	0
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to veh 6
0	0	13	1	1	300	13	1,94999025	13	1,949999025	13	1,949999025	13	1,949999025	13	1,949999025	13	1,949999025
1	76	44	1	2	363	87,8179936	13,17263318	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245
8	23	14	1	1	410	26,92582404	4,038853411	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586
9	35	48	1	1	411	59,40538696	8,91076349	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589
4	73	73	1	1	413	103,2375901	15,48556108	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077
2	73	87	1	2	423	113,5693621	17,03531913	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579
6	54	55	2	4	437	77,07788269	11,5616246	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662
5	28	80	5	3	480	84,7584804	12,71370849	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657
7	64	20	2	4	508	67,05221846	10,05778248	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774
3	29	93	3	2	512	97,41663102	14,61242159	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735

Figure V.2 – Vehicles sorted on time window/vehicle-customer distance shown

Next, customers are assigned to vehicles. When a customer is assigned to a vehicle, the customer is given a color representing the vehicle, and the location and expected idle time of the vehicle is adjusted. This is repeated till all customers are assigned to a vehicle. Figure V.3 shows the planning steps for the first planning strategy (assigning vehicles to customers), while Figure V.4 does for the second planning strategy (assigning customers to customers).



						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						0	13	0	0	0	0	0	0	0	0	0	
						Idletime:	302	Idletime	0	Idletime	0	Idletime	0	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to veh
0	0	13	1	1	300	0	302	13	1,949999025	13	1,949999025	13	1,949999025	13	1,949999025	13	1,9499990
1	76	44	1	2	363	82,07923002	314,3118229	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	23,02172887	305,4532421	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	49,49747468	309,4245841	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	94,49338601	316,173937	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	103,9471019	317,5919873	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	68,41052551	312,2615275	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	72,61542536	312,8922593	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	64,38167441	311,6572029	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	85,0940656	314,764046	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,612487

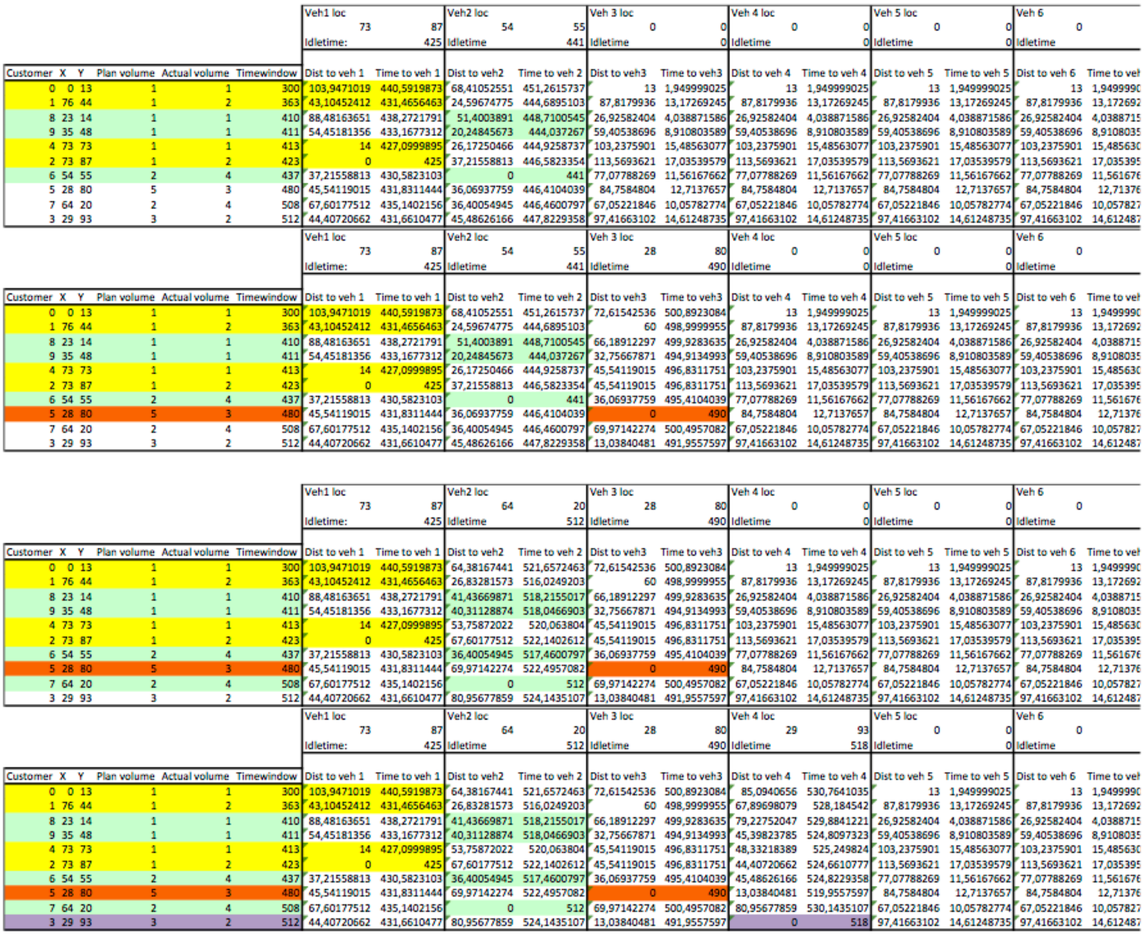
						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						76	44	0	0	0	0	0	0	0	0	0	
						Idletime:	365	Idletime	0	Idletime	0	Idletime	0	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to veh
0	0	13	1	1	300	82,07923002	377,3118229	13	1,949999025	13	1,949999025	13	1,949999025	13	1,949999025	13	1,9499990
1	76	44	1	2	363	0	365	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	60,90155991	374,1351883	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	41,19465985	371,1791681	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	29,15475947	369,3731921	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	43,10452412	371,4656463	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	24,59674775	368,6894937	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	60	373,999955	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	26,83281573	369,0249022	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	67,89698079	375,1844962	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,612487

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						76	44	23	14	0	0	0	0	0	0	0	
						Idletime:	365	Idletime	412	Idletime	0	Idletime	0	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to veh
0	0	13	1	1	300	82,07923002	377,3118229	23,02172887	415,4532576	13	1,949999025	13	1,949999025	13	1,949999025	13	1,9499990
1	76	44	1	2	363	0	365	60,90155991	421,1352294	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	60,90155991	374,1351883	0	412	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	41,19465985	371,1791681	36,05551275	417,4083242	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	29,15475947	369,3731921	77,3369252	423,600533	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	43,10452412	371,4656463	88,48163651	425,2722388	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	24,59674775	368,6894937	51,4003891	419,7100545	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	60	373,999955	66,18912297	421,9283635	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	26,83281573	369,0249022	41,43669871	418,2155017	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	67,89698079	375,1844962	79,22752047	423,8841221	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,612487

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						76	44	35	48	0	0	0	0	0	0	0	
						Idletime:	365	Idletime	419,408	Idletime	0	Idletime	0	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to veh
0	0	13	1	1	300	82,07923002	377,3118229	49,49747468	426,8326175	13	1,949999025	13	1,949999025	13	1,949999025	13	1,9499990
1	76	44	1	2	363	0	365	41,19465985	425,5871959	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	60,90155991	374,1351883	36,05551275	424,8163242	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	41,19465985	371,1791681	0	419,408	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	29,15475947	369,3731921	45,48626166	426,2309358	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	43,10452412	371,4656463	54,45181356	427,575768	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	24,59674775	368,6894937	20,24845673	422,445267	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	60	373,999955	32,75667871	424,3214993	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	26,83281573	369,0249022	40,31128874	425,4546903	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	67,89698079	375,1844962	45,39823785	426,2177323	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,612487

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						73	73	35	48	0	0	0	0	0	0	0	
						Idletime:	415	Idletime	419,408	Idletime	0	Idletime	0	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to veh
0	0	13	1	1	300	94,49338601	429,173937	49,49747468	426,8326175	13	1,949999025	13	1,949999025	13	1,949999025	13	1,9499990
1	76	44	1	2	363	29,15475947	419,3731921	41,19465985	425,5871959	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	77,3369252	426,6004808	36,05551275	424,8163242	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	45,48626166	421,8229051	0	419,408	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	0	415	45,48626166	426,2309358	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	14	417,0999895	54,45181356	427,575768	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	26,17250466	418,9258561	20,24845673	422,445267	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	45,54119015	421,8311444	32,75667871	424,3214993	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	53,75872022	423,0637677	40,31128874	425,4546903	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	48,33218389	422,2497913	45,39823785	426,2177323	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,612487

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						73	87	35	48	0	0	0	0	0	0	0	
						Idletime:	425	Idletime	419,408	Idletime	0	Idletime	0	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to veh
0	0	13	1	1	300	103,9471019	440,5919873	49,49747468	426,8326175	13	1,949999025	13	1,949999025	13	1,949999025	13	1,9499990
1	76	44	1	2	363	43,10452412	431,4656463	41,19465985	425,5871959	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	88,48163651	438,2721791	36,05551275	424,8163242	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	54,45181356	433,1677312	0	419,408	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	14	427,0999895	45,48626166	426,2309358	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	0	425	54,45181356	427,575768	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	37,21558813	430,5823103	20,24845673	422,445267	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	45,54119015	431,8311444	32,75667871	424,3214993	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	67,60177512	435,1402156	40,31128874	425,4546903	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	44,40720662	431,6610477	45,39823785	426,2177323	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,612487



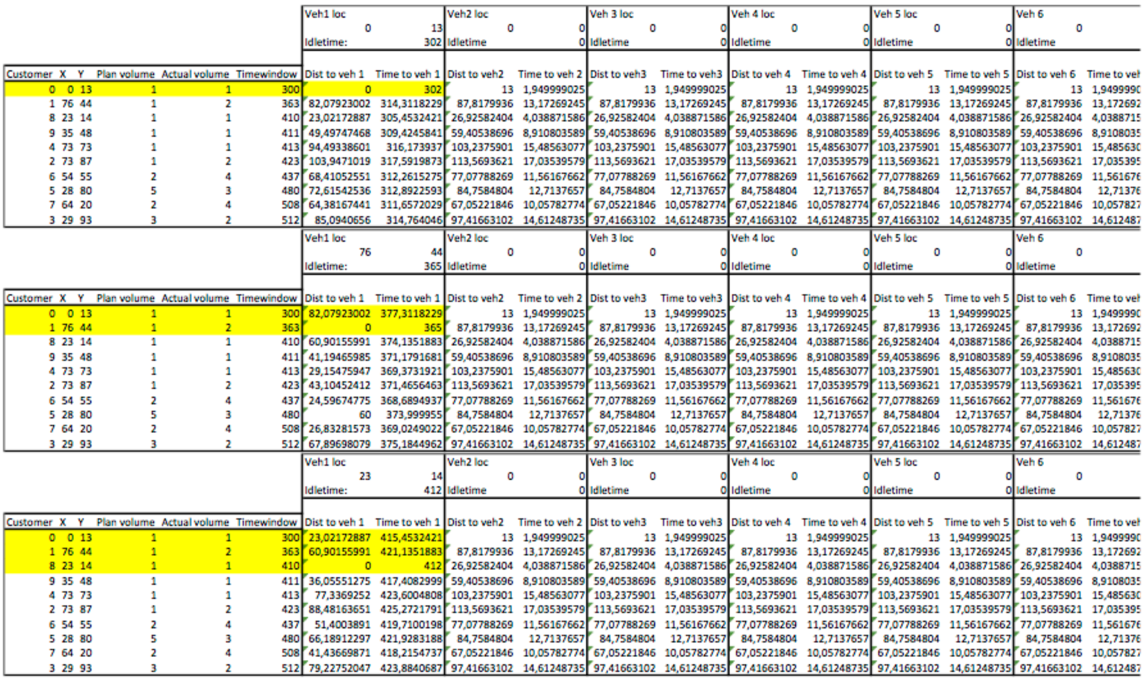
						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						73	87	54	55	0	0	0	0	0	0	0	
						Idletime:	425	Idletime	441	Idletime	0	Idletime	0	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to ve
0	0	13	1	1	300	103,9471019	440,5919873	68,41052551	451,2615737	13	1,949999025	13	1,949999025	13	1,949999025	13	1,9499990
1	76	44	1	2	363	43,10452412	431,4656463	24,59674775	444,6895103	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	88,48163651	438,2721791	51,4003891	448,7100545	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	54,45181356	433,1677312	20,24845673	444,037267	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	14	427,0999895	26,17250466	444,9258737	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	0	425	37,21558813	446,5823354	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	37,21558813	430,5823103	0	441	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	45,54119015	431,8311444	36,06937759	446,4104039	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	67,60177512	435,1402156	36,40054945	446,4600797	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	44,40720662	431,6610477	45,48626166	447,8229358	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,612487

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						73	87	54	55	28	80	0	0	0	0	0	
						Idletime:	425	Idletime	441	Idletime	490	Idletime	0	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to ve
0	0	13	1	1	300	103,9471019	440,5919873	68,41052551	451,2615737	72,61542536	500,8923084	13	1,949999025	13	1,949999025	13	1,9499990
1	76	44	1	2	363	43,10452412	431,4656463	24,59674775	444,6895103	60	498,9999955	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	88,48163651	438,2721791	51,4003891	448,7100545	66,18912297	499,9283635	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	54,45181356	433,1677312	20,24845673	444,037267	32,75667871	494,9134993	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	14	427,0999895	26,17250466	444,9258737	45,54119015	496,8311751	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	0	425	37,21558813	446,5823354	45,54119015	496,8311751	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	37,21558813	430,5823103	0	441	36,06937759	495,4104039	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	45,54119015	431,8311444	36,06937759	446,4104039	0	490	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	67,60177512	435,1402156	36,40054945	446,4600797	69,97142274	500,4957082	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	44,40720662	431,6610477	45,48626166	447,8229358	13,03840481	491,9557597	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,612487

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						73	87	64	20	28	80	0	0	0	0	0	
						Idletime:	425	Idletime	512	Idletime	490	Idletime	0	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to ve
0	0	13	1	1	300	103,9471019	440,5919873	64,38167441	521,6572463	72,61542536	500,8923084	13	1,949999025	13	1,949999025	13	1,9499990
1	76	44	1	2	363	43,10452412	431,4656463	26,83281573	516,0249203	60	498,9999955	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	88,48163651	438,2721791	41,43669871	518,2155017	66,18912297	499,9283635	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	54,45181356	433,1677312	40,31128874	518,0466903	32,75667871	494,9134993	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	14	427,0999895	53,75872022	520,063804	45,54119015	496,8311751	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	0	425	67,60177512	522,1402612	45,54119015	496,8311751	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	37,21558813	430,5823103	36,40054945	517,4600797	36,06937759	495,4104039	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	45,54119015	431,8311444	69,97142274	522,4957082	0	490	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	67,60177512	435,1402156	0	512	69,97142274	500,4957082	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	44,40720662	431,6610477	80,95677859	524,1435107	13,03840481	491,9557597	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,612487

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						73	87	64	20	28	80	29	93	0	0	0	
						Idletime:	425	Idletime	512	Idletime	490	Idletime	518	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to ve
0	0	13	1	1	300	103,9471019	440,5919873	64,38167441	521,6572463	72,61542536	500,8923084	85,0940656	530,7641035	13	1,949999025	13	1,9499990
1	76	44	1	2	363	43,10452412	431,4656463	26,83281573	516,0249203	60	498,9999955	67,89698079	528,184542	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	88,48163651	438,2721791	41,43669871	518,2155017	66,18912297	499,9283635	79,22752047	529,8841221	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	54,45181356	433,1677312	40,31128874	518,0466903	32,75667871	494,9134993	45,39823785	524,8097323	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	14	427,0999895	53,75872022	520,063804	45,54119015	496,8311751	48,33218389	525,249824	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	0	425	67,60177512	522,1402612	45,54119015	496,8311751	44,40720662	524,6610777	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	37,21558813	430,5823103	36,40054945	517,4600797	36,06937759	495,4104039	45,48626166	524,8229358	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	45,54119015	431,8311444	69,97142274	522,4957082	0	490	13,03840481	519,9557597	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	67,60177512	435,1402156	0	512	69,97142274	500,4957082	80,95677859	530,1435107	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	44,40720662	431,6610477	80,95677859	524,1435107	13,03840481	491,9557597	0	518	97,41663102	14,61248735	97,41663102	14,612487

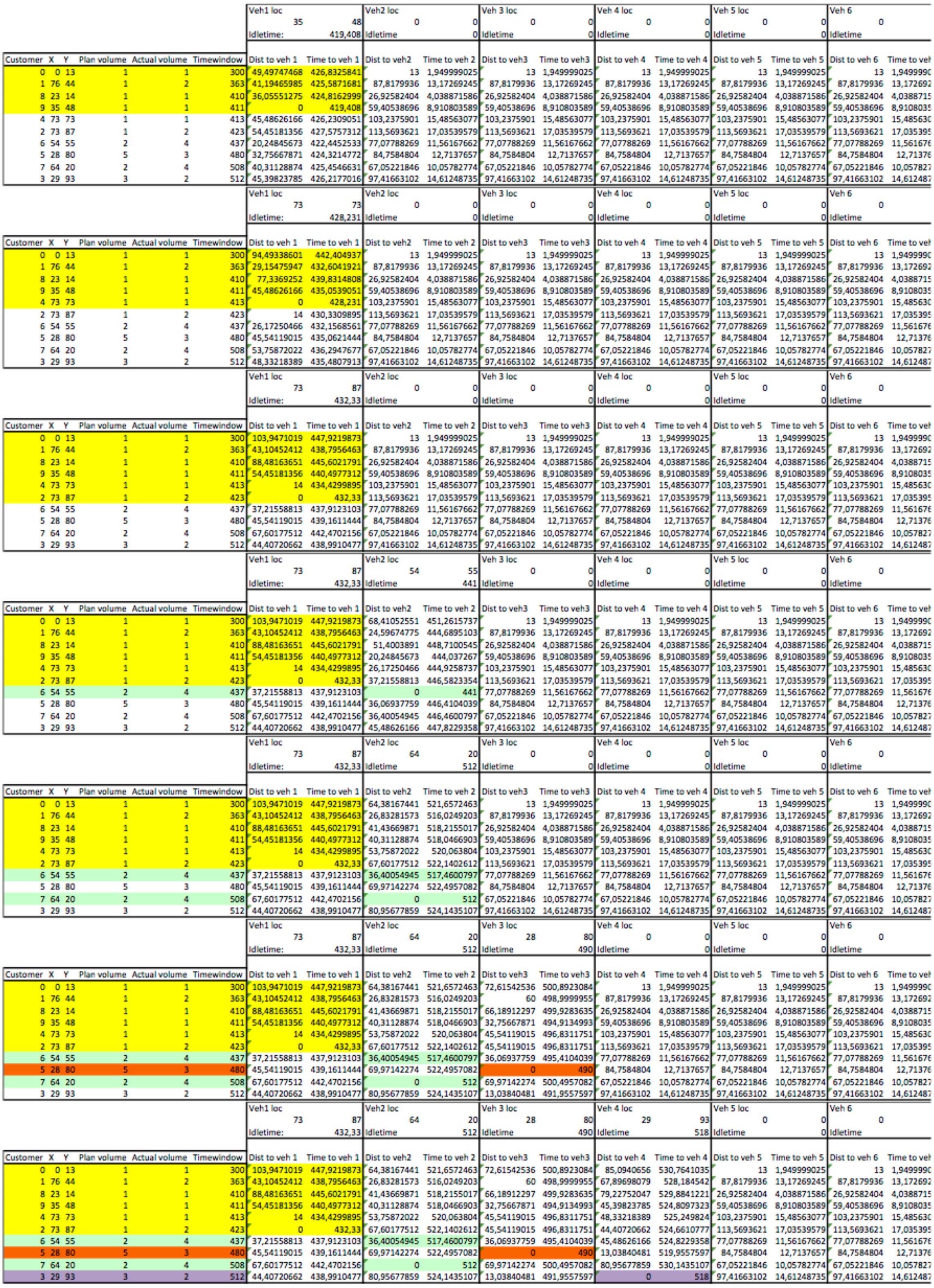
Figure V.3 – Manual planning (first planning strategy)



						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						0	13	0	0	0	0	0	0	0	0	0	
						Idletime:	302	Idletime	0	Idletime	0	Idletime	0	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to ve
0	0	13	1	1	300	0	302	13	1,949999025	13	1,949999025	13	1,949999025	13	1,949999025	13	1,9499990
1	76	44	1	2	363	82,07923002	314,3118229	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	23,02172887	305,4532421	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	49,49747468	309,4245841	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	94,49338601	316,173937	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	103,9471019	317,5919873	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	68,41052551	312,2615275	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	72,61542536	312,8922593	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	64,38167441	311,6572029	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	85,0940656	314,764046	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,612487

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						76	44	0	0	0	0	0	0	0	0	0	
						Idletime:	365	Idletime	0	Idletime	0	Idletime	0	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to ve
0	0	13	1	1	300	82,07923002	377,3118229	13	1,949999025	13	1,949999025	13	1,949999025	13	1,949999025	13	1,9499990
1	76	44	1	2	363	0	365	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	60,90155991	374,1351883	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	41,19465985	371,1791681	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	29,15475947	369,3731921	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	43,10452412	371,4656463	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	24,59674775	368,6894937	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	60	373,999955	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	26,83281573	369,0249022	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	67,89698079	375,1844962	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,612487

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						23	14	0	0	0	0	0	0	0	0	0	
						Idletime:	412	Idletime	0	Idletime	0	Idletime	0	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to ve
0	0	13	1	1	300	23,02172887	415,4532421	13	1,949999025	13	1,949999025	13	1,949999025	13	1,949999025	13	1,9499990
1	76	44	1	2	363	60,90155991	421,1351883	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	0	412	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	36,05551275	417,4082999	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	77,3369252	423,6004808	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	88,48163651	425,2721791	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	51,4003891	419,7100198	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	66,18912297	421,9283188	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	41,43669871	418,2154737	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	79,22752047	423,8840687	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,612487



						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						35	48	0	0	0	0	0	0	0	0	0	
						Idletime:	419,408	Idletime	0	Idletime	0	Idletime	0	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to ve
0	0	13	1	1	300	49,49747468	426,8325841	13	1,949999025	13	1,949999025	13	1,949999025	13	1,949999025	13	1,9499990
1	76	44	1	2	363	41,19465985	425,5871681	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	36,05551275	424,8162999	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	0	419,408	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	45,48626166	426,2309051	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	54,45181356	427,5757312	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	20,24845673	422,4452533	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	32,75667871	424,3214772	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	40,31128874	425,4546631	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	45,39823785	426,2177016	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,612487

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						73	73	0	0	0	0	0	0	0	0	0	
						Idletime:	428,231	Idletime	0	Idletime	0	Idletime	0	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to ve
0	0	13	1	1	300	94,49338601	442,404937	13	1,949999025	13	1,949999025	13	1,949999025	13	1,949999025	13	1,9499990
1	76	44	1	2	363	29,15475947	432,6041921	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	77,3369252	439,8314808	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	45,48626166	435,0539051	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	0	428,231	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	14	430,3309895	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	26,17250466	432,1568561	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	45,54119015	435,0621444	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	53,75872022	436,2947677	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	48,33218389	435,4807913	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,612487

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						73	87	0	0	0	0	0	0	0	0	0	
						Idletime:	432,33	Idletime	0	Idletime	0	Idletime	0	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to ve
0	0	13	1	1	300	103,9471019	447,9219873	13	1,949999025	13	1,949999025	13	1,949999025	13	1,949999025	13	1,9499990
1	76	44	1	2	363	43,10452412	438,7956463	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	88,48163651	445,6021791	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	54,45181356	440,4977312	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	14	434,4299895	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	0	432,33	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	37,21558813	437,9123103	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	45,54119015	439,1611444	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	67,60177512	442,4702156	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	44,40720662	438,9910477	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,612487

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						73	87	54	55	0	0	0	0	0	0	0	
						Idletime:	432,33	Idletime	441	Idletime	0	Idletime	0	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to ve
0	0	13	1	1	300	103,9471019	447,9219873	68,41052551	451,2615737	13	1,949999025	13	1,949999025	13	1,949999025	13	1,9499990
1	76	44	1	2	363	43,10452412	438,7956463	24,59674775	444,6895103	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	88,48163651	445,6021791	51,4003891	448,7100545	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	54,45181356	440,4977312	20,24845673	444,037267	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	14	434,4299895	26,17250466	444,9258737	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	0	432,33	37,21558813	446,5823354	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	37,21558813	437,9123103	0	441	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	45,54119015	439,1611444	36,06937759	446,4104039	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	67,60177512	442,4702156	36,40054945	446,4600797	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	44,40720662	438,9910477	45,48626166	447,8229358	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,612487

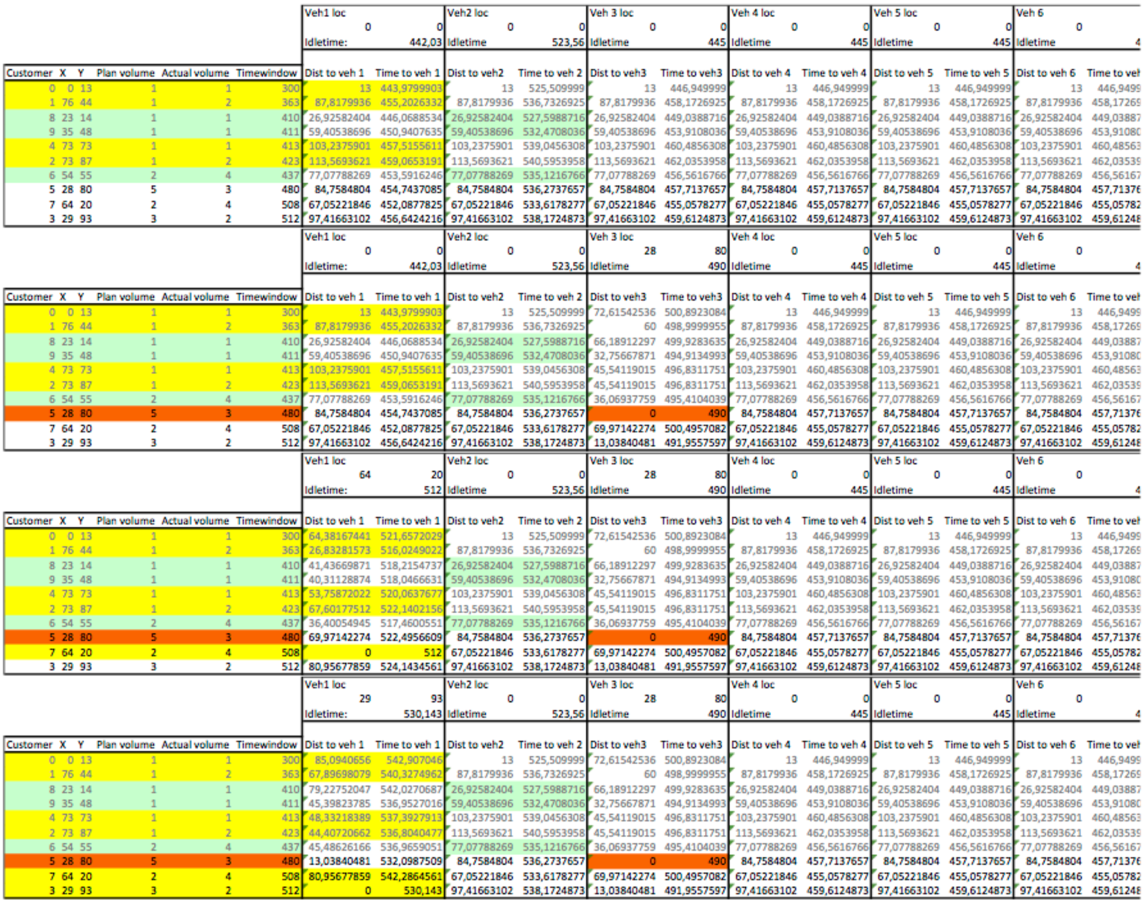
						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						73	87	64	20	0	0	0	0	0	0	0	
						Idletime:	432,33	Idletime	512	Idletime	0	Idletime	0	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to ve
0	0	13	1	1	300	103,9471019	447,9219873	64,38167441	521,6572463	13	1,949999025	13	1,949999025	13	1,949999025	13	1,9499990
1	76	44	1	2	363	43,10452412	438,7956463	26,83281573	516,0249203	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	88,48163651	445,6021791	41,43669871	518,2155017	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	54,45181356	440,4977312	40,31128874	518,0466903	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	14	434,4299895	53,75872022	520,063804	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	0	432,33	67,60177512	522,1402612	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	37,21558813	437,9123103	36,40054945	517,4600797	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	45,54119015	439,1611444	69,97142274	522,4957082	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	67,60177512	442,4702156	0	512	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	44,40720662	438,9910477	80,95677859	524,1435107	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,612487

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						73	87	64	20	28	80	0	0	0	0	0	
						Idletime:	432,33	Idletime	512	Idletime	490	Idletime	0	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to ve
0	0	13	1	1	300	103,9471019	447,9219873	64,38167441	521,6572463	72,61542536	500,8923084	13	1,949999025	13	1,949999025	13	1,9499990
1	76	44	1	2	363	43,10452412	438,7956463	26,83281573	516,0249203	60	498,9999955	87,8179936	13,17269245	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	88,48163651	445,6021791	41,43669871	518,2155017	66,18912297	499,9283635	26,92582404	4,038871586	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	54,45181356	440,4977312	40,31128874	518,0466903	32,75667871	494,9134993	59,40538696	8,910803589	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	14	434,4299895	53,75872022	520,063804	45,54119015	496,8311751	103,2375901	15,48563077	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	0	432,33	67,60177512	522,1402612	45,54119015	496,8311751	113,5693621	17,03539579	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	37,21558813	437,9123103	36,40054945	517,4600797	36,06937759	495,4104039	77,07788269	11,56167662	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	45,54119015	439,1611444	69,97142274	522,4957082	0	490	84,7584804	12,7137657	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	67,60177512	442,4702156	0	512	69,97142274	500,4957082	67,05221846	10,05782774	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	44,40720662	438,9910477	80,95677859	524,1435107	13,03840481	491,9557597	97,41663102	14,61248735	97,41663102	14,61248735	97,41663102	14,612487

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						73	87	64	20	28	80	29	93	0	0	0	
						Idletime:	432,33	Idletime	512	Idletime	490	Idletime	518	Idletime	0	Idletime	
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to ve
0	0	13	1	1	300	103,9471019	447,9219873	64,38167441	521,6572463	72,61542536	500,8923084	85,0940656	530,7641035	13	1,949999025	13	1,9499990
1	76	44	1	2	363	43,10452412	438,7956463	26,83281573	516,0249203	60	498,9999955	67,89698079	528,184542	87,8179936	13,17269245	87,8179936	13,172692
8	23	14	1	1	410	88,48163651	445,6021791	41,43669871	518,2155017	66,18912297	499,9283635	79,22752047	529,8841221	26,92582404	4,038871586	26,92582404	4,0388715
9	35	48	1	1	411	54,45181356	440,4977312	40,31128874	518,0466903	32,75667871	494,9134993	45,39823785	524,8097323	59,40538696	8,910803589	59,40538696	8,9108035
4	73	73	1	1	413	14	434,4299895	53,75872022	520,063804	45,54119015	496,8311751	48,33218389	525,249824	103,2375901	15,48563077	103,2375901	15,485630
2	73	87	1	2	423	0	432,33	67,60177512	522,1402612	45,54119015	496,8311751	44,40720662	524,6610777	113,5693621	17,03539579	113,5693621	17,035395
6	54	55	2	4	437	37,21558813	437,9123103	36,40054945	517,4600797	36,06937759	495,4104039	45,48626166	524,8229358	77,07788269	11,56167662	77,07788269	11,561676
5	28	80	5	3	480	45,54119015	439,1611444	69,97142274	522,4957082	0	490	13,03840481	519,9557597	84,7584804	12,7137657	84,7584804	12,71376
7	64	20	2	4	508	67,60177512	442,4702156	0	512	69,97142274	500,4957082	80,95677859	530,1435107	67,05221846	10,05782774	67,05221846	10,057827
3	29	93	3	2	512	44,40720662	438,9910477	80,95677859	524,1435107	13,03840481	491,9557597	0	518	97,41663102	14,61248735	97,41663102	14,612487

Figure V.4 – Manual planning (second planning strategy)

Next, the customer are replanned after the occurrence of a vehicle not having sufficient. The approach followed is similar, and again shown for both the first strategy (Figure V.5) as well as the second planning strategy (Figure V.6).



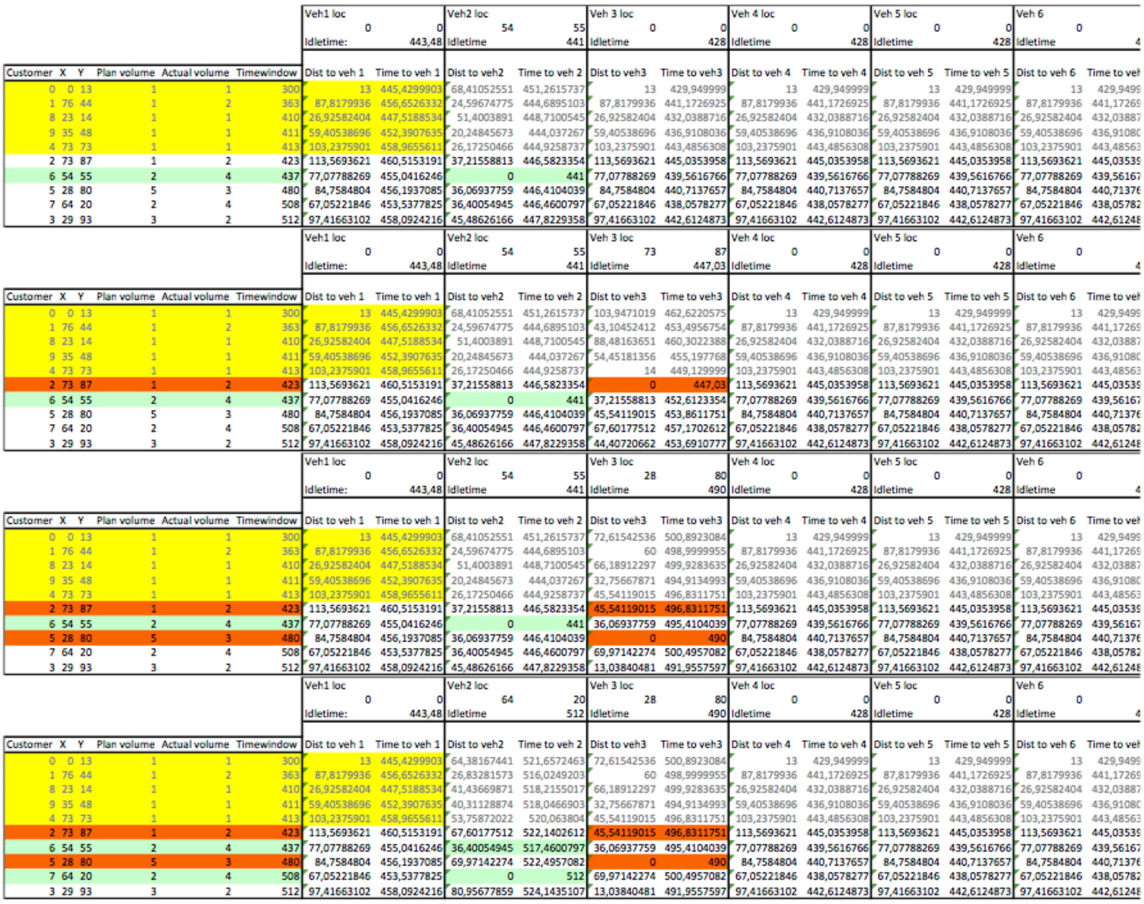
						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						0	0	0	0	0	0	0	0	0	0	0	
						Idletime:	442,03	Idletime	523,56	Idletime	445	Idletime	445	Idletime	445	Idletime	4
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to vel
0	0	13	1	1	300	13	443,9799903	13	525,509999	13	446,949999	13	446,949999	13	446,949999	13	446,9499
1	76	44	1	2	363	87,8179936	455,2026332	87,8179936	536,7326925	87,8179936	458,1726925	87,8179936	458,1726925	87,8179936	458,1726925	87,8179936	458,17269
8	23	14	1	1	410	26,92582404	446,0688534	26,92582404	527,5988716	26,92582404	449,0388716	26,92582404	449,0388716	26,92582404	449,0388716	26,92582404	449,03887
9	35	48	1	1	411	59,40538696	450,9407635	59,40538696	532,4708036	59,40538696	453,9108036	59,40538696	453,9108036	59,40538696	453,9108036	59,40538696	453,91080
4	73	73	1	1	413	103,2375901	457,5155611	103,2375901	539,0456308	103,2375901	460,4856308	103,2375901	460,4856308	103,2375901	460,4856308	103,2375901	460,48563
2	73	87	1	2	423	113,5693621	459,0653191	113,5693621	540,5953958	113,5693621	462,0353958	113,5693621	462,0353958	113,5693621	462,0353958	113,5693621	462,03539
6	54	55	2	4	437	77,07788269	453,5916246	77,07788269	535,1216766	77,07788269	456,5616766	77,07788269	456,5616766	77,07788269	456,5616766	77,07788269	456,56167
5	28	80	5	3	480	84,7584804	454,7437085	84,7584804	536,2737657	84,7584804	457,7137657	84,7584804	457,7137657	84,7584804	457,7137657	84,7584804	457,71376
7	64	20	2	4	508	67,05221846	452,0877825	67,05221846	533,6178277	67,05221846	455,0578277	67,05221846	455,0578277	67,05221846	455,0578277	67,05221846	455,05782
3	29	93	3	2	512	97,41663102	456,6424216	97,41663102	538,1724873	97,41663102	459,6124873	97,41663102	459,6124873	97,41663102	459,6124873	97,41663102	459,61248

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						0	0	0	0	28	80	0	0	0	0	0	
						Idletime:	442,03	Idletime	523,56	Idletime	490	Idletime	445	Idletime	445	Idletime	4
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to vel
0	0	13	1	1	300	13	443,9799903	13	525,509999	72,61542536	500,8923084	13	446,949999	13	446,949999	13	446,9499
1	76	44	1	2	363	87,8179936	455,2026332	87,8179936	536,7326925	60	498,9999955	87,8179936	458,1726925	87,8179936	458,1726925	87,8179936	458,17269
8	23	14	1	1	410	26,92582404	446,0688534	26,92582404	527,5988716	66,18912297	499,9283635	26,92582404	449,0388716	26,92582404	449,0388716	26,92582404	449,03887
9	35	48	1	1	411	59,40538696	450,9407635	59,40538696	532,4708036	32,75667871	494,9134993	59,40538696	453,9108036	59,40538696	453,9108036	59,40538696	453,91080
4	73	73	1	1	413	103,2375901	457,5155611	103,2375901	539,0456308	45,54119015	496,8311751	103,2375901	460,4856308	103,2375901	460,4856308	103,2375901	460,48563
2	73	87	1	2	423	113,5693621	459,0653191	113,5693621	540,5953958	45,54119015	496,8311751	113,5693621	462,0353958	113,5693621	462,0353958	113,5693621	462,03539
6	54	55	2	4	437	77,07788269	453,5916246	77,07788269	535,1216766	36,06937759	495,4104039	77,07788269	456,5616766	77,07788269	456,5616766	77,07788269	456,56167
5	28	80	5	3	480	84,7584804	454,7437085	84,7584804	536,2737657	0	490	84,7584804	457,7137657	84,7584804	457,7137657	84,7584804	457,71376
7	64	20	2	4	508	67,05221846	452,0877825	67,05221846	533,6178277	69,97142274	500,4957082	67,05221846	455,0578277	67,05221846	455,0578277	67,05221846	455,05782
3	29	93	3	2	512	97,41663102	456,6424216	97,41663102	538,1724873	13,03840481	491,9557597	97,41663102	459,6124873	97,41663102	459,6124873	97,41663102	459,61248

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						64	20	0	0	28	80	0	0	0	0	0	
						Idletime:	512	Idletime	523,56	Idletime	490	Idletime	445	Idletime	445	Idletime	4
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to vel
0	0	13	1	1	300	64,38167441	521,6572029	13	525,509999	72,61542536	500,8923084	13	446,949999	13	446,949999	13	446,9499
1	76	44	1	2	363	26,83281573	516,0249022	87,8179936	536,7326925	60	498,9999955	87,8179936	458,1726925	87,8179936	458,1726925	87,8179936	458,17269
8	23	14	1	1	410	41,43669871	518,2154737	26,92582404	527,5988716	66,18912297	499,9283635	26,92582404	449,0388716	26,92582404	449,0388716	26,92582404	449,03887
9	35	48	1	1	411	40,31128874	518,0466631	59,40538696	532,4708036	32,75667871	494,9134993	59,40538696	453,9108036	59,40538696	453,9108036	59,40538696	453,91080
4	73	73	1	1	413	53,75872022	520,0637677	103,2375901	539,0456308	45,54119015	496,8311751	103,2375901	460,4856308	103,2375901	460,4856308	103,2375901	460,48563
2	73	87	1	2	423	67,60177512	522,1402156	113,5693621	540,5953958	45,54119015	496,8311751	113,5693621	462,0353958	113,5693621	462,0353958	113,5693621	462,03539
6	54	55	2	4	437	36,40054945	517,4600551	77,07788269	535,1216766	36,06937759	495,4104039	77,07788269	456,5616766	77,07788269	456,5616766	77,07788269	456,56167
5	28	80	5	3	480	69,97142274	522,4956609	84,7584804	536,2737657	0	490	84,7584804	457,7137657	84,7584804	457,7137657	84,7584804	457,71376
7	64	20	2	4	508	0	512	67,05221846	533,6178277	69,97142274	500,4957082	67,05221846	455,0578277	67,05221846	455,0578277	67,05221846	455,05782
3	29	93	3	2	512	80,95677859	524,1434561	97,41663102	538,1724873	13,03840481	491,9557597	97,41663102	459,6124873	97,41663102	459,6124873	97,41663102	459,61248

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						29	93	0	0	28	80	0	0	0	0	0	
						Idletime:	530,143	Idletime	523,56	Idletime	490	Idletime	445	Idletime	445	Idletime	4
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to vel
0	0	13	1	1	300	85,0940656	542,907046	13	525,509999	72,61542536	500,8923084	13	446,949999	13	446,949999	13	446,9499
1	76	44	1	2	363	67,89698079	540,3274962	87,8179936	536,7326925	60	498,9999955	87,8179936	458,1726925	87,8179936	458,1726925	87,8179936	458,17269
8	23	14	1	1	410	79,22752047	542,0270687	26,92582404	527,5988716	66,18912297	499,9283635	26,92582404	449,0388716	26,92582404	449,0388716	26,92582404	449,03887
9	35	48	1	1	411	45,39823785	536,9527016	59,40538696	532,4708036	32,75667871	494,9134993	59,40538696	453,9108036	59,40538696	453,9108036	59,40538696	453,91080
4	73	73	1	1	413	48,33218389	537,3927913	103,2375901	539,0456308	45,54119015	496,8311751	103,2375901	460,4856308	103,2375901	460,4856308	103,2375901	460,48563
2	73	87	1	2	423	44,40720662	536,8040477	113,5693621	540,5953958	45,54119015	496,8311751	113,5693621	462,0353958	113,5693621	462,0353958	113,5693621	462,03539
6	54	55	2	4	437	45,48626166	536,9659051	77,07788269	535,1216766	36,06937759	495,4104039	77,07788269	456,5616766	77,07788269	456,5616766	77,07788269	456,56167
5	28	80	5	3	480	13,03840481	532,0987509	84,7584804	536,2737657	0	490	84,7584804	457,7137657	84,7584804	457,7137657	84,7584804	457,71376
7	64	20	2	4	508	80,95677859	542,2864561	67,05221846	533,6178277	69,97142274	500,4957082	67,05221846	455,0578277	67,05221846	455,0578277	67,05221846	455,05782
3	29	93	3	2	512	0	530,143	97,41663102	538,1724873	13,03840481	491,9557597	97,41663102	459,6124873	97,41663102	459,6124873	97,41663102	459,61248

Figure V.5 – Manual replanning (first strategy)

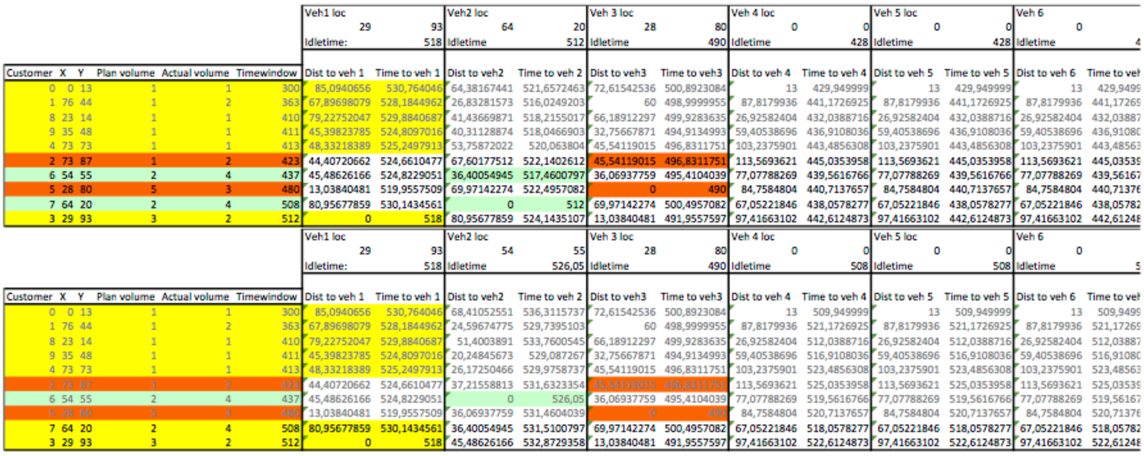


						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						0	0	54	55	0	0	0	0	0	0	0	
						Idletime:	443,48	Idletime	441	Idletime	428	Idletime	428	Idletime	428	Idletime	4
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to vel
0	0	13	1	1	300	13	445,4299903	68,41052551	451,2615737	13	429,949999	13	429,949999	13	429,949999	13	429,9499
1	76	44	1	2	363	87,8179936	456,6526332	24,59674775	444,6895103	87,8179936	441,1726925	87,8179936	441,1726925	87,8179936	441,1726925	87,8179936	441,17269
8	23	14	1	1	410	26,92582404	447,5188534	51,4003891	448,7100545	26,92582404	432,0388716	26,92582404	432,0388716	26,92582404	432,0388716	26,92582404	432,03887
9	35	48	1	1	411	59,40538696	452,3907635	20,24845673	444,037267	59,40538696	436,9108036	59,40538696	436,9108036	59,40538696	436,9108036	59,40538696	436,91080
4	73	73	1	1	413	103,2375901	458,9655611	26,17250466	444,9258737	103,2375901	443,4856308	103,2375901	443,4856308	103,2375901	443,4856308	103,2375901	443,48563
2	73	87	1	2	423	113,5693621	460,5153191	37,21558813	446,5823354	113,5693621	445,0353958	113,5693621	445,0353958	113,5693621	445,0353958	113,5693621	445,03539
6	54	55	2	4	437	77,07788269	455,0416246	0	441	77,07788269	439,5616766	77,07788269	439,5616766	77,07788269	439,5616766	77,07788269	439,56167
5	28	80	5	3	480	84,7584804	456,1937085	36,06937759	446,4104039	84,7584804	440,7137657	84,7584804	440,7137657	84,7584804	440,7137657	84,7584804	440,71376
7	64	20	2	4	508	67,05221846	453,5377825	36,40054945	446,4600797	67,05221846	438,0578277	67,05221846	438,0578277	67,05221846	438,0578277	67,05221846	438,05782
3	29	93	3	2	512	97,41663102	458,0924216	45,48626166	447,8229358	97,41663102	442,6124873	97,41663102	442,6124873	97,41663102	442,6124873	97,41663102	442,61248

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						0	0	54	55	73	87	0	0	0	0	0	
						Idletime:	443,48	Idletime	441	Idletime	447,03	Idletime	428	Idletime	428	Idletime	4
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to vel
0	0	13	1	1	300	13	445,4299903	68,41052551	451,2615737	103,9471019	462,6220575	13	429,949999	13	429,949999	13	429,9499
1	76	44	1	2	363	87,8179936	456,6526332	24,59674775	444,6895103	43,10452412	453,4956754	87,8179936	441,1726925	87,8179936	441,1726925	87,8179936	441,17269
8	23	14	1	1	410	26,92582404	447,5188534	51,4003891	448,7100545	88,48163651	460,3022388	26,92582404	432,0388716	26,92582404	432,0388716	26,92582404	432,03887
9	35	48	1	1	411	59,40538696	452,3907635	20,24845673	444,037267	54,45181356	455,197768	59,40538696	436,9108036	59,40538696	436,9108036	59,40538696	436,91080
4	73	73	1	1	413	103,2375901	458,9655611	26,17250466	444,9258737	14	449,129999	103,2375901	443,4856308	103,2375901	443,4856308	103,2375901	443,48563
2	73	87	1	2	423	113,5693621	460,5153191	37,21558813	446,5823354	0	447,03	113,5693621	445,0353958	113,5693621	445,0353958	113,5693621	445,03539
6	54	55	2	4	437	77,07788269	455,0416246	0	441	37,21558813	452,6123354	77,07788269	439,5616766	77,07788269	439,5616766	77,07788269	439,56167
5	28	80	5	3	480	84,7584804	456,1937085	36,06937759	446,4104039	45,54119015	453,8611751	84,7584804	440,7137657	84,7584804	440,7137657	84,7584804	440,71376
7	64	20	2	4	508	67,05221846	453,5377825	36,40054945	446,4600797	67,60177512	457,1702612	67,05221846	438,0578277	67,05221846	438,0578277	67,05221846	438,05782
3	29	93	3	2	512	97,41663102	458,0924216	45,48626166	447,8229358	44,40720662	453,6910777	97,41663102	442,6124873	97,41663102	442,6124873	97,41663102	442,61248

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						0	0	54	55	28	80	0	0	0	0	0	
						Idletime:	443,48	Idletime	441	Idletime	490	Idletime	428	Idletime	428	Idletime	4
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to vel
0	0	13	1	1	300	13	445,4299903	68,41052551	451,2615737	72,61542536	500,8923084	13	429,949999	13	429,949999	13	429,9499
1	76	44	1	2	363	87,8179936	456,6526332	24,59674775	444,6895103	60	498,9999955	87,8179936	441,1726925	87,8179936	441,1726925	87,8179936	441,17269
8	23	14	1	1	410	26,92582404	447,5188534	51,4003891	448,7100545	66,18912297	499,9283635	26,92582404	432,0388716	26,92582404	432,0388716	26,92582404	432,03887
9	35	48	1	1	411	59,40538696	452,3907635	20,24845673	444,037267	32,75667871	494,9134993	59,40538696	436,9108036	59,40538696	436,9108036	59,40538696	436,91080
4	73	73	1	1	413	103,2375901	458,9655611	26,17250466	444,9258737	45,54119015	496,8311751	103,2375901	443,4856308	103,2375901	443,4856308	103,2375901	443,48563
2	73	87	1	2	423	113,5693621	460,5153191	37,21558813	446,5823354	45,54119015	496,8311751	113,5693621	445,0353958	113,5693621	445,0353958	113,5693621	445,03539
6	54	55	2	4	437	77,07788269	455,0416246	0	441	36,06937759	495,4104039	77,07788269	439,5616766	77,07788269	439,5616766	77,07788269	439,56167
5	28	80	5	3	480	84,7584804	456,1937085	36,06937759	446,4104039	0	490	84,7584804	440,7137657	84,7584804	440,7137657	84,7584804	440,71376
7	64	20	2	4	508	67,05221846	453,5377825	36,40054945	446,4600797	69,97142274	500,4957082	67,05221846	438,0578277	67,05221846	438,0578277	67,05221846	438,05782
3	29	93	3	2	512	97,41663102	458,0924216	45,48626166	447,8229358	13,03840481	491,9557597	97,41663102	442,6124873	97,41663102	442,6124873	97,41663102	442,61248

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						0	0	64	20	28	80	0	0	0	0	0	
						Idletime:	443,48	Idletime	512	Idletime	490	Idletime	428	Idletime	428	Idletime	4
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to vel
0	0	13	1	1	300	13	445,4299903	64,38167441	521,6572463	72,61542536	500,8923084	13	429,949999	13	429,949999	13	429,9499
1	76	44	1	2	363	87,8179936	456,6526332	26,83281573	516,0249203	60	498,9999955	87,8179936	441,1726925	87,8179936	441,1726925	87,8179936	441,17269
8	23	14	1	1	410	26,92582404	447,5188534	41,43669871	518,2155017	66,18912297	499,9283635	26,92582404	432,0388716	26,92582404	432,0388716	26,92582404	432,03887
9	35	48	1	1	411	59,40538696	452,3907635	40,31128874	518,0466903	32,75667871	494,9134993	59,40538696	436,9108036	59,40538696	436,9108036	59,40538696	436,91080
4	73	73	1	1	413	103,2375901	458,9655611	53,75872022	520,063804	45,54119015	496,8311751	103,2375901	443,4856308	103,2375901	443,4856308	103,2375901	443,48563
2	73	87	1	2	423	113,5693621	460,5153191	67,60177512	522,1402612	45,54119015	496,8311751	113,5693621	445,0353958	113,5693621	445,0353958	113,5693621	445,03539
6	54	55	2	4	437	77,07788269	455,0416246	36,40054945	517,4600797	36,06937759	495,4104039	77,07788269	439,5616766	77,07788269	439,5616766	77,07788269	439,56167
5	28	80	5	3	480	84,7584804	456,1937085	69,97142274	522,4957082	0	490	84,7584804	440,7137657	84,7584804	440,7137657	84,7584804	440,71376
7	64	20	2	4	508	67,05221846	453,5377825	0	512	69,97142274	500,4957082	67,05221846	438,0578277	67,05221846	438,0578277	67,05221846	438,05782
3	29	93	3	2	512	97,41663102	458,0924216	80,95677859	524,1435107	13,03840481	491,9557597	97,41663102	442,6124873	97,41663102	442,6124873	97,41663102	442,61248



						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						29	93	64	20	28	80	0	0	0	0	0	
						Idletime:	518	Idletime	512	Idletime	490	Idletime	428	Idletime	428	Idletime	4
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to vel
0	0	13	1	1	300	85,0940656	530,764046	64,38167441	521,6572463	72,61542536	500,8923084	13	429,949999	13	429,949999	13	429,9499
1	76	44	1	2	363	67,89698079	528,1844962	26,83281573	516,0249203	60	498,9999955	87,8179936	441,1726925	87,8179936	441,1726925	87,8179936	441,17269
8	23	14	1	1	410	79,22752047	529,8840687	41,43669871	518,2155017	66,18912297	499,9283635	26,92582404	432,0388716	26,92582404	432,0388716	26,92582404	432,03887
9	35	48	1	1	411	45,39823785	524,8097016	40,31128874	518,0466903	32,75667871	494,9134993	59,40538696	436,9108036	59,40538696	436,9108036	59,40538696	436,91080
4	73	73	1	1	413	48,33218389	525,2497913	53,75872022	520,063804	45,54119015	496,8311751	103,2375901	443,4856308	103,2375901	443,4856308	103,2375901	443,48563
2	73	87	1	2	423	44,40720662	524,6610477	67,60177512	522,1402612	45,54119015	496,8311751	113,5693621	445,0353958	113,5693621	445,0353958	113,5693621	445,03539
6	54	55	2	4	437	45,48626166	524,8229051	36,40054945	517,4600797	36,06937759	495,4104039	77,07788269	439,5616766	77,07788269	439,5616766	77,07788269	439,56167
5	28	80	5	3	480	13,03840481	519,9557509	69,97142274	522,4957082	0	490	84,7584804	440,7137657	84,7584804	440,7137657	84,7584804	440,71376
7	64	20	2	4	508	80,95677859	530,1434561	0	512	69,97142274	500,4957082	67,05221846	438,0578277	67,05221846	438,0578277	67,05221846	438,05782
3	29	93	3	2	512	0	518	80,95677859	524,1435107	13,03840481	491,9557597	97,41663102	442,6124873	97,41663102	442,6124873	97,41663102	442,61248

						Veh1 loc		Veh2 loc		Veh 3 loc		Veh 4 loc		Veh 5 loc		Veh 6	
						29	93	54	55	28	80	0	0	0	0	0	
						Idletime:	518	Idletime	526,05	Idletime	490	Idletime	508	Idletime	508	Idletime	5
Customer	X	Y	Plan volume	Actual volume	Timewindow	Dist to veh 1	Time to veh 1	Dist to veh2	Time to veh 2	Dist to veh3	Time to veh3	Dist to veh 4	Time to veh 4	Dist to veh 5	Time to veh 5	Dist to veh 6	Time to vel
0	0	13	1	1	300	85,0940656	530,764046	68,41052551	536,3115737	72,61542536	500,8923084	13	509,949999	13	509,949999	13	509,9499
1	76	44	1	2	363	67,89698079	528,1844962	24,59674775	529,7395103	60	498,9999955	87,8179936	521,1726925	87,8179936	521,1726925	87,8179936	521,17269
8	23	14	1	1	410	79,22752047	529,8840687	51,4003891	533,7600545	66,18912297	499,9283635	26,92582404	512,0388716	26,92582404	512,0388716	26,92582404	512,03887
9	35	48	1	1	411	45,39823785	524,8097016	20,24845673	529,087267	32,75667871	494,9134993	59,40538696	516,9108036	59,40538696	516,9108036	59,40538696	516,91080
4	73	73	1	1	413	48,33218389	525,2497913	26,17250466	529,9758737	45,54119015	496,8311751	103,2375901	523,4856308	103,2375901	523,4856308	103,2375901	523,48563
2	73	87	1	2	423	44,40720662	524,6610477	37,21558813	531,6323354	45,54119015	496,8311751	113,5693621	525,0353958	113,5693621	525,0353958	113,5693621	525,03539
6	54	55	2	4	437	45,48626166	524,8229051	0	526,05	36,06937759	495,4104039	77,07788269	519,5616766	77,07788269	519,5616766	77,07788269	519,56167
5	28	80	5	3	480	13,03840481	519,9557509	36,06937759	531,4604039	0	490	84,7584804	520,7137657	84,7584804	520,7137657	84,7584804	520,71376
7	64	20	2	4	508	80,95677859	530,1434561	36,40054945	531,5100797	69,97142274	500,4957082	67,05221846	518,0578277	67,05221846	518,0578277	67,05221846	518,05782
3	29	93	3	2	512	0	518	45,48626166	532,8729358	13,03840481	491,9557597	97,41663102	522,6124873	97,41663102	522,6124873	97,41663102	522,61248

Figure V.6 – Manual replanning (second strategy)

The manual planning results in the routes and distances travelled shown in Table V.3 for the first strategy, and Table V.4 for the second strategy.

Vehicle	**Route from**	**Route to**	**KM driven**
0-0	Depot	Customer 0	1,30
	Customer 0	Customer 1	8,21
	Customer 1	Customer 4	2,92
	Customer 4	Customer 2	1,4
	Customer 2	Depot	11,4
	Depot	Customer 7	6,71
	Customer 7	Customer 3	8,10
	Customer 3	Depot	9,74
0-1	Depot	Customer 8	2,70
	Customer 8	Customer 9	3,61
	Customer 9	Customer 6	2,02
	Customer 6	Depot	7,71
0-2	Depot	Customer 5	8,48
	Customer 5	Depot	8,48
Total			***82,78***

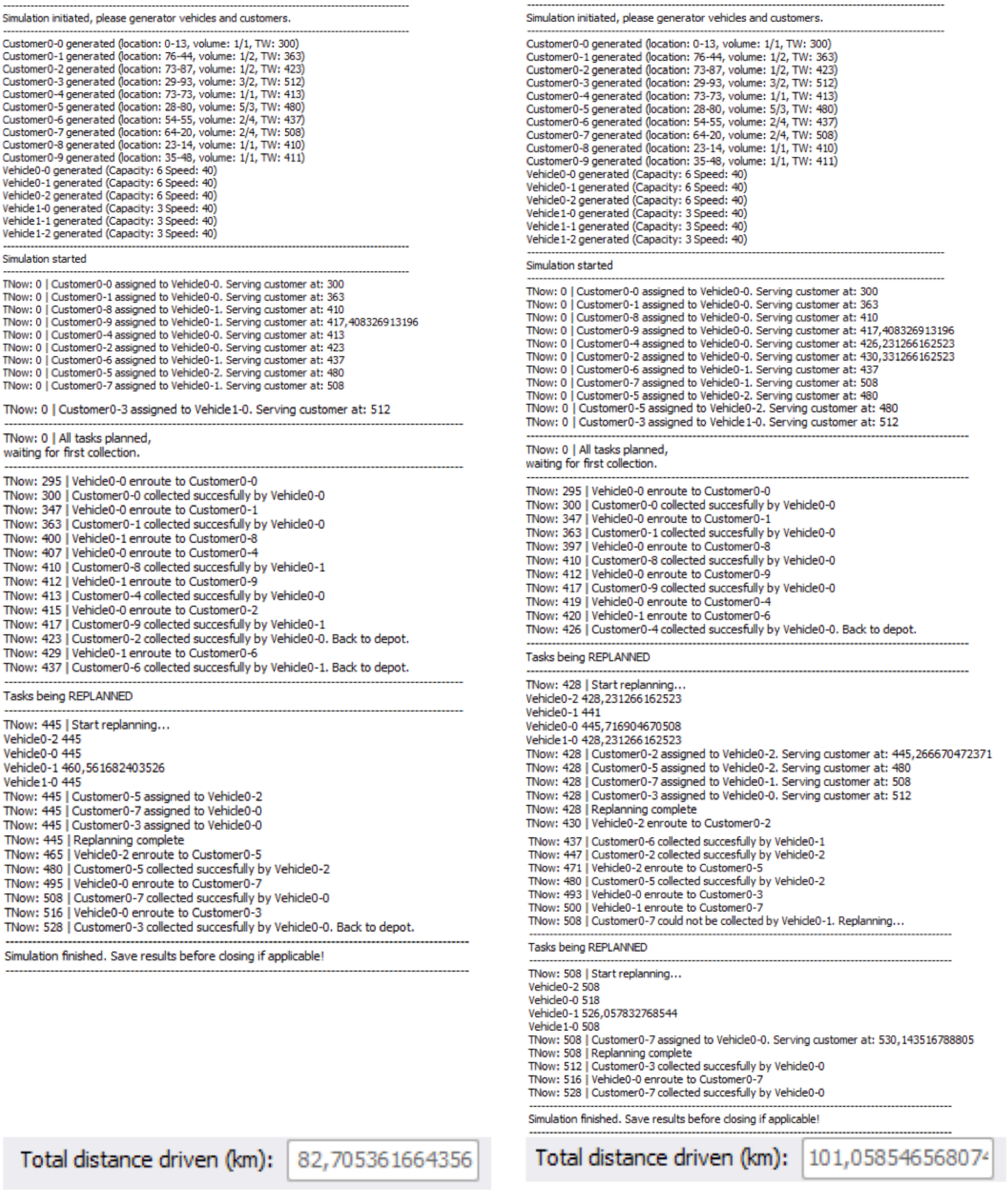
Table V.3 – Result manual planning (first strategy)

Vehicle	**Route from**	**Route to**	**KM driven**
0-0	Depot	Customer 0	1,30
	Customer 0	Customer 1	8,21
	Customer 1	Customer 8	6,10
	Customer 8	Customer 9	3,61
	Customer 9	Customer 4	4,55
	Customer 4	Depot	10,32
	Depot	Customer 3	9,74
	Customer 3	Customer 7	8,10
	Customer 7	Depot	6,71
0-1	Depot	Customer 6	7,71
	Customer 6	Customer 7	3,64
	Customer 7	Depot	6,71
0-2	Depot	Customer 2	11,36
	Customer 2	Customer 5	4,55
	Customer 5	Depot	8,48
Total			***101,09***

Table V.4 – Results manual planning (second strategy).

Simulation results

Figure IV.7 shows the results when planning the customer sample using either of the two strategies using the simulation model. The results are the same for the simulation as they were for the manual calculation, helping to verify the simulation model.



Planning vehicles to customers:

```
------------------------------------------------------------------------
Simulation initiated, please generator vehicles and customers.
------------------------------------------------------------------------
Customer0-0 generated (location: 0-13, volume: 1/1, TW: 300)
Customer0-1 generated (location: 76-44, volume: 1/2, TW: 363)
Customer0-2 generated (location: 73-87, volume: 1/2, TW: 423)
Customer0-3 generated (location: 29-93, volume: 3/2, TW: 512)
Customer0-4 generated (location: 73-73, volume: 1/1, TW: 413)
Customer0-5 generated (location: 28-80, volume: 5/3, TW: 480)
Customer0-6 generated (location: 54-55, volume: 2/4, TW: 437)
Customer0-7 generated (location: 64-20, volume: 2/4, TW: 508)
Customer0-8 generated (location: 23-14, volume: 1/1, TW: 410)
Customer0-9 generated (location: 35-48, volume: 1/1, TW: 411)
Vehicle0-0 generated (Capacity: 6 Speed: 40)
Vehicle0-1 generated (Capacity: 6 Speed: 40)
Vehicle0-2 generated (Capacity: 6 Speed: 40)
Vehicle1-0 generated (Capacity: 3 Speed: 40)
Vehicle1-1 generated (Capacity: 3 Speed: 40)
Vehicle1-2 generated (Capacity: 3 Speed: 40)
------------------------------------------------------------------------
Simulation started
------------------------------------------------------------------------
TNow: 0 | Customer0-0 assigned to Vehicle0-0. Serving customer at: 300
TNow: 0 | Customer0-1 assigned to Vehicle0-0. Serving customer at: 363
TNow: 0 | Customer0-8 assigned to Vehicle0-1. Serving customer at: 410
TNow: 0 | Customer0-9 assigned to Vehicle0-1. Serving customer at: 417,408326913196
TNow: 0 | Customer0-4 assigned to Vehicle0-0. Serving customer at: 413
TNow: 0 | Customer0-2 assigned to Vehicle0-0. Serving customer at: 423
TNow: 0 | Customer0-6 assigned to Vehicle0-1. Serving customer at: 437
TNow: 0 | Customer0-5 assigned to Vehicle0-2. Serving customer at: 480
TNow: 0 | Customer0-7 assigned to Vehicle0-1. Serving customer at: 508

TNow: 0 | Customer0-3 assigned to Vehicle1-0. Serving customer at: 512
------------------------------------------------------------------------
TNow: 0 | All tasks planned,
waiting for first collection.
------------------------------------------------------------------------
TNow: 295 | Vehicle0-0 enroute to Customer0-0
TNow: 300 | Customer0-0 collected succesfully by Vehicle0-0
TNow: 347 | Vehicle0-0 enroute to Customer0-1
TNow: 363 | Customer0-1 collected succesfully by Vehicle0-0
TNow: 400 | Vehicle0-1 enroute to Customer0-8
TNow: 407 | Vehicle0-0 enroute to Customer0-4
TNow: 410 | Customer0-8 collected succesfully by Vehicle0-1
TNow: 412 | Vehicle0-1 enroute to Customer0-9
TNow: 413 | Customer0-4 collected succesfully by Vehicle0-0
TNow: 415 | Vehicle0-0 enroute to Customer0-2
TNow: 417 | Customer0-9 collected succesfully by Vehicle0-1
TNow: 423 | Customer0-2 collected succesfully by Vehicle0-0. Back to depot.
TNow: 429 | Vehicle0-1 enroute to Customer0-6
TNow: 437 | Customer0-6 collected succesfully by Vehicle0-1. Back to depot.
------------------------------------------------------------------------
Tasks being REPLANNED
------------------------------------------------------------------------
TNow: 445 | Start replanning...
Vehicle0-2 445
Vehicle0-0 445
Vehicle0-1 460,561682403526
Vehicle1-0 445
TNow: 445 | Customer0-5 assigned to Vehicle0-2
TNow: 445 | Customer0-7 assigned to Vehicle0-0
TNow: 445 | Customer0-3 assigned to Vehicle0-0
TNow: 445 | Replanning complete
TNow: 465 | Vehicle0-2 enroute to Customer0-5
TNow: 480 | Customer0-5 collected succesfully by Vehicle0-2
TNow: 495 | Vehicle0-0 enroute to Customer0-7
TNow: 508 | Customer0-7 collected succesfully by Vehicle0-0
TNow: 516 | Vehicle0-0 enroute to Customer0-3
TNow: 528 | Customer0-3 collected succesfully by Vehicle0-0. Back to depot.
------------------------------------------------------------------------
Simulation finished. Save results before closing if applicable!
------------------------------------------------------------------------
```

Total distance driven (km): 82,705361664356

Planning customers to vehicles:

```
------------------------------------------------------------------------
Simulation initiated, please generator vehicles and customers.
------------------------------------------------------------------------
Customer0-0 generated (location: 0-13, volume: 1/1, TW: 300)
Customer0-1 generated (location: 76-44, volume: 1/2, TW: 363)
Customer0-2 generated (location: 73-87, volume: 1/2, TW: 423)
Customer0-3 generated (location: 29-93, volume: 3/2, TW: 512)
Customer0-4 generated (location: 73-73, volume: 1/1, TW: 413)
Customer0-5 generated (location: 28-80, volume: 5/3, TW: 480)
Customer0-6 generated (location: 54-55, volume: 2/4, TW: 437)
Customer0-7 generated (location: 64-20, volume: 2/4, TW: 508)
Customer0-8 generated (location: 23-14, volume: 1/1, TW: 410)
Customer0-9 generated (location: 35-48, volume: 1/1, TW: 411)
Vehicle0-0 generated (Capacity: 6 Speed: 40)
Vehicle0-1 generated (Capacity: 6 Speed: 40)
Vehicle0-2 generated (Capacity: 6 Speed: 40)
Vehicle1-0 generated (Capacity: 3 Speed: 40)
Vehicle1-1 generated (Capacity: 3 Speed: 40)
Vehicle1-2 generated (Capacity: 3 Speed: 40)
------------------------------------------------------------------------
Simulation started
------------------------------------------------------------------------
TNow: 0 | Customer0-0 assigned to Vehicle0-0. Serving customer at: 300
TNow: 0 | Customer0-1 assigned to Vehicle0-0. Serving customer at: 363
TNow: 0 | Customer0-8 assigned to Vehicle0-0. Serving customer at: 410
TNow: 0 | Customer0-9 assigned to Vehicle0-0. Serving customer at: 417,408326913196
TNow: 0 | Customer0-4 assigned to Vehicle0-0. Serving customer at: 426,231266162523
TNow: 0 | Customer0-2 assigned to Vehicle0-0. Serving customer at: 430,331266162523
TNow: 0 | Customer0-6 assigned to Vehicle0-1. Serving customer at: 437
TNow: 0 | Customer0-7 assigned to Vehicle0-1. Serving customer at: 508
TNow: 0 | Customer0-5 assigned to Vehicle0-2. Serving customer at: 480
TNow: 0 | Customer0-5 assigned to Vehicle0-2. Serving customer at: 480
TNow: 0 | Customer0-3 assigned to Vehicle1-0. Serving customer at: 512
------------------------------------------------------------------------
TNow: 0 | All tasks planned,
waiting for first collection.
------------------------------------------------------------------------
TNow: 295 | Vehicle0-0 enroute to Customer0-0
TNow: 300 | Customer0-0 collected succesfully by Vehicle0-0
TNow: 347 | Vehicle0-0 enroute to Customer0-1
TNow: 363 | Customer0-1 collected succesfully by Vehicle0-0
TNow: 397 | Vehicle0-0 enroute to Customer0-8
TNow: 410 | Customer0-8 collected succesfully by Vehicle0-0
TNow: 412 | Vehicle0-0 enroute to Customer0-9
TNow: 417 | Customer0-9 collected succesfully by Vehicle0-0
TNow: 419 | Vehicle0-0 enroute to Customer0-4
TNow: 420 | Vehicle0-1 enroute to Customer0-6
TNow: 426 | Customer0-4 collected succesfully by Vehicle0-0. Back to depot.
------------------------------------------------------------------------
Tasks being REPLANNED
------------------------------------------------------------------------
TNow: 428 | Start replanning...
Vehicle0-2 428,231266162523
Vehicle0-1 441
Vehicle0-0 445,716904670508
Vehicle1-0 428,231266162523
TNow: 428 | Customer0-2 assigned to Vehicle0-2. Serving customer at: 445,266670472371
TNow: 428 | Customer0-5 assigned to Vehicle0-2. Serving customer at: 480
TNow: 428 | Customer0-7 assigned to Vehicle0-1. Serving customer at: 508
TNow: 428 | Customer0-3 assigned to Vehicle0-0. Serving customer at: 512
TNow: 428 | Replanning complete
TNow: 430 | Vehicle0-2 enroute to Customer0-2

TNow: 437 | Customer0-6 collected succesfully by Vehicle0-1
TNow: 447 | Customer0-2 collected succesfully by Vehicle0-2
TNow: 471 | Vehicle0-2 enroute to Customer0-5
TNow: 480 | Customer0-5 collected succesfully by Vehicle0-2
TNow: 493 | Vehicle0-0 enroute to Customer0-3
TNow: 500 | Vehicle0-1 enroute to Customer0-7
TNow: 508 | Customer0-7 could not be collected by Vehicle0-1. Replanning...
------------------------------------------------------------------------
Tasks being REPLANNED
------------------------------------------------------------------------
TNow: 508 | Start replanning...
Vehicle0-2 508
Vehicle0-0 518
Vehicle0-1 526,057832768544
Vehicle1-0 508
TNow: 508 | Customer0-7 assigned to Vehicle0-0. Serving customer at: 530,143516788805
TNow: 508 | Replanning complete
TNow: 512 | Customer0-3 collected succesfully by Vehicle0-0
TNow: 516 | Vehicle0-0 enroute to Customer0-7
TNow: 528 | Customer0-7 collected succesfully by Vehicle0-0
------------------------------------------------------------------------
Simulation finished. Save results before closing if applicable!
------------------------------------------------------------------------
```

Total distance driven (km): 101,05854656807

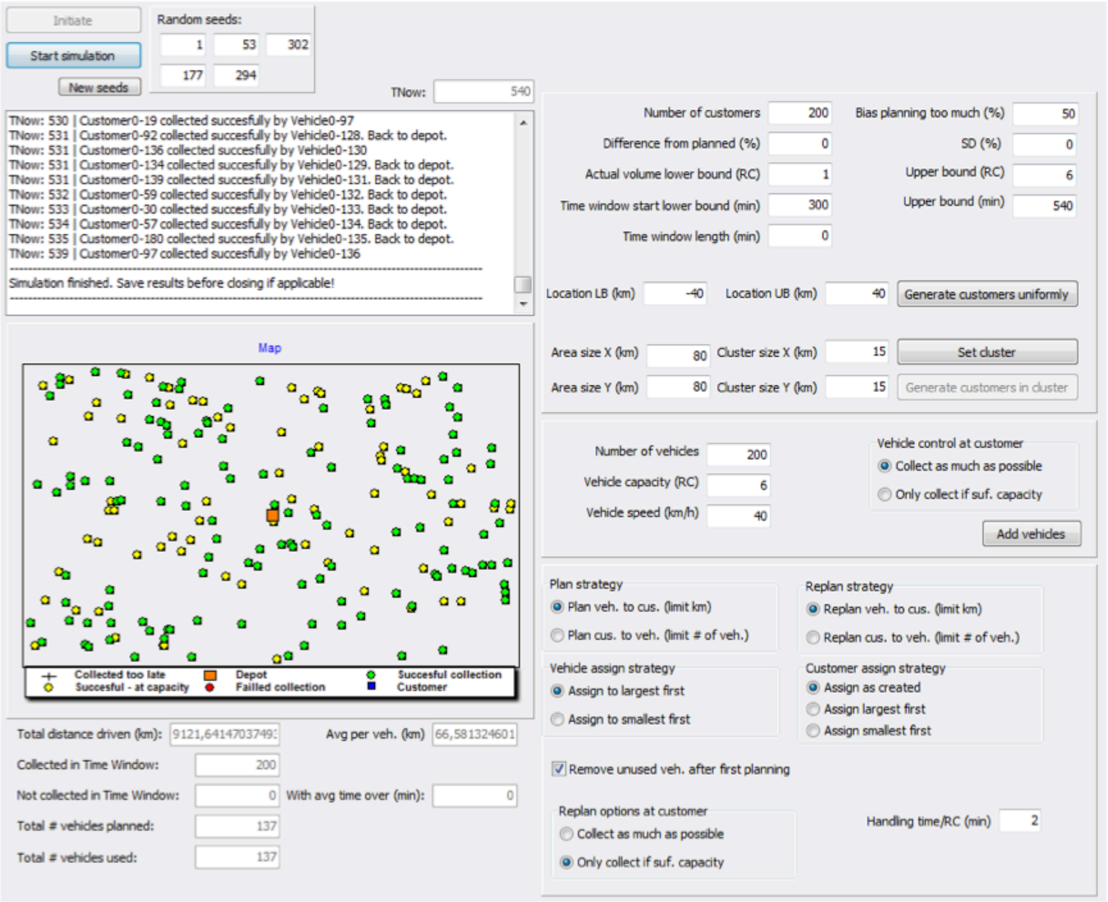
Figure V.7 – Simulation results (both planning strategies shown).

V.ii Extreme values

The next step in verification is checking the model behavior for extreme or boundary values.

Single time unit time window

Figure V.8 shows the result for 3 samples of 200 customers each without a difference between planned and actual volume, show that no replan or out of time window collection occurs even for a time window of a single simulation time. Model behavior is as expected



Random seeds: 1 53 302 177 294

TNow: 540

```
TNow: 530 | Customer0-19 collected succesfully by Vehicle0-97
TNow: 531 | Customer0-92 collected succesfully by Vehicle0-128. Back to depot.
TNow: 531 | Customer0-136 collected succesfully by Vehicle0-130
TNow: 531 | Customer0-134 collected succesfully by Vehicle0-129. Back to depot.
TNow: 531 | Customer0-139 collected succesfully by Vehicle0-131. Back to depot.
TNow: 532 | Customer0-59 collected succesfully by Vehicle0-132. Back to depot.
TNow: 533 | Customer0-30 collected succesfully by Vehicle0-133. Back to depot.
TNow: 534 | Customer0-57 collected succesfully by Vehicle0-134. Back to depot.
TNow: 535 | Customer0-180 collected succesfully by Vehicle0-135. Back to depot.
TNow: 539 | Customer0-97 collected succesfully by Vehicle0-136
--------------------------------------------------------------------------------
Simulation finished. Save results before closing if applicable!
--------------------------------------------------------------------------------
```

Total distance driven (km): 9121,64147037493
Avg per veh. (km): 66,581324601
Collected in Time Window: 200
Not collected in Time Window: 0
With avg time over (min): 0
Total # vehicles planned: 137
Total # vehicles used: 137

Number of customers: 200
Bias planning too much (%): 50
Difference from planned (%): 0
SD (%): 0
Actual volume lower bound (RC): 1
Upper bound (RC): 6
Time window start lower bound (min): 300
Upper bound (min): 540
Time window length (min): 0
Location LB (km): -40
Location UB (km): 40
Area size X (km): 80
Cluster size X (km): 15
Area size Y (km): 80
Cluster size Y (km): 15

Number of vehicles: 200
Vehicle capacity (RC): 6
Vehicle speed (km/h): 40

Vehicle control at customer
● Collect as much as possible
○ Only collect if suf. capacity

Plan strategy
● Plan veh. to cus. (limit km)
○ Plan cus. to veh. (limit # of veh.)

Replan strategy
● Replan veh. to cus. (limit km)
○ Replan cus. to veh. (limit # of veh.)

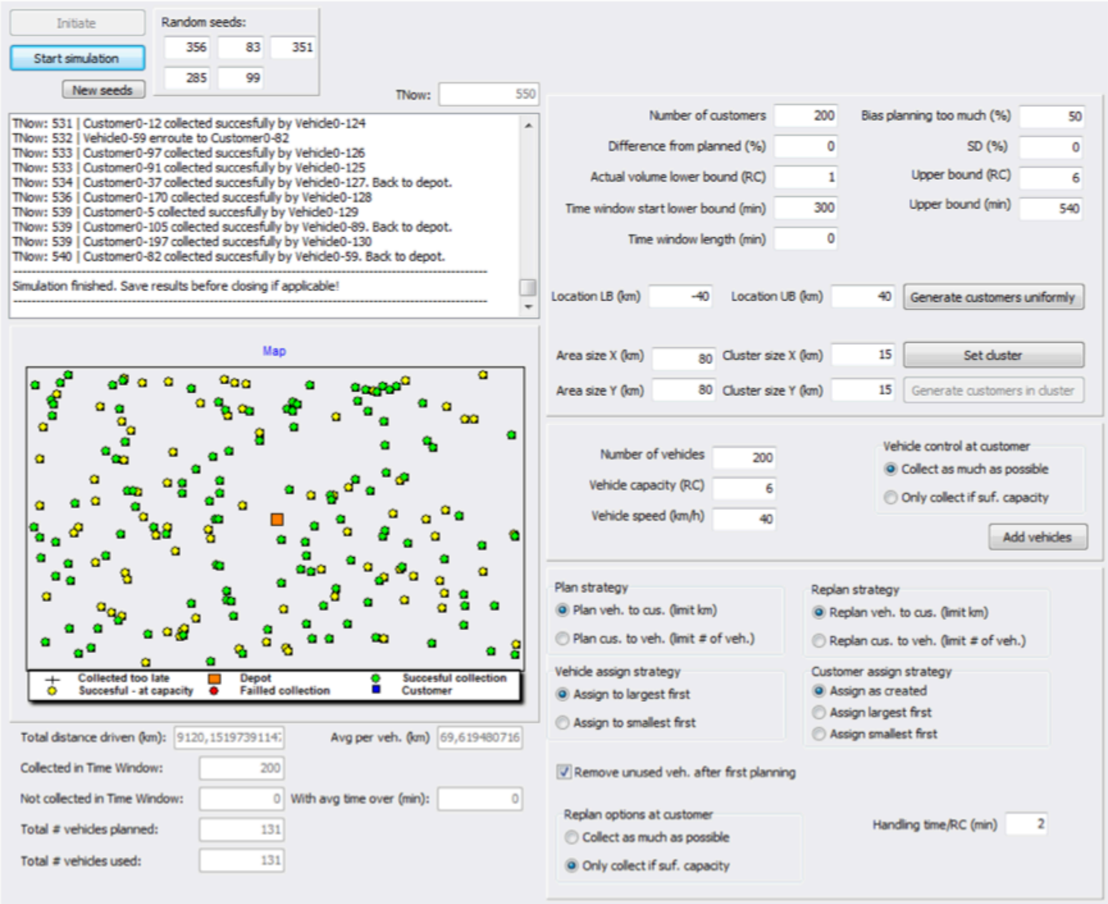
Vehicle assign strategy
● Assign to largest first
○ Assign to smallest first

Customer assign strategy
● Assign as created
○ Assign largest first
○ Assign smallest first

☑ Remove unused veh. after first planning

Replan options at customer
○ Collect as much as possible
● Only collect if suf. capacity

Handling time/RC (min): 2



Random seeds: 356 83 351 285 99

TNow: 550

```
TNow: 531 | Customer0-12 collected succesfully by Vehicle0-124
TNow: 532 | Vehicle0-59 enroute to Customer0-82
TNow: 533 | Customer0-97 collected succesfully by Vehicle0-126
TNow: 533 | Customer0-91 collected succesfully by Vehicle0-125
TNow: 534 | Customer0-37 collected succesfully by Vehicle0-127. Back to depot.
TNow: 536 | Customer0-170 collected succesfully by Vehicle0-128
TNow: 539 | Customer0-5 collected succesfully by Vehicle0-129
TNow: 539 | Customer0-105 collected succesfully by Vehicle0-89. Back to depot.
TNow: 539 | Customer0-197 collected succesfully by Vehicle0-130
TNow: 540 | Customer0-82 collected succesfully by Vehicle0-59. Back to depot.
------------------------------------------------------------------------------------------------
Simulation finished. Save results before closing if applicable!
------------------------------------------------------------------------------------------------
```

Total distance driven (km): 9120,15197391147
Avg per veh. (km) 69,619480716
Collected in Time Window: 200
Not collected in Time Window: 0
With avg time over (min): 0
Total # vehicles planned: 131
Total # vehicles used: 131

Number of customers 200
Bias planning too much (%) 50
Difference from planned (%) 0
SD (%) 0
Actual volume lower bound (RC) 1
Upper bound (RC) 6
Time window start lower bound (min) 300
Upper bound (min) 540
Time window length (min) 0
Location LB (km) -40
Location UB (km) 40
Area size X (km) 80
Cluster size X (km) 15
Area size Y (km) 80
Cluster size Y (km) 15

Number of vehicles 200
Vehicle capacity (RC) 6
Vehicle speed (km/h) 40

Vehicle control at customer
● Collect as much as possible
○ Only collect if suf. capacity

Plan strategy
● Plan veh. to cus. (limit km)
○ Plan cus. to veh. (limit # of veh.)

Replan strategy
● Replan veh. to cus. (limit km)
○ Replan cus. to veh. (limit # of veh.)

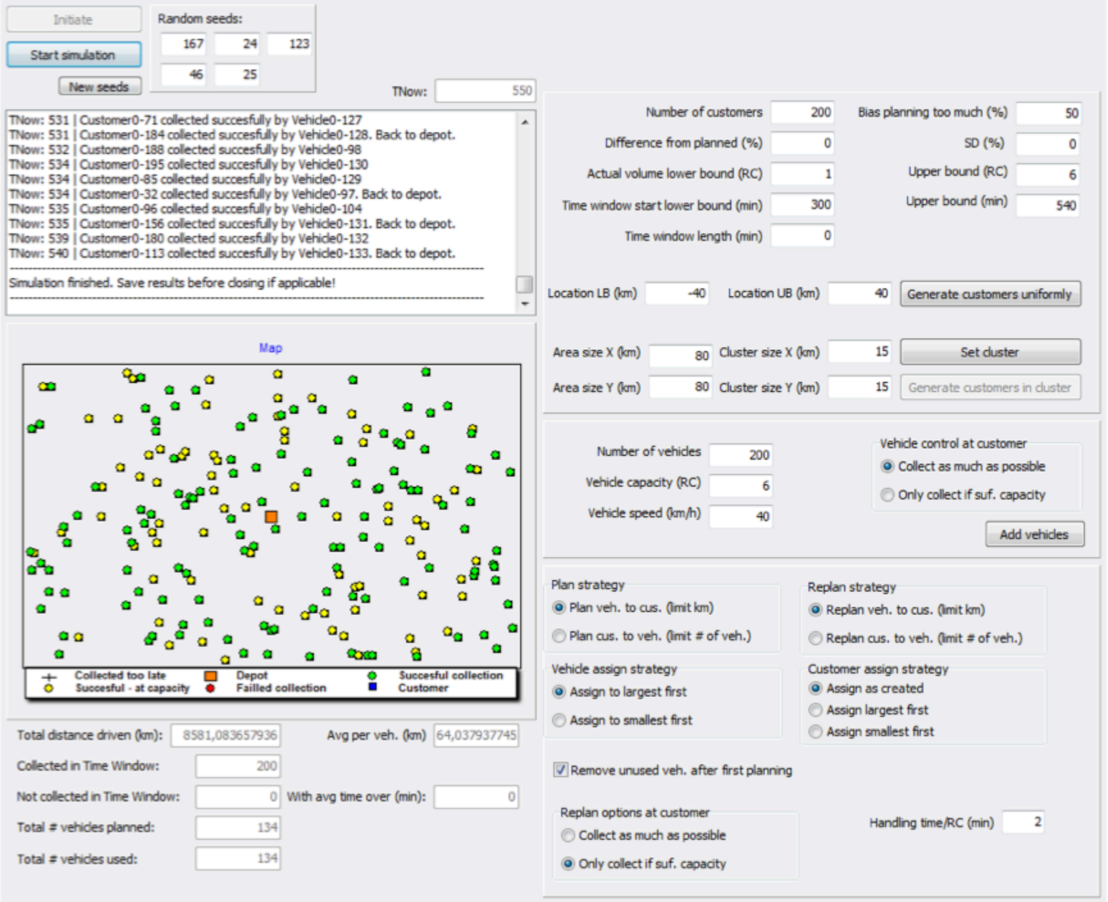
Vehicle assign strategy
● Assign to largest first
○ Assign to smallest first

Customer assign strategy
● Assign as created
○ Assign largest first
○ Assign smallest first

☑ Remove unused veh. after first planning

Replan options at customer
○ Collect as much as possible
● Only collect if suf. capacity

Handling time/RC (min) 2



Random seeds: 167 24 123 46 25

TNow: 550

```
TNow: 531 | Customer0-71 collected succesfully by Vehicle0-127
TNow: 531 | Customer0-184 collected succesfully by Vehicle0-128. Back to depot.
TNow: 532 | Customer0-188 collected succesfully by Vehicle0-98
TNow: 534 | Customer0-195 collected succesfully by Vehicle0-130
TNow: 534 | Customer0-85 collected succesfully by Vehicle0-129
TNow: 534 | Customer0-32 collected succesfully by Vehicle0-97. Back to depot.
TNow: 535 | Customer0-96 collected succesfully by Vehicle0-104
TNow: 535 | Customer0-156 collected succesfully by Vehicle0-131. Back to depot.
TNow: 539 | Customer0-180 collected succesfully by Vehicle0-132
TNow: 540 | Customer0-113 collected succesfully by Vehicle0-133. Back to depot.
------------------------------------------------------------------------------------------------
Simulation finished. Save results before closing if applicable!
------------------------------------------------------------------------------------------------
```

Total distance driven (km): 8581,083657936
Avg per veh. (km) 64,037937745
Collected in Time Window: 200
Not collected in Time Window: 0
With avg time over (min): 0
Total # vehicles planned: 134
Total # vehicles used: 134

Number of customers 200
Bias planning too much (%) 50
Difference from planned (%) 0
SD (%) 0
Actual volume lower bound (RC) 1
Upper bound (RC) 6
Time window start lower bound (min) 300
Upper bound (min) 540
Time window length (min) 0
Location LB (km) -40
Location UB (km) 40
Area size X (km) 80
Cluster size X (km) 15
Area size Y (km) 80
Cluster size Y (km) 15

Number of vehicles 200
Vehicle capacity (RC) 6
Vehicle speed (km/h) 40

Vehicle control at customer
● Collect as much as possible
○ Only collect if suf. capacity

Plan strategy
● Plan veh. to cus. (limit km)
○ Plan cus. to veh. (limit # of veh.)

Replan strategy
● Replan veh. to cus. (limit km)
○ Replan cus. to veh. (limit # of veh.)

Vehicle assign strategy
● Assign to largest first
○ Assign to smallest first

Customer assign strategy
● Assign as created
○ Assign largest first
○ Assign smallest first

☑ Remove unused veh. after first planning

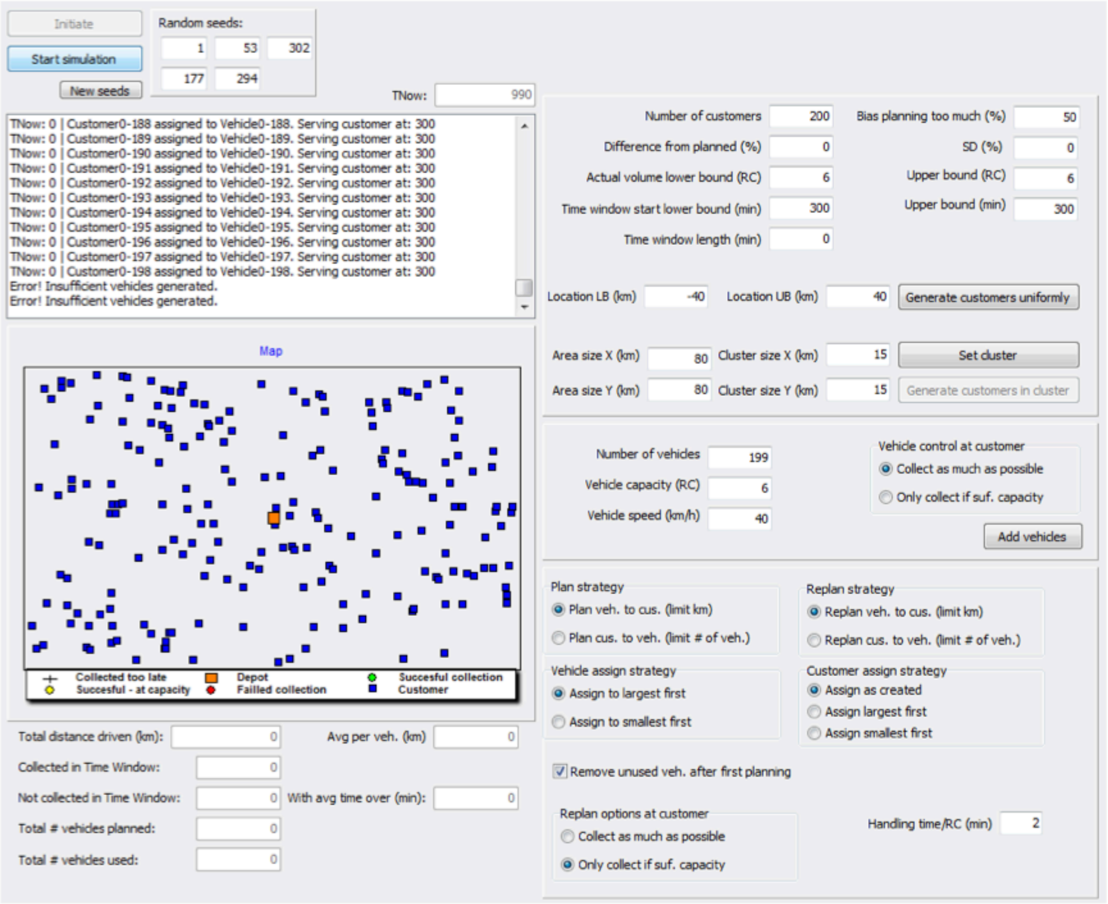
Replan options at customer
○ Collect as much as possible
● Only collect if suf. capacity

Handling time/RC (min) 2

Figure V.8 – Three simulation runs using a time window length of 0 time units

Available vehicles

Figure V.9 shows the model behavior when the total vehicle capacity is just below, equal to, or just above total customer collection demands. Model behavior is as expected.



Random seeds: 1 53 302 177 294

TNow: 990

```
TNow: 0 | Customer0-188 assigned to Vehicle0-188. Serving customer at: 300
TNow: 0 | Customer0-189 assigned to Vehicle0-189. Serving customer at: 300
TNow: 0 | Customer0-190 assigned to Vehicle0-190. Serving customer at: 300
TNow: 0 | Customer0-191 assigned to Vehicle0-191. Serving customer at: 300
TNow: 0 | Customer0-192 assigned to Vehicle0-192. Serving customer at: 300
TNow: 0 | Customer0-193 assigned to Vehicle0-193. Serving customer at: 300
TNow: 0 | Customer0-194 assigned to Vehicle0-194. Serving customer at: 300
TNow: 0 | Customer0-195 assigned to Vehicle0-195. Serving customer at: 300
TNow: 0 | Customer0-196 assigned to Vehicle0-196. Serving customer at: 300
TNow: 0 | Customer0-197 assigned to Vehicle0-197. Serving customer at: 300
TNow: 0 | Customer0-198 assigned to Vehicle0-198. Serving customer at: 300
Error! Insufficient vehicles generated.
Error! Insufficient vehicles generated.
```

Total distance driven (km): 0
Avg per veh. (km) 0
Collected in Time Window: 0
Not collected in Time Window: 0
With avg time over (min): 0
Total # vehicles planned: 0
Total # vehicles used: 0

Number of customers 200
Bias planning too much (%) 50
Difference from planned (%) 0
SD (%) 0
Actual volume lower bound (RC) 6
Upper bound (RC) 6
Time window start lower bound (min) 300
Upper bound (min) 300
Time window length (min) 0

Location LB (km) -40
Location UB (km) 40

Area size X (km) 80
Cluster size X (km) 15
Area size Y (km) 80
Cluster size Y (km) 15

Number of vehicles 199
Vehicle capacity (RC) 6
Vehicle speed (km/h) 40

Vehicle control at customer
● Collect as much as possible
○ Only collect if suf. capacity

Plan strategy
● Plan veh. to cus. (limit km)
○ Plan cus. to veh. (limit # of veh.)

Replan strategy
● Replan veh. to cus. (limit km)
○ Replan cus. to veh. (limit # of veh.)

Vehicle assign strategy
● Assign to largest first
○ Assign to smallest first

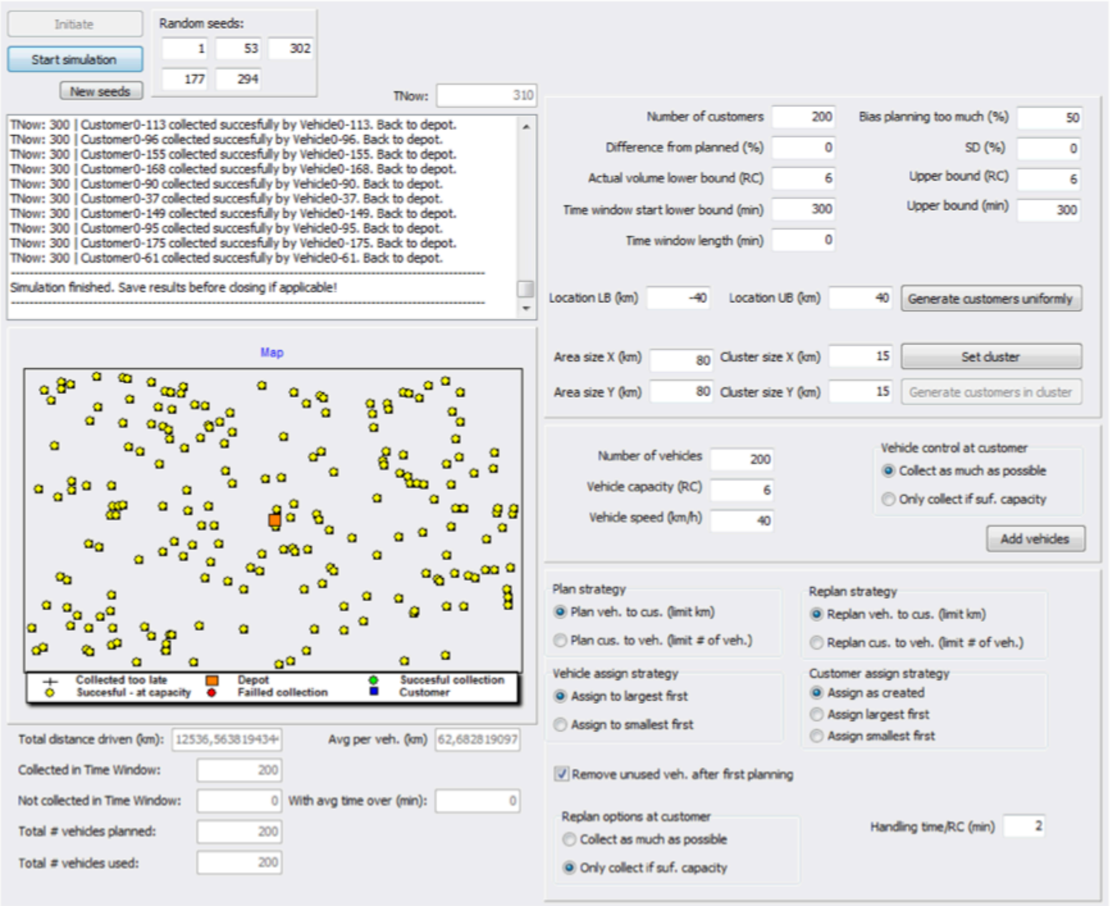
Customer assign strategy
● Assign as created
○ Assign largest first
○ Assign smallest first

☑ Remove unused veh. after first planning

Replan options at customer
○ Collect as much as possible
● Only collect if suf. capacity

Handling time/RC (min) 2

Figure V.9 (1) – Verification results capacity



Random seeds: 1 53 302 177 294

TNow: 310

```
TNow: 300 | Customer0-113 collected succesfully by Vehicle0-113. Back to depot.
TNow: 300 | Customer0-96 collected succesfully by Vehicle0-96. Back to depot.
TNow: 300 | Customer0-155 collected succesfully by Vehicle0-155. Back to depot.
TNow: 300 | Customer0-168 collected succesfully by Vehicle0-168. Back to depot.
TNow: 300 | Customer0-90 collected succesfully by Vehicle0-90. Back to depot.
TNow: 300 | Customer0-37 collected succesfully by Vehicle0-37. Back to depot.
TNow: 300 | Customer0-149 collected succesfully by Vehicle0-149. Back to depot.
TNow: 300 | Customer0-95 collected succesfully by Vehicle0-95. Back to depot.
TNow: 300 | Customer0-175 collected succesfully by Vehicle0-175. Back to depot.
TNow: 300 | Customer0-61 collected succesfully by Vehicle0-61. Back to depot.
----------------------------------------------------------------------------
Simulation finished. Save results before closing if applicable!
----------------------------------------------------------------------------
```

+ Collected too late
● Succesful - at capacity
■ Depot
● Failled collection
● Succesful collection
■ Customer

Total distance driven (km): 12536,563819434
Avg per veh. (km) 62,682819097
Collected in Time Window: 200
Not collected in Time Window: 0
With avg time over (min): 0
Total # vehicles planned: 200
Total # vehicles used: 200

Number of customers 200
Bias planning too much (%) 50
Difference from planned (%) 0
SD (%) 0
Actual volume lower bound (RC) 6
Upper bound (RC) 6
Time window start lower bound (min) 300
Upper bound (min) 300
Time window length (min) 0
Location LB (km) -40
Location UB (km) 40
Area size X (km) 80
Cluster size X (km) 15
Area size Y (km) 80
Cluster size Y (km) 15

Number of vehicles 200
Vehicle capacity (RC) 6
Vehicle speed (km/h) 40

Vehicle control at customer
● Collect as much as possible
○ Only collect if suf. capacity

Plan strategy
● Plan veh. to cus. (limit km)
○ Plan cus. to veh. (limit # of veh.)

Replan strategy
● Replan veh. to cus. (limit km)
○ Replan cus. to veh. (limit # of veh.)

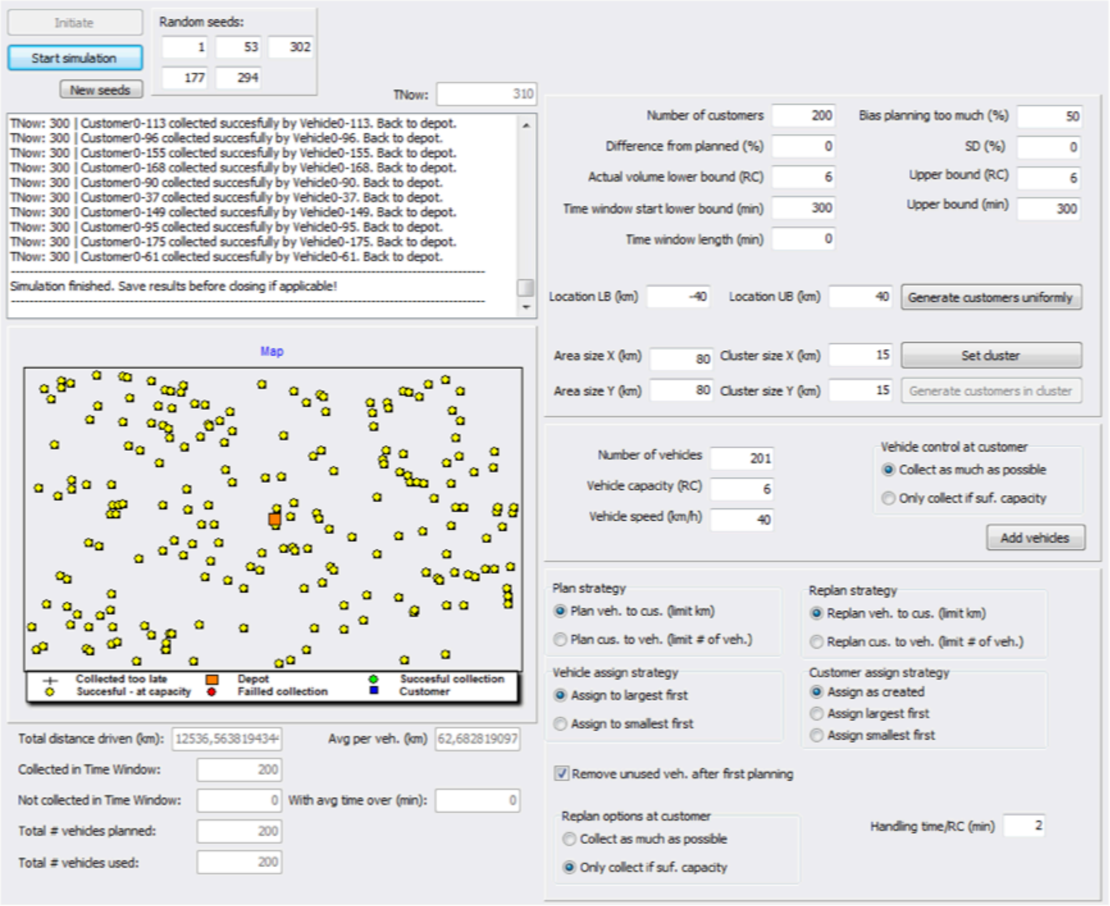
Vehicle assign strategy
● Assign to largest first
○ Assign to smallest first

Customer assign strategy
● Assign as created
○ Assign largest first
○ Assign smallest first

☑ Remove unused veh. after first planning

Replan options at customer
○ Collect as much as possible
● Only collect if suf. capacity

Handling time/RC (min) 2



Random seeds: 1 53 302 177 294

TNow: 310

```
TNow: 300 | Customer0-113 collected succesfully by Vehicle0-113. Back to depot.
TNow: 300 | Customer0-96 collected succesfully by Vehicle0-96. Back to depot.
TNow: 300 | Customer0-155 collected succesfully by Vehicle0-155. Back to depot.
TNow: 300 | Customer0-168 collected succesfully by Vehicle0-168. Back to depot.
TNow: 300 | Customer0-90 collected succesfully by Vehicle0-90. Back to depot.
TNow: 300 | Customer0-37 collected succesfully by Vehicle0-37. Back to depot.
TNow: 300 | Customer0-149 collected succesfully by Vehicle0-149. Back to depot.
TNow: 300 | Customer0-95 collected succesfully by Vehicle0-95. Back to depot.
TNow: 300 | Customer0-175 collected succesfully by Vehicle0-175. Back to depot.
TNow: 300 | Customer0-61 collected succesfully by Vehicle0-61. Back to depot.
----------------------------------------------------------------------------
Simulation finished. Save results before closing if applicable!
----------------------------------------------------------------------------
```

+ Collected too late
● Succesful - at capacity
■ Depot
● Failled collection
● Succesful collection
■ Customer

Total distance driven (km): 12536,563819434
Avg per veh. (km) 62,682819097
Collected in Time Window: 200
Not collected in Time Window: 0
With avg time over (min): 0
Total # vehicles planned: 200
Total # vehicles used: 200

Number of customers 200
Bias planning too much (%) 50
Difference from planned (%) 0
SD (%) 0
Actual volume lower bound (RC) 6
Upper bound (RC) 6
Time window start lower bound (min) 300
Upper bound (min) 300
Time window length (min) 0
Location LB (km) -40
Location UB (km) 40
Area size X (km) 80
Cluster size X (km) 15
Area size Y (km) 80
Cluster size Y (km) 15

Number of vehicles 201
Vehicle capacity (RC) 6
Vehicle speed (km/h) 40

Vehicle control at customer
● Collect as much as possible
○ Only collect if suf. capacity

Plan strategy
● Plan veh. to cus. (limit km)
○ Plan cus. to veh. (limit # of veh.)

Replan strategy
● Replan veh. to cus. (limit km)
○ Replan cus. to veh. (limit # of veh.)

Vehicle assign strategy
● Assign to largest first
○ Assign to smallest first

Customer assign strategy
● Assign as created
○ Assign largest first
○ Assign smallest first

☑ Remove unused veh. after first planning

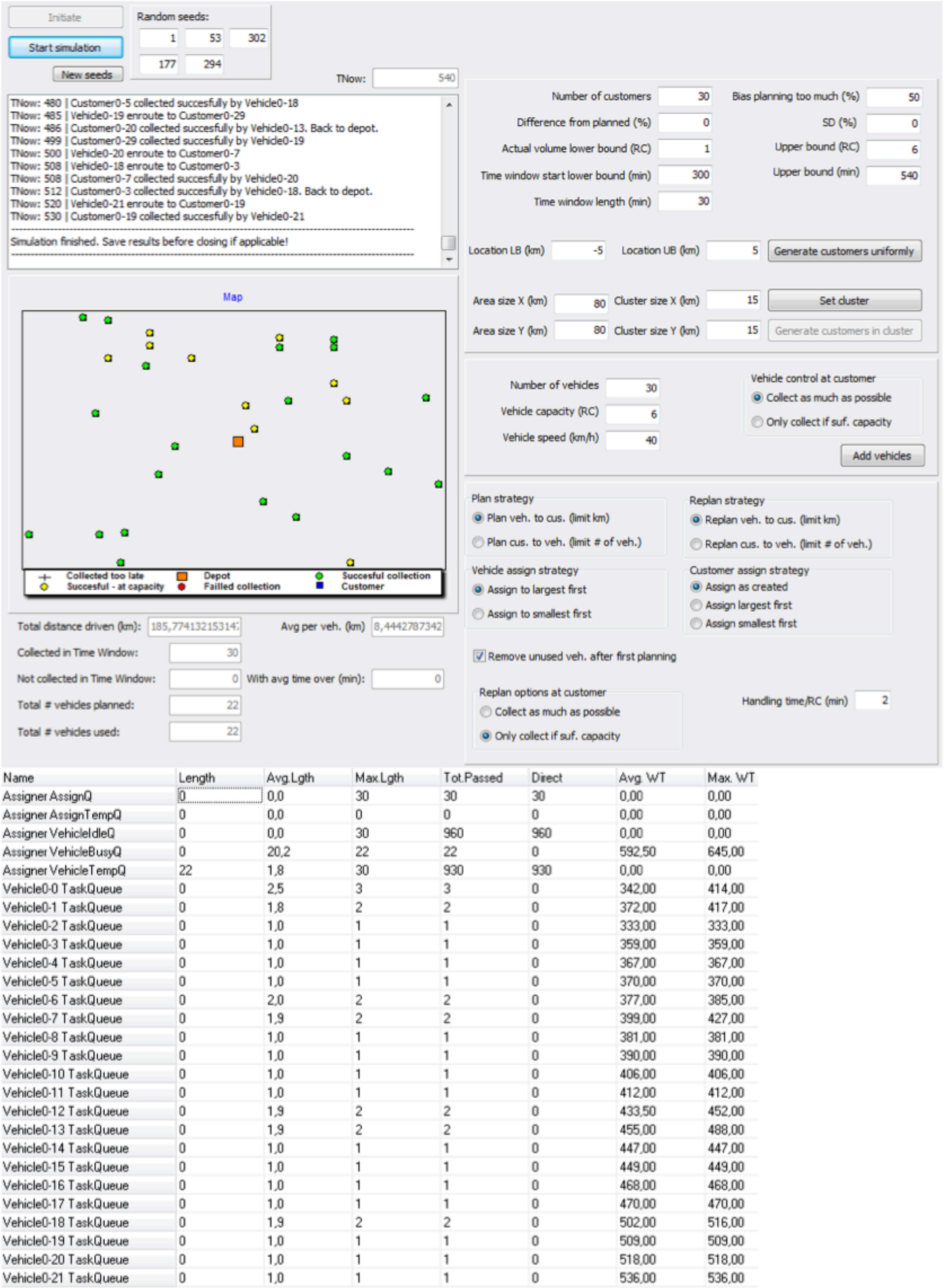
Replan options at customer
○ Collect as much as possible
● Only collect if suf. capacity

Handling time/RC (min) 2

Figure V.9 (2) – Verification results capacity

V.iii Tomas balance check

Finally, the features of Tomas are used to check that for a sample of 30 customers with known volumes, all customers will pass one and only one vehicle task queue, and that all customers will only pass the assign queue once as well. Doing so confirms that the sum over the number of elements that passed the task queue for each vehicle results in the number of customers generated, further verifying the model. The results are shown in Figure V.10.



Random seeds: 1 53 302 177 294

TNow: 540

```
TNow: 480 | Customer0-5 collected succesfully by Vehicle0-18
TNow: 485 | Vehicle0-19 enroute to Customer0-29
TNow: 486 | Customer0-20 collected succesfully by Vehicle0-13. Back to depot.
TNow: 499 | Customer0-29 collected succesfully by Vehicle0-19
TNow: 500 | Vehicle0-20 enroute to Customer0-7
TNow: 508 | Vehicle0-18 enroute to Customer0-3
TNow: 508 | Customer0-7 collected succesfully by Vehicle0-20
TNow: 512 | Customer0-3 collected succesfully by Vehicle0-18. Back to depot.
TNow: 520 | Vehicle0-21 enroute to Customer0-19
TNow: 530 | Customer0-19 collected succesfully by Vehicle0-21
--------------------------------------------------------------------------------
Simulation finished. Save results before closing if applicable!
--------------------------------------------------------------------------------
```

Number of customers: 30
Bias planning too much (%): 50
Difference from planned (%): 0
SD (%): 0
Actual volume lower bound (RC): 1
Upper bound (RC): 6
Time window start lower bound (min): 300
Upper bound (min): 540
Time window length (min): 30
Location LB (km): -5
Location UB (km): 5
Area size X (km): 80
Cluster size X (km): 15
Area size Y (km): 80
Cluster size Y (km): 15

Number of vehicles: 30
Vehicle capacity (RC): 6
Vehicle speed (km/h): 40

Vehicle control at customer
● Collect as much as possible
○ Only collect if suf. capacity

Plan strategy
● Plan veh. to cus. (limit km)
○ Plan cus. to veh. (limit # of veh.)

Replan strategy
● Replan veh. to cus. (limit km)
○ Replan cus. to veh. (limit # of veh.)

Vehicle assign strategy
● Assign to largest first
○ Assign to smallest first

Customer assign strategy
● Assign as created
○ Assign largest first
○ Assign smallest first

☑ Remove unused veh. after first planning

Replan options at customer
○ Collect as much as possible
● Only collect if suf. capacity

Handling time/RC (min): 2

Total distance driven (km): 185,77413215314
Avg per veh. (km): 8,4442787342
Collected in Time Window: 30
Not collected in Time Window: 0
With avg time over (min): 0
Total # vehicles planned: 22
Total # vehicles used: 22

Name	Length	Avg.Lgth	Max.Lgth	Tot.Passed	Direct	Avg. WT	Max. WT
Assigner AssignQ	0	0,0	30	30	30	0,00	0,00
Assigner AssignTempQ	0	0,0	0	0	0	0,00	0,00
Assigner VehicleIdleQ	0	0,0	30	960	960	0,00	0,00
Assigner VehicleBusyQ	0	20,2	22	22	0	592,50	645,00
Assigner VehicleTempQ	22	1,8	30	930	930	0,00	0,00
Vehicle0-0 TaskQueue	0	2,5	3	3	0	342,00	414,00
Vehicle0-1 TaskQueue	0	1,8	2	2	0	372,00	417,00
Vehicle0-2 TaskQueue	0	1,0	1	1	0	333,00	333,00
Vehicle0-3 TaskQueue	0	1,0	1	1	0	359,00	359,00
Vehicle0-4 TaskQueue	0	1,0	1	1	0	367,00	367,00
Vehicle0-5 TaskQueue	0	1,0	1	1	0	370,00	370,00
Vehicle0-6 TaskQueue	0	2,0	2	2	0	377,00	385,00
Vehicle0-7 TaskQueue	0	1,9	2	2	0	399,00	427,00
Vehicle0-8 TaskQueue	0	1,0	1	1	0	381,00	381,00
Vehicle0-9 TaskQueue	0	1,0	1	1	0	390,00	390,00
Vehicle0-10 TaskQueue	0	1,0	1	1	0	406,00	406,00
Vehicle0-11 TaskQueue	0	1,0	1	1	0	412,00	412,00
Vehicle0-12 TaskQueue	0	1,9	2	2	0	433,50	452,00
Vehicle0-13 TaskQueue	0	1,9	2	2	0	455,00	488,00
Vehicle0-14 TaskQueue	0	1,0	1	1	0	447,00	447,00
Vehicle0-15 TaskQueue	0	1,0	1	1	0	449,00	449,00
Vehicle0-16 TaskQueue	0	1,0	1	1	0	468,00	468,00
Vehicle0-17 TaskQueue	0	1,0	1	1	0	470,00	470,00
Vehicle0-18 TaskQueue	0	1,9	2	2	0	502,00	516,00
Vehicle0-19 TaskQueue	0	1,0	1	1	0	509,00	509,00
Vehicle0-20 TaskQueue	0	1,0	1	1	0	518,00	518,00
Vehicle0-21 TaskQueue	0	1,0	1	1	0	536,00	536,00

Figure V.10

VI Full simulation experiment results

This appendix shows the full simulation results. All results are the average over running the simulation for two weeks of collections (or 10 workdays) for the three different areas as described in the main report.

VI.i Combining the mail and parcel division

Area 1

Total nr of KM driven	6583,93312	5658,90375	-14%
Pick-ups in window	1003,3	994,1	-1%
Pick-ups not in window	5,7	14,9	161%
(excluding mail boxes)	4,8	8	67%
Vehicles planned	110,4	94,2	-15%
Vehicles used	106,5	83,4	-22%
Average time exceeding time window	9,39134153	9,41029533	0%
Max time exceeding time window	15,6909992	21,8889656	40%

Area 2

Total nr of KM driven	7575,19841	6274,85206	-17%
Pick-ups in window	996,8	992	0%
Pick-ups not in window	12,2	17	39%
(excluding mail boxes)	6,7	8,8	31%
Vehicles planned	105,7	91,7	-13%
Vehicles used	102,6	83,8	-18%
Average time exceeding time window	11,1093949	11,691334	5%
Max time exceeding time window	20,2795623	27,8582068	37%

Area 3

Total nr of KM driven	7675,96664	6560,3373	-15%
Pick-ups in window	999,6	994,6	-1%
Pick-ups not in window	9,4	14,4	53%
(excluding mail boxes)	8,2	7,1	-13%
Vehicles planned	107,2	98,3	-8%
Vehicles used	104,3	88,8	-15%
Average time exceeding time window	10,7560775	10,4721397	-3%
Max time exceeding time window	19,9982235	24,8188384	24%

VI.ii Accuracy following prediction model

Area 1	**Base**	**Pred. 1**		**Pred 2**	
Total nr of KM driven	5658,90375	5548,4843	*-2%*	6080,05352	*7%*
Pick-ups in window	994,1	987,2	*-1%*	995,9	*0%*
Pick-ups not in window	14,9	21,8	*46%*	13,1	*-12%*
(excluding mail boxes)	8	16,6	*108%*	7,8	*-3%*
Vehicles planned	94,2	83,1	*-12%*	96,3	*2%*
Vehicles used	83,4	79,3	*-5%*	92,1	*10%*
Average time exceeding time window	9,41029533	10,675532	*13%*	6,87425073	*-27%*
Max time exceeding time window	21,8889656	26,3673088	*20%*	14,3876695	*-34%*
Area 2					
Total nr of KM driven	6274,85206	6541,76943	*4%*	6873,73718	*10%*
Pick-ups in window	992	984,6	*-1%*	994,7	*0%*
Pick-ups not in window	17	24,4	*44%*	14,3	*-16%*
(excluding mail boxes)	8,8	15,2	*73%*	6,3	*-28%*
Vehicles planned	91,7	86,5	*-6%*	93	*1%*
Vehicles used	83,8	83,3	*-1%*	89,8	*7%*
Average time exceeding time window	11,691334	12,69883	*9%*	9,95252945	*-15%*
Max time exceeding time window	27,8582068	27,0477503	*-3%*	19,9286187	*-28%*
Area 3					
Total nr of KM driven	6560,3373	6558,92251	*0%*	7074,38238	*8%*
Pick-ups in window	994,6	984,5	*-1%*	1006,5	*1%*
Pick-ups not in window	14,4	24,5	*70%*	2,5	*-83%*
(excluding mail boxes)	7,1	15,6	*120%*	2	*-72%*
Vehicles planned	98,3	88,2	*-10%*	94,2	*-4%*
Vehicles used	88,8	85,6	*-4%*	93,1	*5%*
Average time exceeding time window	10,4721397	11,9888413	*14%*	2,90184681	*-72%*
Max time exceeding time window	24,8188384	27,2443733	*10%*	5,32483965	*-79%*

VI.iii Keeping back-up vehicles

(Norm accuracy)

Area 1	**No backup**	**Backup**	
Total nr of KM driven	5658,90375	5482,26037	*-3%*
Pick-ups in window	994,1	992,5	*0%*
Pick-ups not in window	14,9	16,5	*11%*
(excluding mail boxes)	8	10,8	*35%*
Vehicles planned	94,2	137	*45%*
Vehicles used	83,4	83,1	*0%*
Average time exceeding time window	9,41029533	9,12793932	*-3%*
Max time exceeding time window	21,8889656	24,2817363	*11%*
Area 2			
Total nr of KM driven	6274,85206	6348,89175	*1%*
Pick-ups in window	992	991,3	*0%*
Pick-ups not in window	17	17,7	*4%*
(excluding mail boxes)	8,8	7,6	*-14%*
Vehicles planned	91,7	120,7	*32%*
Vehicles used	83,8	85,1	*2%*
Average time exceeding time window	11,691334	10,7260975	*-8%*
Max time exceeding time window	27,8582068	20,8830699	*-25%*
Area 3			
Total nr of KM driven	6560,3373	6363,95482	*-3%*
Pick-ups in window	994,6	988	*-1%*
Pick-ups not in window	14,4	21	*46%*
(excluding mail boxes)	7,1	14,7	*107%*
Vehicles planned	98,3	126,6	*29%*
Vehicles used	88,8	86,6	*-2%*
Average time exceeding time window	10,4721397	11,3569684	*8%*
Max time exceeding time window	24,8188384	24,1783794	*-3%*

(High accuracy)

	No backup	**Backup**	
Total nr of KM driven	5548,4843	5580,13129	*1%*
Pick-ups in window	987,2	987,2	*0%*
Pick-ups not in window	21,8	21,8	*0%*
(excluding mail boxes)	16,6	13,8	*-17%*
Vehicles planned	83,1	112,6	*35%*
Vehicles used	79,3	81,1	*2%*
Average time exceeding time window	10,675532	10,0199899	*-6%*
Max time exceeding time window	26,3673088	25,6881098	*-3%*
Total nr of KM driven	6541,76943	6623,20358	*1%*
Pick-ups in window	984,6	988,2	*0%*
Pick-ups not in window	24,4	20,8	*-15%*
(excluding mail boxes)	15,2	14	*-8%*
Vehicles planned	86,5	121,3	*40%*
Vehicles used	83,3	85,5	*3%*
Average time exceeding time window	12,69883	11,6718732	*-8%*
Max time exceeding time window	27,0477503	27,4372699	*1%*
Total nr of KM driven	6558,92251	6454,08669	*-2%*
Pick-ups in window	984,5	987,5	*0%*
Pick-ups not in window	24,5	21,5	*-12%*
(excluding mail boxes)	15,6	14,5	*-7%*
Vehicles planned	88,2	106,9	*21%*
Vehicles used	85,6	83,6	*-2%*
Average time exceeding time window	11,9888413	13,0101644	*9%*
Max time exceeding time window	27,2443733	27,5157559	*1%*

VI.iv Additional vehicle (15 RC capacity)

(Norm accuracy)

Total nr of KM driven	5658,90375	5697,19381	*1%*
Pick-ups in window	994,1	992,5	*0%*
Pick-ups not in window	14,9	16,5	*11%*
(excluding mail boxes)	8	10,9	*36%*
Vehicles planned	94,2	98,6	*5%*
Vehicles used	83,4	88,1	*6%*
Average time exceeding time window	9,41029533	9,10275716	*-3%*
Max time exceeding time window	21,8889656	20,4835353	*-6%*
Total nr of KM driven	6274,85206	6494,52862	*4%*
Pick-ups in window	992	988	*0%*
Pick-ups not in window	17	21	*24%*
(excluding mail boxes)	8,8	11,3	*28%*
Vehicles planned	91,7	97,9	*7%*
Vehicles used	83,8	86,5	*3%*
Average time exceeding time window	11,691334	10,7077499	*-8%*
Max time exceeding time window	27,8582068	26,3876006	*-5%*
Total nr of KM driven	6560,3373	6690,72535	*2%*
Pick-ups in window	994,6	997,7	*0%*
Pick-ups not in window	14,4	11,3	*-22%*
(excluding mail boxes)	7,1	7,8	*10%*
Vehicles planned	98,3	99,6	*1%*
Vehicles used	88,8	89,3	*1%*
Average time exceeding time window	10,4721397	10,3159913	*-1%*
Max time exceeding time window	24,8188384	23,0904148	*-7%*

(High accuracy)

Total nr of KM driven	5548,4843	5657,65638	*2%*
Pick-ups in window	987,2	986,2	*0%*
Pick-ups not in window	21,8	22,8	*5%*
(excluding mail boxes)	16,6	16,9	*2%*
Vehicles planned	83,1	86,2	*4%*
Vehicles used	79,3	83	*5%*
Average time exceeding time window	10,675532	9,48390532	*-11%*
Max time exceeding time window	26,3673088	25,4198096	*-4%*
Total nr of KM driven	6541,76943	6642,52778	*2%*
Pick-ups in window	984,6	989,8	*1%*
Pick-ups not in window	24,4	19,2	*-21%*
(excluding mail boxes)	15,2	14,3	*-6%*
Vehicles planned	86,5	88,5	*2%*
Vehicles used	83,3	85,6	*3%*
Average time exceeding time window	12,69883	12,2793396	*-3%*
Max time exceeding time window	27,0477503	26,7060896	*-1%*
Total nr of KM driven	6558,92251	6713,26995	*2%*
Pick-ups in window	984,5	992,6	*1%*
Pick-ups not in window	24,5	16,4	*-33%*
(excluding mail boxes)	15,6	11,5	*-26%*
Vehicles planned	88,2	90,2	*2%*
Vehicles used	85,6	87,4	*2%*
Average time exceeding time window	11,9888413	10,5321445	*-12%*
Max time exceeding time window	27,2443733	24,776217	*-9%*

VI.v Additional vehicle (3 RC capacity)

(Norm accuracy)			
Total nr of KM driven	5658,90375	5734,54241	*1%*
Pick-ups in window	994,1	996,7	*0%*
Pick-ups not in window	14,9	12,3	*-17%*
(excluding mail boxes)	8	8,9	*11%*
Vehicles planned	94,2	117,3	*25%*
Vehicles used	83,4	95,9	*15%*
Average time exceeding time window	9,41029533	9,39147302	*0%*
Max time exceeding time window	21,8889656	21,4214672	*-2%*
Total nr of KM driven	6274,85206	6695,34256	*7%*
Pick-ups in window	992	991,7	*0%*
Pick-ups not in window	17	17,3	*2%*
(excluding mail boxes)	8,8	9,7	*10%*
Vehicles planned	91,7	116,4	*27%*
Vehicles used	83,8	95,8	*14%*
Average time exceeding time window	11,691334	10,0514464	*-14%*
Max time exceeding time window	27,8582068	22,340674	*-20%*
Total nr of KM driven	6560,3373	6827,78188	*4%*
Pick-ups in window	994,6	992	*0%*
Pick-ups not in window	14,4	17	*18%*
(excluding mail boxes)	7,1	11	*55%*
Vehicles planned	98,3	116,1	*18%*
Vehicles used	88,8	99,9	*13%*
Average time exceeding time window	10,4721397	11,7352273	*12%*
Max time exceeding time window	24,8188384	26,5774777	*7%*

(High accuracy)			
Total nr of KM driven	5548,4843	6212,04682	*12%*
Pick-ups in window	987,2	997,4	*1%*
Pick-ups not in window	21,8	11,6	*-47%*
(excluding mail boxes)	16,6	8,9	*-46%*
Vehicles planned	83,1	108,3	*30%*
Vehicles used	79,3	104,7	*32%*
Average time exceeding time window	10,675532	11,7430929	*10%*
Max time exceeding time window	26,3673088	23,3696883	*-11%*
Total nr of KM driven	6541,76943	7502,43088	*15%*
Pick-ups in window	984,6	989,4	*0%*
Pick-ups not in window	24,4	19,6	*-20%*
(excluding mail boxes)	15,2	16,4	*8%*
Vehicles planned	86,5	113,2	*31%*
Vehicles used	83,3	108,6	*30%*
Average time exceeding time window	12,69883	13,8906895	*9%*
Max time exceeding time window	27,0477503	27,2450555	*1%*
Total nr of KM driven	6558,92251	7820,10833	*19%*
Pick-ups in window	984,5	992,8	*1%*
Pick-ups not in window	24,5	16,2	*-34%*
(excluding mail boxes)	15,6	14,4	*-8%*
Vehicles planned	88,2	118,8	*35%*
Vehicles used	85,6	114,1	*33%*
Average time exceeding time window	11,9888413	13,5721869	*13%*
Max time exceeding time window	27,2443733	26,5606719	*-3%*