Bachelor Thesis

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Customer preferred time window scheduling

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HOEKSTRA

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Management summary

Hoekstra Sneek is a transport company specialized in transport of divergent goods. They transport these goods for and from small and medium enterprise (SME) to customers in the Netherlands, Flanders and western Germany. The company has a transport fleet of more than 60 vehicles of various types to fulfil customer demand.

The customers that Hoekstra currently visits, are informed by an e-mail the day before delivery with a time window of 2 hours in which their order is scheduled. On the delivery day, a text message is send to customer when the delivery is 30 minutes away. Hoekstra perceives that this service could be improved anymore for some of their customers and therefore wants to investigate the possibility for customers to choose their own preferred time window for delivery.

To investigate the possibilities for customer chosen time windows, a model of the old situation and the new situation has to be created and compared. This research uses an adaptation of the VRP solver developed by Erdoğan (2017). This solver is able to model multiple routing problems, including an VRP with time windows for the desired situation at Hoekstra. The old situation is a theoretical adaptation of the current situation, while in the new situation some customers get to choose a specific time window. The input of the model is based upon historical transport and customer data provided by Hoekstra.

With these models, multiple experiments are run to find which factors limit in which degree the possibility of successful implement customer chosen time windows. The experiments cover the geographical region in which customers can choose time windows; the width of the time windows customers can choose and the number of customers that can choose a time window. Afterwards, combinational analysis of all experiments to compare the results between cases fairly. Therefore, a benefits formula is created that generates additional profit when customer time windows are applied.

From the experiments can be concluded that dense regions have lower costs increase when implementing customer chosen time window. However, the experiments do not prove that distant regions are performing worse with customer chosen time windows. The time window size shows an exponential relation with increase in costs when the width of the time windows decreases. The number of chosen time windows shows a linear relation with costs increase as the number of chosen time windows increases. The combinational analysis showed that small time windows are sensitive to large costs increase when the number of chosen time window is too high. Computational results show that schedules with less or severe restrictions are solved more easily. Validation with the company has confirmed that driving time limits are not violated when driving possible pick up routes and that when small time windows generated more revenue than the two-hour time window is most beneficial.

The general conclusion of this research is that customer-preferred time window scheduling is possible. However, it cannot be done without an increase in costs and therefore additional revenue has to generated. It is recommended to start implementation on a small scale. A small-time window of 1 hour is not recommended due to higher cost increase when demand for chosen time windows becomes unmanageable.

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1 Introduction

This chapter introduces Hoekstra Sneek and describes how the research will be approached. Firstly, the company and their problem will be introduced. Afterwards, in Sections 1.3 to 1.5, the problem will be further investigated, and the core problem will be selected. Sections 1.6 and 1.7 will describe the research questions and how these will be solved.

1.1 Hoekstra

This research project is done for Hoekstra. Hoekstra is a transport company located in the north of the Netherlands, Sneek. They have a transport fleet of approximately 60 trucks of various sizes. Besides the 100 drivers they employ, there are also have personnel in warehousing and in the office. Hoekstra provides multiple services for their customers, which are mainly small and medium sized enterprises (SMEs). Their services cover the whole of the Netherlands, Flanders and western Germany. They transport deliveries for these companies are too small or do not have the experience to do their own transport to their customers, mainly individuals. Therefore, they hire a transport company to do their deliveries. Examples of the services they provide are transport for transmigrate for companies as well as individuals and storage/warehousing. However, their main occupation is delivery of goods.

Hoekstra is specialized in the delivery of vulnerable and divergent goods. Examples of those goods are fireplaces, garden furniture and glass sheets. The complexity and size of the goods causes that the fleet consist of large vehicles. Delivery of these goods requires a more specialised service-based method. The mentioned goods are not easily placed in a truck for delivery. Therefore, Hoekstra must dedicate time to schedule which goods they place in a truck and how they route their trucks. Together with the multiple services they provide, it makes Hoekstra's business model a service-based model, rather than a volume-based model. Therefore, the service they provide to the customer is valuable.

The customers Hoekstra serves differs per service type. They distinguish between the two types, which is important for the understanding of further content. The first type of customers (shippers) are SMEs. These companies produce goods to be delivered to the second type of customers. In this paper when referring to a SME, a customer of Hoekstra is intended; otherwise, it will be stated explicitly. SMEs are for example the customers who store the goods at Hoekstra. The other type of customers are the customers of the SMEs, the individuals (receivers). These customers order products at an SME. This order will be submitted to Hoekstra by an SME and as soon as possible shipped to this individual. In this paper, referring to this type of customer will be done with customer(s).

1.2 Problem context

Before the delivery scheduling starts, the goods have to be retrieved from the SMEs. Afterwards, they will be delivered to an individual. This is done in the following way. After a driver finishes his/her delivery route of that day, he/she contacts the scheduling department. They determine which SME has to be visited for the pickup goods of before returning to Sneek. Generally, truck is first emptied, before the pickups start. For the company this way of working makes sure that utilization remains high and to be able provide service for an acceptable price.

The scheduling services provided by the customer works as follows. An SME submits orders for deliveries for customers. Hoekstra then schedules at which date they will deliver the goods. The latest SMEs can submit orders is 18:00 for a delivery for tomorrow. At 18:00 the scheduling personnel starts scheduling. This process finishes around 22:00 and afterwards, the customers (receivers) are notified about the expected time of delivery in a time window of two hours (e.g. 10:30-12:30). At the day of delivery, an extra service is provided. Customers will get a text message 30 minutes before the expected arrival time with the information that the driver is 30 minutes away.

This procedure lacks a way for the customers to determine when they are served. For Hoekstra this is a reason to investigate the possibilities to implement a system where customers can choose a time window in which the goods will be delivered. One of the companies who has implemented such a system is Coolblue. Customers (receivers) from Hoekstra often compare their delivery with a shipper as Coolblue. Coolblue states about chosen time windows on their website: "For big products like fridges, televisions you can choose your own time window of 4 hours" (Coolblue, 2020). The question remains if this will increase the service satisfaction perceived by customers. The Dutch consumer association states they are the best performing web shop in the category electronics. According to Meijer (2019), Coolblue achieves this with the highest score on promised delivery time (97%) and the highest score on delivery (96%). These scores show not directly that time windows are increasing the satisfaction of customers for delivery. Nevertheless, for the Hoekstra this increases their interest in the possibilities of customer chosen time windows in their schedules to increase their service.

1.3 Action problem

The management of Hoekstra stated that they signalled that customers perceive the delivery service not optimal. According to the management, the cause is that customers cannot decide their delivery window. This can be seen as customers are dissatisfied, by the fact that choosing a time window is not a possibility. Therefore, the action problem is that customers are dissatisfied about the current assigned time windows. Hoekstra sets the norm that customers can decide their time window for their delivery. The current reality is however that this is not possible at Hoekstra.

1.4 Problem cluster

The company hinted that implementation of customer chosen time windows is the solution to the action problem. However, this could be not the most beneficial way to solve this problem. Therefore, looking at the bigger picture of scheduling services as explained in Section 1.2 is necessary. Otherwise, there is a possibility that the wrong problem will be researched. This process is done with a problem cluster (Figure 1). The search for causes starts with the action problem. Section 1.3 explains that customer dissatisfaction is action problem, which can be solved by the middle path in Figure 1. It states: "No decision possibility on delivery time". This means that customer cannot decide or influence at which time Hoekstra delivers their order. Another consequence of this problem is that customer know late when their goods will be delivered. If customers decide their delivery time themselves, it will be directly announced when the delivery will happen.

The first problem of the left branch states: "Expected delivery indication", which is about the fact that customers currently receive a time indication window of two hours. The reason for this size is that transport delivery has some uncertainties in determining the arrival time. This is due to possible traffic jams, but also can be caused by delays at previous stops of the truck.

The right branch is about the announcement of the delivery time to the customer. Hoekstra informs customers around 22:00 about when they will visit the next day. Announcing the time window this late causes that customers cannot reschedule appointments easily anymore for the delivery day. The late scheduling from the scheduling department between 18:00 and 22:00 causes this. It takes about 4 hours because most of the scheduling is done manually because of the nature of transport. The last causal relation in the right branch is between the schedule development and the order submitting. Because orders can be submitted until 18:00, scheduling cannot start until all orders are known. That means that late SME order submitting is a possible core problem.

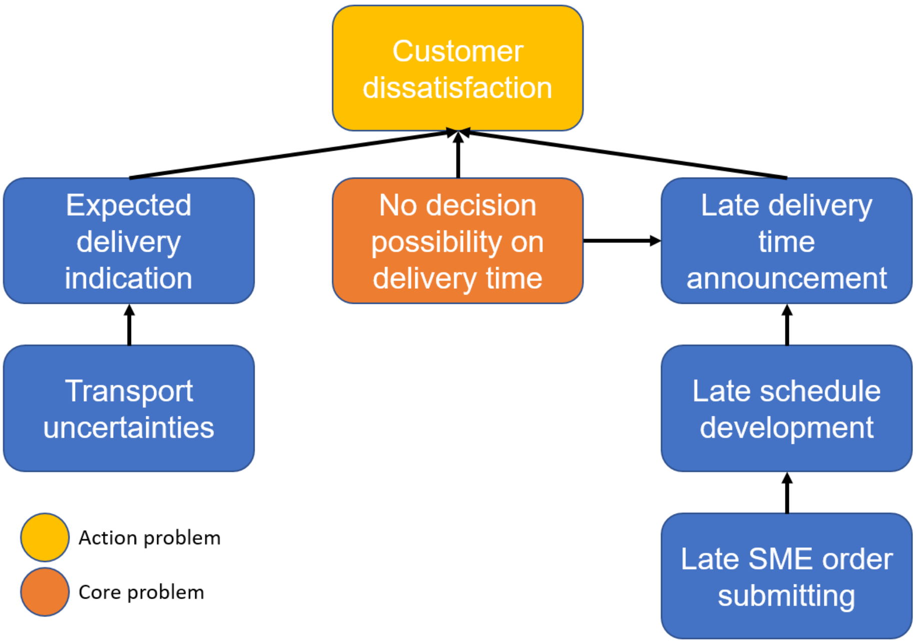

Figure 1: Problem cluster of Hoekstra's problem on customer dissatisfaction

1.5 Core problem

From the three problems mentioned as possible core problems, only viable problems can be solved in research. That problem will be the core problem(s). For each of the problems arguments will be presented whether or not this is a viable problem to solve.

The first one is the transport uncertainties. It will not be a good core problem since it is not influenceable and those cannot be taken away. Real time traffic information is for example already used and possible delays when delivering at earlier stops is not solvable or will not result in much gain in customer satisfaction.

Another possible problem is, "Late SME order submitting". The late order submitting is one of the ways to create service for the SMEs. They want to submit order as late as possible because then they can process all orders of that day at ones. The company turned down the possible solution of splitting submitting deadlines because of the labour-intensive scheduling process and the decrease in efficiency in the routing.

Then, the only solution of this problem is to expedite the submitting deadline. Changing may increase customers' satisfaction since customers who submit before the deadline will know their delivery time earlier. However, customers who order after the new deadline but before 18:00 will now receive their package a day later. Those customers will be even more dissatisfied. Therefore, when solving this problem, it will be difficult to increase overall customers' satisfaction. This problem is therefore not suitable as a core problem.

The last possible core problem is the fact that customers cannot decide their delivery time. This problem affects directly customer dissatisfaction and gives customers directly the announcement about their delivery time, which increase customer satisfaction as well (when all chosen time windows are honoured). It solves the action problem in two ways and will therefore have a great impact on the satisfaction. It is also suitable as core problem because it is solvable with the implementation of chosen time windows for customers. In the next chapters will be more elaborated upon the proposed solution of time windows.

1.6 Research question

This section will elaborate on the problem-solving approach for this project. For a large project the division is smaller tasks is important, but firstly the main research question will be discussed.

1.6.1 Main research question

The main research question has to tackle the main problem of the lack of influence perceived by customer on their delivery time.

The possible implementation of customer chosen time windows does not only have positive effects. Implementing these time windows restricts the scheduling department in determining the most efficient routes. The less efficient routes will increase the costs of transport. The extra service (for customers) of self-chosen time windows can be offered as an extra paid service at SMEs to customers. This means that a trade-off has to been made. This trade-off has to be visible in the main research question.

The main research question will be**: "How can Hoekstra implement customer preferred time window scheduling without decreasing profitability?**" In this question, the trade-off between profitability and the customer preferred time windows (service) is stated. The variable profitability cannot be directly modelled in a Vehicle Routing Problem with Time Windows (VRPTW). However, an increase in costs of chosen time windows can be compensated when charging the customers for this service.

1.6.2 Sub research questions

The main research question is a broad question to answer directly. Therefore, multiple sub research questions are created in order to cover all aspects needed to find a well-founded solution for the core problem.

How is the current situation at Hoekstra?

To give a well-thought advice, the current situation has to be taken into account. The suggested change should contribute to the company and not counteract other work within the company. An example is the scheduling method used for the route of one vehicle. According to the planning department, routes are created based upon pre-determined customers (Section 2.1.4). A change in this procedure needs to be well-explained and cannot be explained by the fact that it has not been researched. To determine the possibilities in changing the scheduling method an interview with the management is necessary. Not only for determining the scheduling method preferred, but also to determine key performance indicators (KPI) and constraints.

The KPIs determine if a schedule can be considered good or bad. When changing the schedules, the values of KPIs changes. If one of these indicators decreases too much, a schedule may be considered bad. The values when a solution is rejected for each KPI and the KPIs itself have to be discussed or maybe determined in this interview. If Hoekstra states that, a variable may not exceed a certain value it becomes a constraint. These constraints have to be satisfied; otherwise, the proposed schedule is invalid. All the constraints have to be determined with interview(s). An example question for this interview about a KPI and/or constraint is, "Is capacity utilization a KPI and is there a maximum allow decrease in utilization?" This interview will be analysed, and the results will be taken into account in the design of the models and the experiments with the model.

What does literature state about VRPTW?

Before designing models and experimenting with variables it is useful to know what theories are available in literature. In Chapter 3, theory will be discussed about how to model time windows in a VRP. One decision to make is whether hard or soft time windows will be used. Studies of other researchers may help to determine which option is more suitable for Hoekstra. The literature is also useful for other reasons. For example, the researchers have already made objective functions and constraints in order to find solutions to the routing problem. These objective functions and constraints may not be directly suited for the situation at Hoekstra, but they provide information on what and how to formulate these. The goal of this question is to gain insights in what already in literature has be done on this topic in order to develop models easier and to prevent reinventing the wheel.

How does a model with time windows of Hoekstra look like?

In this sub-research question, the findings of sub-research questions 1 and 2 come together. The information about the current situations is combined with the theory in order to design a model. The design of the model has to fulfil the requirements of theory and has to be adapted to the situation as it is currently at Hoekstra. Besides the model of the current situation, a similar model about the desired situation with customer chosen time windows has to be created. The model about the desired situation will use the chosen perspectives explained in Section 3.1.4 and 3.2.5. This perspective has to be combined with information provided in the interview in order to determine for example on how penalties will be calculated when services is performed outside the time window.

Which experiments will be performed?

When the model design is finished, experiments have to be determined and performed before being able to make conclusions. Those experiments will always cover changes in the desired situation and will always be compared with the current situation. An example experiment could be to compare 4-hour customer chosen time windows with a 2-hour time window. These are done in the desired situation model. The results are presented in comparison with the current situation. For example, 2-hour customer chosen time window decrease utilization with 4% while 4-hour windows decrease utilization only with 1%.

Another experiment, which will be conducted about regions. The company expected that implementing customer chosen time windows is only profitable in customer dense regions, like the city of Amsterdam. An investigation about the influence of customer density on the KPIs is necessary to confirm the companies' hypothesis.

Which insights and recommendations can be given to Hoekstra?

The last question to answer for completely answering the main research question is about the results of the experiments. What information can be retrieved from the performed experiments in the previous sub question? A possible insight can be that regions with on average 15 deliveries per day can have customer chosen time window of 2 hours, but with time windows of 3 hours, there is no lower bound on customer density in a region. These insights and recommendations will be explained as the answer to this research question. With that information, the main research question can be answered.

1.7 Deliverables

The deliverables will be based upon the (sub) research questions. Each question will have an answer of a certain type. Therefore, for each question a different deliverable will be the output. These deliverables can be found in Table 1.

Table 1: Research Questions with deliverable and explanation

Question	Deliverable	Explanation
How can Hoekstra implement customer preferred time window scheduling without decreasing profitability?	Report	This report is a bundle of the outputs from the different sub questions together with the standard addition is a research report (e.g., management summary etc.)
How is the current situation at Hoekstra?	Analysis	This analysis will consist out of the elaboration upon the method currently used at Hoekstra
What does literature state about VRPTW?	Systematic literature review	This research question will be answered with a literature review. This is partly done but still has to be done for solving heuristics.
Which VRPTW solution approach will be used?	Model design	For this question, the model will be made with corresponding variables, assumption, restrictions.
Which experiments will be performed?	Experiment design description + results	In this deliverable, the test for the model will be explained and the output will be shown.
Which insights and recommendations can be given to Hoekstra?	Qualitative analysis of results	The last sub-question will generate conclusion from the results, those will be qualitative interpreted, and textual explained.

1.8 Summary

In this chapter, the company is introduced, and the core problem is found. The fact that customer cannot choose their own time window is the core problem. Therefore, the following main research question has determined: “How can Hoekstra implement customer preferred time window scheduling without decreasing profitability?” To solve this question a model will be created which will perform several experiments before giving recommendation for the company in the end.

2 Current situation

This chapter covers the current situation at Hoekstra, answering the similar formulated research question. Section 2.1 will cover several aspects of the current vehicle routing. Section 2.2 will elaborated upon the performance. Sections 2.3-2.5 all discuss different aspects of the current situation and its consequences for the model in Chapter 4.

2.1 Current vehicle routing

This section will discuss the current vehicle routing at Hoekstra. The first section covers the characteristics of the routes and location at Hoekstra. Secondly, the vehicles types and the products the transport will be discussed. The third section discusses the orders and the customer types at Hoekstra. Afterwards, the software tool will be discussed which is currently used for scheduling. Lastly, the reliability of delivering is discussed.

2.1.1 Location and routes

Hoekstra is located in the north of the Netherlands (see Figure 2). The family company Hoekstra is already for 100 years located in this part of the province. This remote location within the Netherlands has many implication in their routes. The first implication is that a vast majority of the customers is located in another region than the neighbourhood of Sneek (Figure 3). Figure 3 shows that most of the customer density is located in the Randstad. This results in that for most destinations, the distance to the depot (Sneek) is larger than to other customers. Therefore, Hoekstra currently clusters their deliveries as much as possible.

Figure 2: Location of Hoekstra Sneek (Depot)

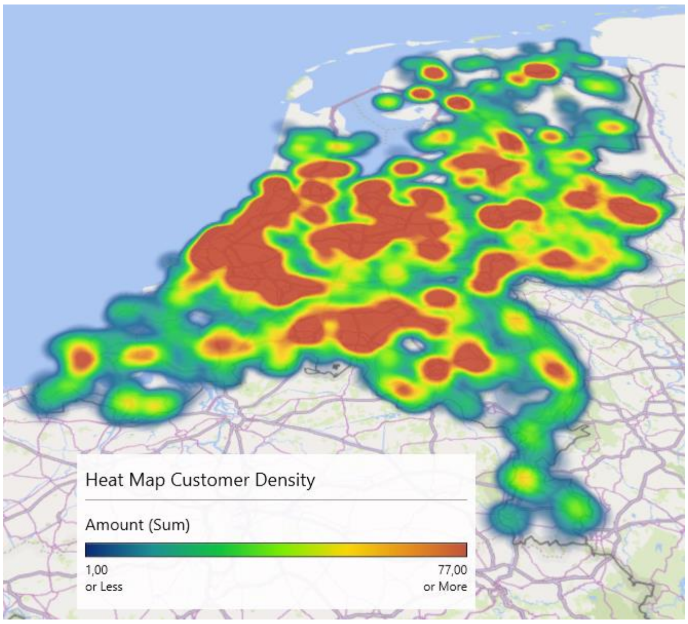

Figure 3: Heat map of Hoekstra's customers

These clusters are within the company referred to as cities. However, these cluster differ per day. An example would be the cluster Amsterdam. On one day the centre of the cluster could be Zaandam, but then there will be still referred to as the cluster Amsterdam. In the company data the cluster can be reviewed by their postal code. The most appropriate method therefore is to use the first two digits of the zip code (e.g. **10**11 AB or **54**67 JX). These clusters are dynamic per day and per vehicle and therefore it is hard to determine a cluster which represents the average cluster in a region on a certain day. Therefore, the number of unloading actions within the region should be as high as possible. This number as percentage of the total unloading action of the vehicles which have driven in this region is an indicator of the accuracy to call this a cluster. In Appendix A the calculation of this value will be further explained as well as other information about these regions.

2.1.2 Vehicles and products

Another important factor in the deliveries Hoekstra performs are the vehicles (and their capacity) and the products the transport. In Section 1.1 is already stated that the company transports many different goods and those goods require well thought through scheduling. At Hoekstra they have many different truck types in their fleet. Table 2 represents the truck time and the activities they perform at the company and their capacity.

Table 2: Different vehicle types with their capacity and their main activities

Vehicle Type	**Activity**	**Capacity (relative)**
Box truck	Pickup and delivery of (vulnerable) goods	Middle
Trailer truck	Pickup and delivery of (vulnerable) goods	Large
Vans (multiple sizes)	Transmigration and movement of individuals, or unplanned pickups/deliveries	Small

Each of the vehicle types has a different role within Hoekstra's fleet and therefore their usage is also within the delivery activities is also different. The type of vehicle used for a certain route is chosen by the scheduling department, this depends on the route itself and the products shipped. The other way around also happens. The route is chosen by the trailer and the products shipped. This manual process makes that modelling Hoekstra's situation is hard and multiple assumptions have to be made, which will be discussed in Section 2.3.

2.1.3 Orders and customers

The third factor to discuss in this section are the orders and to who they are delivered. Section 1.1 explains the difference in customers and SMEs. However, there is another distinction to make between customers. The customers who can order at SMEs can be individuals or other SMEs. Individuals are the customer type which benefits from customer chosen time windows. Whether an SME receives their goods in the morning or afternoon does not matter for them since their company is open within the working hours. This distinction is essential to display the routes as accurate as possible in the models. The implementation will be discussed in Section 2.3.4.

2.1.4 Software and performance

The scheduling at Hoekstra is mainly done manually, but for a transport company in 2020 this does not mean analogue. Hoekstra uses the software of Tracc to assist in creating routes and to instruct the on-board computer of each vehicle with the route. During the day the pickup addresses are added to the on-board computer. In the scheduling process the software provide suggestion to the schedulers of the most efficient set of customers for vehicles, according to the cluster principle explained in Section 2.1.1. They evaluate the suggestions and when needed, they change the routing. The environment provided by Tracc is not suitable for numerical experiments to evaluate the implementation of customer chosen time windows. It requires much time and effort to create schedules with and without customer chosen time windows. The quality of the schedules is hardly comparable since the manual part of scheduling has a major influence and there are no resources to perform this. Therefore, a digital environment will be used to predict the impact of the implementation of customer chosen time windows.

2.1.5 Reliability and service

Before implementing customer chosen time windows, the current reliability of deliveries has to be evaluated. When implementing customer chosen time windows, the current reliability needs to be sufficient to ensure that the chosen time windows can be met. Therefore, an analysis on the deviation in expected arrival time and actual arrival time is performed. The results in Figure 4 show that almost 90% of deliveries is performed within 15 minutes of the estimated delivery time. The estimated arrival time is determined on the minute, which is more precise than necessary to schedule a delivery within a chosen time window. Unfortunately, no data is available on the success rate of delivering the goods within the assigned time window send to customer (Section 1.2). According to the data, there a no reasons to assume that Hoekstra is not capable of reliable deliver within a chosen time window.

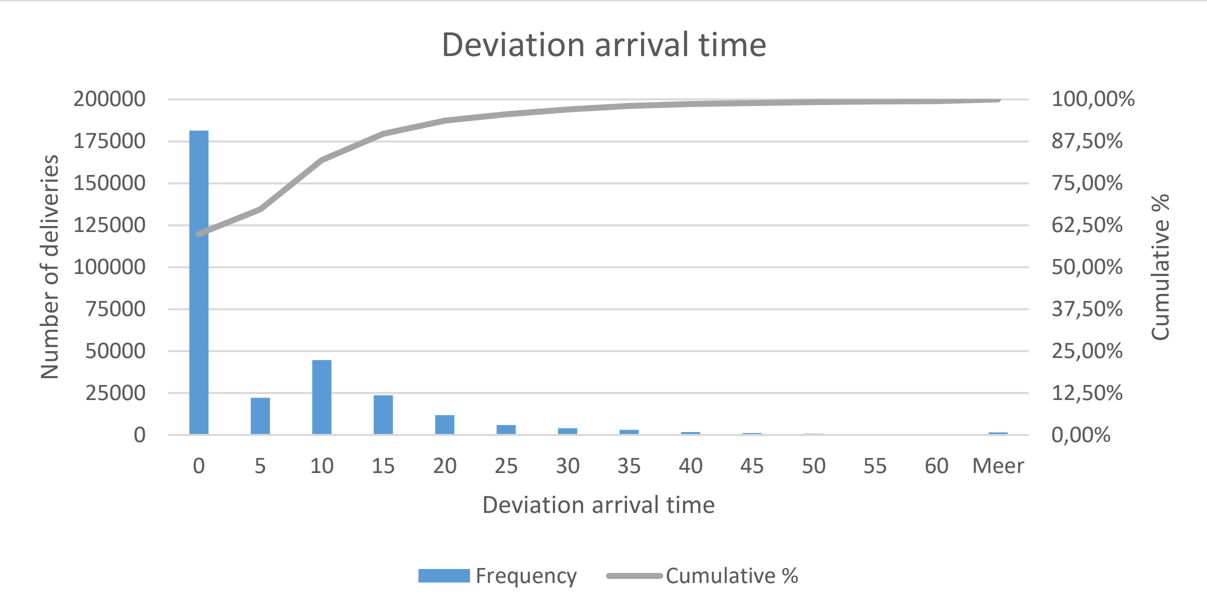

Figure 4: Deviation of the arrival time with the expected arrival time

2.2 Current schedule performance

In this section the goal is to evaluate the current performance of the schedules to be able to find a model of the current situation. However, at Hoekstra different KPIs measure the performance of the schedule at this moment. This can be explained with an example of a vehicle loaded with shower enclosures.

Each of the vehicle types at Hoekstra can carry dozens of shower enclosures since they can be placed parallel in a vehicle. If a vehicle is loaded with only shower enclosures and a route is constructed, then driver time limit will be reached within in general 30 visits, but the vehicle can fit for example hundred enclosures. The score of this route in terms of utilization is 30%, but at maximum driving time 100%. Therefore, Hoekstra does not assign a general score is not given to a schedule, because they do not find that the performance of the schedule is expressible in one parameter.

Another reason that the performance of the schedule is not measured with one parameter is the flexibility needed for the pickup route. The demand for pick up is unknown when scheduling deliveries the evening before, resulting in possible higher number of vehicles in regions than necessary for all deliveries. Consequently, the performance on the previously mentioned KPIs is lower whilst the schedule is more robust than less vehicles are used.

This flexibility scheduled by the schedulers at Hoekstra is hardly programmable in a model, causing that an automated schedule always outperforms the solution of a schedulers because less vehicles are used. This makes that the usage of a current schedule KPIs is not possible in the new model in which customers can choose their own time windows. Therefore, new KPIs have to be determined to evaluate the schedules created in another environment than used currently by Hoekstra. (Section 2.1.4)

2.3 Assumptions

In each study which involves modelling assumption on the situation have to be made. In this section the assumptions which have to do with the current situation will be discussed.

2.3.1 Cluster size

One of the assumptions is to evaluate regions instead of the whole schedule at once. The reason is that modelling a schedule with 50 trucks with 2000 addresses is computational very costly, because for a theoretical evaluation all distances between addresses have to be known (in this case almost 4 million). The current software does not evaluate all distances since it creates suggestion clusters. So therefore, regions have to be evaluated individually. A region will be determined according the postal codes in this region. Regions will not be larger than 120 customers which will reduce the number of used vehicles to a maximum of approximately 6. This will make sure that the solutions can be created in a reasonable time frame. An advantage of this approach is that regions can be compared individually with each other. This evaluation of regions was also requested by the company to evaluate whether regions influence the profitability of time windows. A major drawback is that vehicles performing deliveries in reality may also have visits outside the suggested cluster, because daily the cluster centre may be in Zaandam, but the average cluster centre is in Amsterdam. This causes that some of the edges of the cluster Zaandam are not part of the average cluster Amsterdam. Resulting in that not 100% of the deliveries within the trucks is addressed to selected region. Therefore, it is an assumption that all demand in a region (cluster) is fulfilled with vehicles only serving in this region.

2.3.2 Input data

The second assumption that has to be made is about the input data. For this research the customer data of 2019 is used. The assumption is that this data is the most accurate and representative for the current situation at Hoekstra. However, due to the corona crisis and the change in order weight of each SME, this may not be representative. Also, the length of the period can be open for discussion. A shorter period than a year can be more representative for an SME order distribution but not for the change in seasonal demand. A longer period can be more accurate in determining the number of deliveries in a region but could be contain more irrelevant orders from SMEs which are not transporting with Hoekstra anymore. This assumption leads to the following input data in Table 3. The calculations of those values are explained in Appendix B.

Table 3: Input data for modelling

Variable	**Explanation**
Average number(#) of vehicles present in the region	This number is the average number of vehicles per day which have at least one delivery in the selected region.
Average # of orders in a vehicle for this region	This number is the average amount of orders within the route which have as destination a postal code in this region.

Average # of orders in a vehicle	This is the average number of orders loaded in a vehicle which has at least one delivery in this region.

2.3.3 Vehicle and product simplification

This assumption is the simplification of the vehicles and products at Hoekstra. As explained in Section 2.1.2 Hoekstra has a wide variety of truck and trailers and even a wider product selection. Modelling this would have too many implications, since every combination of divergent goods Hoekstra delivers has a different impact on the utilization of the capacity. Another implication is that it is unknown at Hoekstra how many of each product is delivered, resulting in that the demand per product has to be assumed. Therefore, the following simplification will be made. In the models there will be only one product type which takes a fixed amount of capacity in the vehicle. There will be also one vehicle type which can therefore carry a fixed number of products. This value is stated in Section 2.5.2.

2.3.4 Customer and SME orders

The fourth assumption is about the division between customers which can choose a time window and the customer who cannot choose. It will be assumed that all customers from an SME are either individuals or other SMEs. Hoekstra stated that for most SMEs this is the case and therefore this assumption will be made.

The value is calculated as follows; each order has a debtor value which corresponds with the SME for which Hoekstra transports the product. For each SME is determined whether they transport to other SMEs (B company) or to individual customers (P company). This value differs per region and is part of the schedule values in Appendix B.

2.3.5 Customer service time

The last assumption is about the service time for each customer. The service time is the time the driver spends at the customers location to unload the goods. According to Hoekstra, this is very close to 10 minutes for each delivery. Since no data on the start of the service and the end of the service is recorded. No distribution can be derived, or more representative value can be determined. Therefore, it will be assumed that each delivery has a service time of 10 minutes.

2.4 Solution key performance indicators

This section covers all key performance indicators (KPIs) used for the model explained in Chapter 4. A KPI is a measurable value that demonstrates how effective the company performs on the specific activity, in this case scheduling the delivery route. In this section the total costs of transport and the percentage achieved time windows are discussed.

2.4.1 Total cost of transport

Section 2.2 explained that Hoekstra does not have a way to determine the performance of their schedules. Therefore, new KPIs has to be created in order to evaluate the schedule. The most logical is total costs of transport. Hoekstra calculates their costs towards customers with the cost-price-application of Transport Logistics Netherlands (TLN) (TLN Kostrpijsapplicatie, sd). The total cost of transport has two components. The first component is the costs of the driver in the vehicle. The second component is the costs of the vehicle itself. Beside the two component the calculation method also differs per vehicle type. In Section 2.1.2 and 2.3.3 is described that many vehicle types are used, but Hoekstra uses differs two types of vehicles for the cost calculation for the deliveries covered in this research, the box trucks and trailer trucks. The total cost of transport will be the weighted average of the costs according to the division of trucks, which is 32 box trucks and 30 trailer trucks.

The costs of the driver are calculated per hour. This factor includes the salary, but also other costs included in the collective labour agreement. Examples of those costs are number of holidays, but also an estimation of average number of illness days. The costs of the vehicle are expressed in the costs per kilometre. This include fuel price, depreciation and vehicle taxes. These both together make the total costs of transport at Hoekstra. However, this number cannot be used as the input of the model. Therefore, the costs will be expressed in the costs per kilometres. The value of this parameter is for box trucks €1,2509/km and for trailer trucks €1,4227/km and therefore the value that will be used in the models will be €1,3340/km. With this value per kilometre the costs of the routes in the old and new situation can be calculated and this KPI will be leading in evaluating the performance of the different experiments performed in Chapter 5.

2.4.2 Percentage achieved time windows

The second KPI is the percentage achieved time windows, which also will be a constraint (Section 2.5.5). This number is stated by the company because it shows how valid the time windows are in their strategy. If the number is for example below 70% then the reliability than it is hard to convince customers that deliveries are done within the time window. In other words, you cannot advertise with customer chosen time windows if seven out of ten customers are not served within the window. The value can be interpret as follows: The higher the percentage the more customers are served in their chosen time window. This variable is only applicable in evaluating new situations with each other since in the current situation is non-existing. The value of this KPI has a minimum which is stated in Section 2.5.5.

2.5 Problem constraints

For the solution and input of the model is also restricted by the company, among others. A list of constraints is presented in Table 4. Besides the name of the constraint the restriction value is given and the reason of restriction. Below the table, each of the constraints is discussed in more detail.

Table 4: Constraint list

Variable	**Restricted value**	**Restricted by**
Lower bound customer chosen time window	07:00	The company
Upper bound customer chosen time window	15:00	The company
Capacity/number of deliveries per truck	20	The company
Max driving time	10 hours (per day)	The Dutch law
Max working time	15 hours (per day)	The Dutch law
Earliest departure time	>05:00 (05:00:01)	The company
Number of customers served within their time window (%)	>95%	The company

2.5.1 Time window boundaries

The bound chosen for the time windows are determined in the following way. Section 2.1.1 explains that there is often an initial drive from the depot in Sneek to the first company. Since vehicle cannot depart before 05:00 (see Section 2.5.4) they cannot visit most customer before 07:00. Therefore, the company decided that the earliest requested time window should start at 07:00, the time window would be for example 07:00-09:00.

The upper bound has other considerations. In Section 1.2 is explained that after finishing the deliveries, a vehicle starts a pickup route to retrieve goods from the SMEs. This route starts for most of the vehicles in the afternoon and after loading the vehicle the vehicle has to return to the depot which also takes often more than 1 hour driving. This trend can be seen in the number of unloading actions per hour (Figure 5). From the data it becomes clear that already 86% of the deliveries are performed before 15:00. After that each hour after 15:00 the number halves compared to the previous hour. Those two factors combined, determined that we should only time windows with an upper bound lower than 15:00 (for example 13:00-15:00).

2.5.2 Capacity / number of deliveries per truck

Due to the simplification of vehicles and products, (Section 2.3.3) the capacity of general vehicle has to be constrained. The value is restricted to 20 products. The company stated that this value is in 99,5% of the case the restriction in capacity. Only in exceptions the number of deliveries is higher than 20.

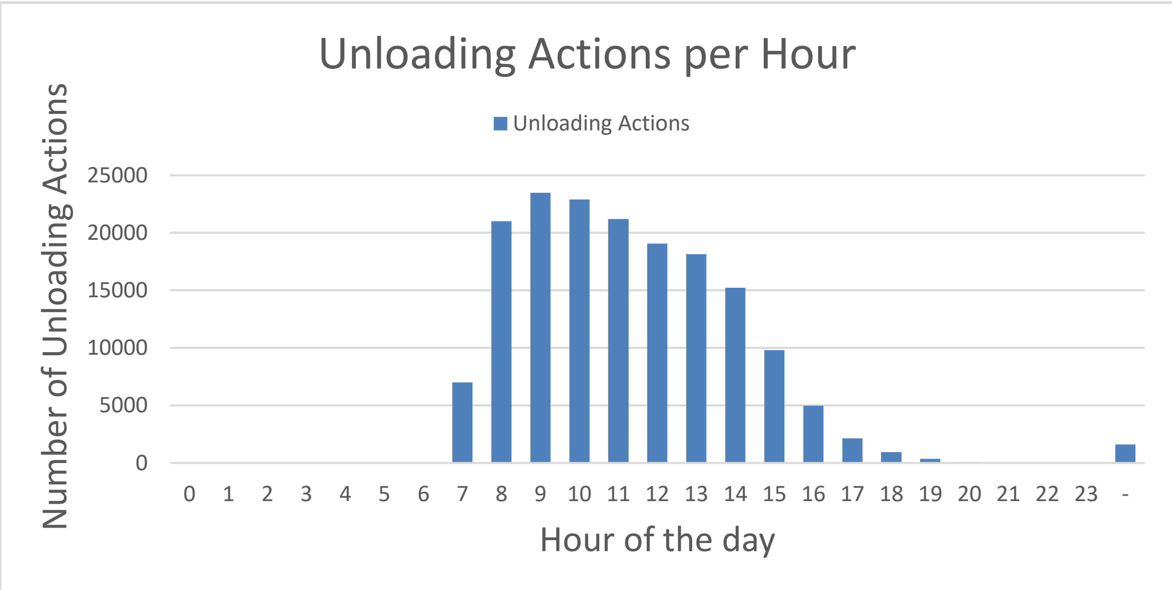

Figure 5: Number of Unloading Actions per hour

2.5.3 Max driving and working time

The Dutch government has created multiple restrictions for delivery companies to prevent exploration of drives and to maintain the safety on Dutch roads. Two of those restrictions are the maximum of hours a driver can drive per day and the maximum hours a driver can work. The driving time only includes only the time on the road, but the working time also includes the load/unload times of the driver. The limits stated in Table 3 are per day. For each of the restriction there are also two-day limits, week limits and two weeks limits. However, those are not applicable for a day route and therefore will not be used in the models. Using these limits simplifies the scheduling of breaks in the models.

2.5.4 Earliest departure time

The earliest departure time (EDP) of a vehicle is a constraint stated by the company. The value is later than 05:00 in the morning. The reason for the constrained is because of the Dutch law for night work. A driver which works at night is more costly for the company. But working at night only applies when more than 1 hour of the shift is between 00:00-06:00. So, when the shift starts just after 5 A.M., the law for nightshifts does not apply. Therefore, the company restricted the EDP to times later than 05:00.

2.5.5 Number of customers served in time window

The last constraint which will be discussed is the percentage of customer served within their chosen time window. The company set this value to be at least 95%. If this value is lower than the service business model is no longer maintained, since more than 5% of the customers the service can be considered dissatisfactory. The explanation of usage of this constraint as KPI can be seen in Section 2.4.2.

2.6 Summary

In this chapter, the current situation of Hoekstra is discussed and the implications for modelling a new situation in which customer can choose their own time windows are stated. Therefore, a more theoretical setting will have to be chosen since the complexity of Hoekstra's deliveries are not suitable for experiments. This results in multiple assumptions to simplify the situation, new KPIs to evaluate the performance and constraint in which the model should find its solutions.

3 Literature review

This chapter covers the theoretical side of the core problem and the solution of implementing customer chosen time windows in the scheduling of Hoekstra. The first part covers the VRPTW model with its different deviations. Afterwards, a perspective will be given on how this information will be used in the research. The second part covers the different ways how solutions can be generated. Four variants are discussed and afterwards will be determined which type of solving methods best suits Hoekstra in the problem setting described in Chapter 2. Lastly in Section 3.3, the theory of the implementation method will be introduced and discussed.

In this research, customer chosen time windows will have to be embedded into the schedules of Hoekstra. These types of problems have been researched already and much literature is available. This framework is therefore largely focused to the modelling procedures of these problems.

In literature, scheduling vehicles for the transport of goods are called Vehicle Routing Problem (VRP). It is a combinatorial optimization problem. The basic VRP consist of vehicles that originate from and return to a single depot that must service each customer or demand point once within designed tour or routes that do not exceed vehicle capacity limitations (Chiang et al., 2009, p.753). These problems are simplified from reality in many ways. Therefore, when time progressed, many variations of VRP have been proposed. The one used in this project is the Vehicle Routing Problem with Time Windows (VRPTW). This extent the problem by adding the constraint that customer have to be served within a predefined time window. According to this definition, it may seem that Hoekstra already uses time windows. This is not the case, because the time windows currently at Hoekstra are determined after the scheduling, whereas in VRPTW, the time windows are determined before scheduling. The extension with time windows is therefore a solution for solving the core problem and therefore an investigation in literature is beneficial. The problem of Hoekstra is a static problem, because before generating the solution, all parameters are known. The problem of Hoekstra will also be considered a deterministic problem, because a particular input (e.g. X number of customers) should always create the same output.

3.1 Modelling time windows

The literature search provides different ways to model the time windows. Each of the ways will be shortly reviewed and afterwards a perspective is chosen for this research.

3.1.1 Hard time windows

Most of the retrieved papers use hard time windows in their models. For example, Lim et al. (2017) state when explaining the time window constraint: “The service can only start during the given time window of a node”. This means that if the vehicle arrives before the earliest time in the time windows, the delivery has to be postponed until the lower bound of the window. For example, if the chosen time window is 13:00-15:00 and the truck arrives at 12:45, the vehicle has to wait until 13:00 to start service. For the upper bound (15:00) this is the same. Service has to be provided before 15:00 otherwise delivery will be postponed to another day.

3.1.2 Soft time windows

The opposite modelling strategy of hard time windows are the soft time windows. In this method, service is possible outside the time windows, but this comes at a cost. Tas et al., (2014) implemented this in the following way: a larger time window is created with the same mean for each time window. For example, the time window equivalent for 13:00-15:00 becomes 12:00-16:00. If a customer is served in the equivalent window instead of in the original window, a cost will be accounted. This cost is represented in the form of a penalty in the model. This penalty function can be modelled linear, exponential or any combination function.

3.1.3 Partly chosen time windows

Some of the retrieved literature provides an example, which varies too much from hard or soft to categorize them underneath one of them. The study from Wang et al., (2020) combines hard customer chosen time windows with another variant of time windows. Namely, time windows which are assigned by the transporter instead of the receiving customer. Hoekstra currently uses assigned time windows for all customers, but a possible combination of customer assigned, and customer chosen time windows could be a solution to the problem.

3.1.4 Chosen perspective

To answer the question: “How does this given information support modelling the specific situation at Hoekstra?” For Hoekstra it is not workable to wait at location before delivery. The large vehicles of Hoekstra make waiting in small streets of neighbourhoods impossible. Therefore, this research will not use fixed lower bounds in their time window. Instead, a penalty function will be chosen. The function itself will be discussed in Section 4.3.1.

The upper bound has more decisions. For Hoekstra delaying delivery to the next day because the time window has expired is unworkable. This is because when not all the goods are unloaded at customers, the pickup at SMEs cannot be done with the intended capacity. For example, 10 garden lounge sets have to be picked up for storage at an SME. When a delivery is not happening because the time window expired the truck cannot store 10 sets, but only 9. Afterwards another truck has to visit the SME just for the remaining lounge set. Therefore, a fixed upper bound is not workable and therefore penalties are more suited for Hoekstra. Penalties will be only applied when delivery starts outside the time window. This is done because service times are not long and therefore the impact of the services, which are partly performed outside the time window, are minimal.

The model will also use the combination of customer chosen time windows and assigned time windows, Section 2.1.3. already explains how the division can be determined. The study of Wang et al., (2020) proves that it is possible to implement and when the data can be retrieved explained in Section 2.3.4. Therefore, the combination of chosen and assigned time windows will be made.

3.2 Solution generation

This second part of the literature review covers the theory about the step from a model to a solution. After setting up the problem a solution needs to be generated. A mathematical model has to be used for that. A mathematical model can be defined as: “An abstract mathematical representation of a process, device or concept; it uses a number of variables to represent inputs, outputs and internal states, and sets of equations and inequalities to describe their interaction” (Mathematical-model, sd). Integer Linear Programming (ILP) is a problem setup in which only integers are used. When an ILP uses real (7,34 or ½) variables as well then it is named Mixed Integer Linear Programming (MILP). These apply to VRPTW. Solving these models can be done in four distinguished ways: A exact approaches, a heuristic, a metaheuristic and a matheuristic. In this section all four will be covered and some sample cases in VRPTW will be discussed. Afterwards, a perspective will be sketched in Section 3.2.5 for the next part of the thesis.

3.2.1 Exact approaches

An exact approach guarantees to find the optimal solution. This sound goods at first glance but the VRP is not an easy problem to solve. However, the problem at Hoekstra is called, a NP-hard problem, which results in exponential increasing possible solutions. For example, when visiting 10 customers with 1 truck there are 10 faculty number of solutions, which is approximately 3.6 million. For 15 customers this number increases to 1307 billion. This incensement in calculation time is the biggest disadvantage for exact algorithms. The most common exact method is the Branch and Bound algorithm it works in the following way. The set of all tours (feasible solutions) is broken up into increasingly small subsets. For each subset a lower bound on the length of the tour is calculated. Eventually, a subset is found that contains a single tour whose length is less than or equal to some lower bound for every tour. (Little et al., 1963)

An example in which branch and bound is applied to VRPTW is the study of (He, Irnich, & Song, 2019). In their performance evaluation can be seen that when the number of instances increases from 25 to 50, the computation time multiplies with at least the factor 300, because the number of instances proved optimally solved decreases. The study of Munari & Morabito (2018) shows this effect as well. The computation time from 25 customer to 50 increased from 7,83 seconds to 392,75 seconds, which is multiplication with factor 50.

3.2.2 Heuristics

The second category of solving methods are the heuristics. A well-formed definition is given by Chen (2019). “Heuristics are a problem-solving method that uses shortcuts to produce good-enough solutions give a limited time frame or deadline”. An example given of a heuristic, which is currently used by Hoekstra. In theory this is called Nearest Neighbour. The advantages of this solving method are that the solution is simple and can be fast calculated. This can be seen in the study of Mohammed, et al. (2017). In this study a Nearest Neighbour algorithm is introduced which finds its optimal solution for a problem with 31 customers in less than a second and for 68 customers in 5,6 seconds. However, the calculated solution is frequently not the optimal solution or an almost optimal solution. Especially when it is used for large problems. Therefore, according to Mejía (2016, p.19) they are commonly treated as the initial solution or first phase of the approach which can be improved in a second phase based on some construction and improvement heuristics. These are called the metaheuristics.

3.2.3 Metaheuristics

Metaheuristics is a solving approach which is a hybridisation of exact approaches and heuristics. This approach tries to combine the best of both worlds and therefore a lot of solving approaches are possible. Metaheuristics have been extensively researched with mixed success (Sörensen, 2013). Many new metaheuristics have been created in the previous years but only a few are fundamental different than the others. The most relevant metaheuristic for VRPTW is the (Large) Neighbourhood Search ((L)NS). This study by Shaw (1998, p.418) introduces this technique as, “LNS makes moves like local search but uses a tree-based search with constraint propagation to evaluate the cost and legality of the move”.

The asked question at the beginning of Chapter 3 gave besides multiple neighbourhood search types of solution algorithms, also population-based approaches. Many of those are inspired by natural behaviour such as the Ant Colony System (ACS). This is firstly applied to VRPTW by Gambardella et al., (1999). The basic idea is that a large number of simple artificial agents are able to build good solutions to hard combinatorial problems via low-level based communications.

The study of Bräysy (2003) compares their own Relative Variable Neighbourhood Search Algorithm with the algorithms of Shaw and Gambardella (Table 5). The algorithms are tested on Solomon instances, which are benchmark problems for performance comparison. The R1 problem has uniform distributed customers with narrow time windows and small capacity. The RC1 problem has besides uniform distributed customer also clustered customers. From Table 5 we can conclude that the performance improvements are in the margins of a few percentages improvement on one dimension, while losing a few percentages on another. Therefore, it is hard to determine which metaheuristics outperforms the other one in terms of these comparison variables. The study of Sherehe & Mujuni (2018) confirms the difficulty in determining the best performing metaheuristic. For the different cases the best performing method differs, and no method outperforms the other on all occasions.

Table 5: Major breakthrough metaheuristics comparison

Solution Approach of:	Problem 1 (Solomon R1)			Problem 2 (Solomon RC1)		
	Number of vehicles	Average total distance	Computation time (minutes)	Number of vehicles	Average total distance	Computation time (minutes)
Shaw	12.5	1198	94.5	12.1	1361	94.5
Gambardella et al.	12.4	1211	210.0	11.9	1388	210.0
Bräysy	12.0	1229	125.7	11.5	1394	102.2

3.2.4 Matheuristics

The most recent development in solution generation for vehicle routing problem is the introduction of matheuristics. This method became more popular due to hardware advances and advance in exact methods (Archetti & Speranza, 2014). The term itself is a contamination of metaheuristic with mathematical programming. Their performance should be in between exact approaches and metaheuristics. An example of Lalla-Ruiz & Voβ (2020) shows that a Matheuristic performs especially well for medium-large instance problems whereas the best known solution is better in small-medium instances.

Another study introducing a matheuristic is the study of Kramer, et al. (2015). In this study an algorithm is proposed, which is compared with an adaptive LNS. Whereas both algorithms find (almost) the best known solution on the large instance of 100 customers, the matheuristic does this almost 3 times as fast, although the calculation device of the matheuristic had 13% more computation power (3.0 over 3.4 GHz) and more memory available (1 over 16 GB). This study confirms that the matheuristics are a reasonable alternative of the metaheuristics for large instances although they are more computational heavy than metaheuristics, but faster than exact approaches.

3.2.5 Chosen perspective

The question to answer is: “What insights have we gained from theory about solution generation?”, It is important which solution method is chosen when generating schedules. Research has shown that the proposed solution methods outperform existing methods on the problems they are tailored to. However, this does not mean that the optimal solution method presented in other studies is the optimal one for the situation stated in Chapter 2. This is explained with the no free lunch theorem of Wolpert and Macready (1997). Defining a solution approach tailored to the situation of Hoekstra itself is a study on itself and can therefore not be considered an option. Therefore, an evaluation on the solution method has to made on the categories purpose and not on the performance on each of the methods itself.

The goal of solution method is to find representative solution within a reasonable timeframe. As stated in Section 2.3.1 the problem instance will not be large than 120 customers and therefore the matheuristic does not suit well in comparison with a metaheuristic. An exact method will require too much computation time on the maximum suggested cluster size of 120 customers. A heuristic approach is the other extremity since they perform fewer iterations to improve the initial solution, which makes them fast, but their solution might be often far from optimal. This is not in line with the current way of working, since a lot of adaptations are performed manually during the planning process. All this information combined, concludes that a metaheuristic is the best solution generation method for this research.

Within the metaheuristics, multiple generation methods are available which all have the problem that the method is not tailored to the problem of Hoekstra. This results in that a decision on the method cannot be proven as the best option for Hoekstra. A comparison study with the most well-known metaheuristics cannot conclude one method outperforms another one, since parameter settings may lead to finding local optima instead of global optima (Asih, Sopha, & Kriptaniadewa, 2017). Therefore, the solving method is determined together with the implementation of the models in Chapter 4.

3.3 Implementation method

In this section the implementation method for the experiments will be introduced. The goal of the section is to introduce and explain the theory used in more detail. Chapter 4 focusses more on the changes made on the model for using it in the situation at Hoekstra. Section 3.3.1 will discuss the solution generation method used in the implementation.

The implementation method which will be used is the Spreadsheet solver for Vehicle Routing Problems (Erdoğan, 2017). The solver is capable of solving 64 VRP variants, including a variant which can solve a VRPTW. The benefits of this system are that it is made in Excel, which is an available software tool at Hoekstra. That makes the process more understandable and accessible for the company. Another advantage is the programming language used, VBA. It is a language which can be understand by medium-level programmers (Erdoğan, 2017). Disadvantages of this system are that because of the wide variety of solvable VRPs the solving algorithm is not tailored to the VRP with time windows. The options in the solver result in that all demand stated in Section 3.1.4 can be fulfilled.

3.3.1 Solution generation method

The solving methods used in the spreadsheet solver is an variant of the Adaptive Large Neighbourhood Search (ALNS) of Pisinger & Ropke (2007). The ALNS can be simply explained in four steps. The first step is generating an initial solution. Secondly, this solution is destroyed and repaired in the third step. The fourth step checks whether or not the solution is better than initial solution. The cycle continues from step two until the time/iteration limit is reached. The difference between the LNS explained in Section 3.2.3, is that the ALNS can adapt in which way the solution will be repaired.

The algorithm of the spreadsheet solver uses slightly changed version of generally known version of ALNS. Firstly, the pseudocode of the algorithm is shown and explained. Afterwards, the changes are stated.

1. Construct an incumbent solution which adds a customer to the route (when possible) which has the minimal cost increase for the route (for each customer added)
2. Improve this solution with local search operators*
3. Record solution as best known solution
4. Perform an improvement cycle with the following steps

a. Destroy increment solution by removing a random customer from the route
b. Repair the route by adding customer to the route according to a heuristic**
c. Improve the solution with local search operators*
d. If the new solution is better than the old solution then:
    i. Replace best known solution with current incumbent solution
e. Else replace the incumbent solution by the best-known solution with probability p***

* The following local search operators are used to improve the incumbent solution:

- Exchange: exchange every pair of customers in the solution.
- 1-OPT: remove every customer in the solution and re-insert it into every different position within the routes.
- 2-OPT: remove the routes from customer a to b and from c to d and replace it with routes a to c and b to d (Figure 6).

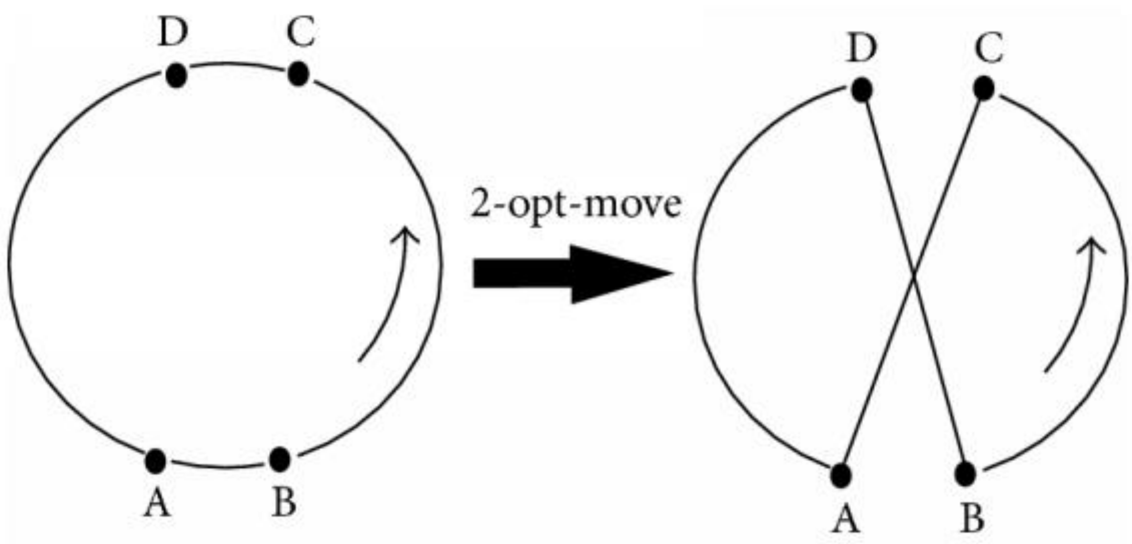

Figure 6: Visual explanation of 2-OPT local search operator

** The following heuristics are used to repair the incumbent solution:

- Greedy insertion: Insert the customer with lowest costs
- Max regret: Insert the customer for which the costs of insertion between the cheapest customer and the second cheapest customer are the largest.

*** The reject probability p decreases linear from 10% at the start to 0% at the end. At the start of algorithm, the search for better solution can be reset to the currently best-known solution (with p = 10%). Otherwise, the improvement cycle continues with the incumbent solution.

Step 4b in the pseudo code slightly differs from the general ALNS. In the general ALNS the decision between the heuristic chosen to repair the solution is made adaptive. This means that the decision between the heuristics is made based upon the results of the heuristics in previous iterations or even runs. In the study of Erdoğan is chosen to have both heuristics chosen with equal probability.

3.4 Summary

In this chapter, theory is discussed about the VRPTW. Firstly, the choices within this type of VRP are discussed and the best version of VRPTW is chosen. An approach in which the time windows are treated soft will best fit Hoekstra, since their complexity (of goods) does not allow rescheduling when arriving too late or waiting when arriving too early. A variant will be used so that some of the customer can choose their time windows and others are not able to. To find the solutions to this VRPTW, a metaheuristic will be used since it best fit for the theoretical situation created for Hoekstra. Lastly, the implementation method is introduced and the theory behind how the solutions will be created is explained.

4 Proposed models

In this chapter, we propose the model used for the experiments in Chapter 5. Section 4.1 describes the conceptual model with the parameters, decision variables, objective function and constraints. Afterwards in Section 4.2 assumptions related to modelling this VRPTW are discussed. The last section discusses how the conceptual model is adapted to the implementation method and how the data of the current situation fits into the computer model.

4.1 Optimization model

In the conceptual model many variables are used with different notations and meaning. Therefore, all variables will be listed before the equations will be presented. This model is developed for the VRPTW of Hoekstra. The optimization model is based upon the theoretical model of Erdoğan (2017) (Section 3.3).

4.1.1 Parameters

The parameters are predetermined values which is the input of the model and will affect the decision made by the model to determine the most optimal solution. Most of the values are discussed in Section 2. All parameters are stated and described in Table 6.

Table 6: Problem parameters

Parameter	**Description**
Customer C_i	This variable stand for the customer which have to be visited. Each individual customer is denoted in subscript with the letter *i*.
Depot D	The second variable states the starting point of the vehicle. For the routing, the depot will be denoted as C_0.
Vehicle V^k	The vehicles are denoted as V^k. In superscript is each individual vehicle indicated with the letter *k*.
Time window $[a_i, b_i]$	The time window lower bound is denoted with the letter a and the upper bound with b. Since the time window is customer depended it is subscripted with the letter *i*.
Delivery amount q_i	The amount of goods to deliver to customer *i* is denoted as q_i
Service time s_i	This variable states the service time per customer *i*.
Capacity Q^k	The maximum capacity of each vehicle *k* is denoted with Q^k
Earliest departure time ET^k	This variable states the earliest departure time for each vehicle *k*
Working time limit WTL^k	The working limit time is the maximum time vehicle *k* can be work
Distant limit DL^k	This variable states the limit in distance vehicle *k* can drive.
Fixed Vehicle costs F^k	The fixed costs of driving vehicle *k* is denoted with F^k
Driving distance d_{ij}	The distance (km) between each of the customer *i* and customer *j*.
Driving time duration dt_{ij}	The duration of traveling between customer *i* and customer *j* is denoted in this variable.

Cost per distance unit U^k	U^k denotes as the costs for the vehicle *k* to travel a certain distance unit for example one kilometre. However, it can also denote as costs per working hour, dependent on the use of D_{ij} or DT_{ij}.
Penalty P	The costs of violating the time window is denoted with P.
Travel Cost C_{ij}^k	The costs of driving between customer *i* and customer *j* with vehicle *k* is denoted with this variable. The value is calculated with the multiplication variables D_{ij} or DT_{ij} and U^k.

4.1.2 Decision variables

Decision variables are the variables which will be changed in order to find solutions for the problem. The decision variables are stated and described in Table 7.

Table 7: Decision variables

Decision variable	**Description**
Travel decision x_{ij}^k	This decision variable is an integer variable. The value equals 1, if vehicle 1 travels from customer *i* to customer *j*. Otherwise, the value is 0.
Visit vehicle y_i^k	y_i^k is an integer decision variable which equals 1, if vehicle *k* visits customer *i*, otherwise 0.
Delivery commodity w_{ij}^k	This decision variable indicates the load of the vehicle *k* between customer *i* and customer *j*.
Arrival time t_i^k	Arrival time t_i^k is the time vehicle *k* arrives at customer *i*.
Violation time v_i	v_i is the amount of time the time window of customer *i* is violated.

4.1.3 Objective function

The objective function is to minimize the total costs of transport, which is the main KPI (see Section 2.4.1). The objective function is divided in three sections, below the function is an elaboration upon each part.

Minimize $\sum_{i,j} \sum_k C_{ij}^k x_{ij}^k + P \sum_i v_i$

The first part determines the variables costs of the transport, by summing over all possible routes with all vehicles, when the route is travelled ($X_{ij}^k = 1$) than the C_{ij}^k is summed.

The last part determines the penalty for each customer when the time window is violated. It is done by summing over all customers and multiply the summation with the penalty P.

4.1.4 Constraints

In this section the constraints of the model will be stated with a short explanation of use.

One vehicle visits one customer constraint

$$\sum_k y_i^k = 1 \quad i > 0$$

This constraint ensure that each customer will be only visited by one vehicle. Therefore, it prevents strange detours and split deliveries.

Flow conservation constraint

$$\sum_i x_{ij}^k = \sum_i x_{ji}^k \quad j > 0, \forall k$$

This constraint is formulated to guarantee the customer visit flow of the model is correctly. Namely, it ensures that the inflow at customers equals the outflow.

Connectivity constraint

$$\sum_j x_{0,j}^k \geq y_i^k \quad i > 0$$

This constraint makes sure that there is a connection between the depot and the customer visited.

Vehicle usage constraint

$$\sum_j x_{0,j}^k \leq 1 \; \forall k$$

This constraint ensures that a vehicle can only be used once to prevent that 1 vehicle does all the routes.

Delivery flow constraints

$$\sum_j w_{ji}^k - \sum_j w_{ij}^k = q_i y_i^k \quad i > 0, \forall k$$

$$\sum_i w_{0j}^k = \sum_i q_i y_i^k \quad \forall k$$

The constraints formulating above makes sure that the deliveries are performed when visiting the customer and that all demand is loaded onto the truck when departing.

Sub-tour elimination constraint

$$t_i^k + \left(DT_{ij} + s_i\right) x_{ij}^k - WTL^k\left(1 - x_{ij}^k\right) \leq t_j^k \quad \forall i, k\; j > 0$$

The sub-tour elimination constraint makes sure that route between two customer which has a longer working time than the shortest route is not allowed.

Time windows constraint

$$a_i \leq t_i^k \leq b_i - s_i + v_i \quad i > 0, \forall k$$

This constraint makes sure that time windows are respected and if they are violated, it determines the value.

Earliest departure time constraint

$$t_0^k \geq ET^k \quad \forall k$$

This constraint makes sure that the departure time from the depot is not earlier than the Earliest departure time.

Capacity constraint

$$w_{ij}^k \leq Q^k x_{ij}^k \quad i, j > 0, \forall k$$

This constraint prevents that the number of deliveries is higher than the capacity of the assigned vehicle k.

Time limit constraints

$$\sum_{ij} d_{ij} x_{ij}^k \leq DL^k \quad i, j > 0, \forall k$$

$$\sum_{ij} dt_{ij} x_{ij}^k + \sum_{i} s_i y_i^k \leq WTL^k \quad i, j > 0, \forall k$$

These constraints ensure that the driving distance, driving time limit and working time limit are not higher than the constrained values of 10 and 15 hours respectively.

Integrality and non-negativity constraints

$$x_{ij}^k \in \{0,1\} \quad i, j > 0, \forall k$$

$$y_i^k \in \{0,1\} \quad i > 0, \forall k$$

$$v_i \geq 0 \quad i > 0$$

$$w_{ij}^k \geq 0 \quad i, j > 0, \forall k$$

These last constraints ensure that the decision variables are binary or non-negative variables.

4.2 Assumptions

In this section, assumptions which are more model related will be discussed. These are assumptions which have not been covered in Section 2.3 already. That section discussed assumptions about the current situation at Hoekstra.

4.2.1 Time window demand distribution

The first modelling assumption covers the demand distribution of the time windows. In practise customers will have a certain demand distribution for the specific time slots. However, this distribution is unknown since it is not implemented or researched. Together with the company we therefore assumed that this distribution is uniform for each of the time windows. We expected that customers would prefer the time slot at the edge of the absolute boundaries, but with the possibility in reality to disable the option to choose time windows which are full. This factor made this assumption of uniform distribution valid for the company.

4.2.2 Vehicle driving speed

The second assumption is about the speed of the vehicles in the routing. In the implementation the distance and the driving time between customers has to be determined. There are multiple methods such as using an average speed over the distance. However, this method does poorly reflect the situation at Hoekstra, because in cities this average speed will not be reached and thus will benefit even more for the fact that the customers are close to each other. Therefore, the driving speed will be not with an average over all routes, but with the driving speed of a car on the route. This results in that a route of 3 kilometre in a city centre has a lower speed than a 100-kilometre highway route. A problem is that in general the speed of a car is higher than the speed of a truck. However, the speed of all routes can be reduced with a duration multiplier. This method is therefore much more accurate than an average speed over all routes of for example 60 km/h. The speed difference will be compensated with a duration multiplier of 1.15 (Section 4.3.2.4).

4.2.3 Distance and time of travel between customers

The last assumption made in the modelling is that the distance (and time) between departure point A and arrival point B, are equivalent to the travel distance between point B and point A. In practise the travel distances are almost equal especially if the distance is large (>10km) but at smaller travels the distance may be slightly off due to one-way traffic lanes. However, this sporadically happens and assuming these distances equal decreases the computation time of distances by 50%. So therefore, this assumption is made.

4.3 Implementation

The implementation will be done in the spreadsheet solver developed by Erdoğan (2017). However, the free accessible tool does not directly fit the Optimization model of Section 4.1, the changes made will be discussed in Section 4.3.1. Section 4.3.2 discusses how the data of Hoekstra will be set up into the solver.

4.3.1 Model adaptation

This section will elaborate upon the changes in the solver to meet the conceptual model from Section 4.1 and the current situation (Chapter 2) of Hoekstra. The four main changes will be one the following sections: Objective function, constraints, penalty function and the solving method. Besides those, the implementation of KPI percentage achieved time window and the changes on the lower bound penalty will be discussed.

The objective function

The objective function in the solver tries to maximize the profit whereas in this research the costs needs to be minimized. The change is easily adapted, since the profit is calculated with the revenue minus the costs. So, when the revenue is zero the costs will be automatically minimized to maximize the profit.

Constraints

The study of Erdoğan (2017, p. 69) includes many more constraints than necessary for this research therefore the constraints in Table 8 are not stated in the conceptual model (Section 4.1). For each constraint an explanation is added why they are not relevant for this study.

Table 8: Excluded constraint in the model

# in study	Constraint	Explanation
3	Customer priority	All customers have the same priority

6	Return to depot	Vehicles will not return to depot
8	Backhaul*	Pickup of goods will not be done
9,10	Pickup demand	Pickup of goods will not be done
17	Return on time to depot	Vehicles will not return to depot

* Backhaul in this study is defined as “delivery must be finished before pick up can start”

Percentage achieved time windows

The KPI and constraint “percentage achieved time window” will be evaluated manually (Sections 2.4.2 and 2.3.5). Therefore, there will be no changes in the model and/or coding to calculate this percentage. In general, the model should strive to serve all customers in the time windows given, but when this constraint is violated due to other constraints being more important, the solution should not be thrown away but be looked into in depth. This done to investigate why the model chooses this solution is better than other solutions which do not violate this constraint. It could indicate that the penalty for violating the time windows is too low or that the benefits of violating (or the penalty for violating other constraint) are too high. Therefore, the solution should be manually be evaluated and can afterwards still be rejected.

Penalty function

The penalty function below is a quadric function multiplied by a large constant M dependent on the size of the problem. Q’ is the value of the violated variable and Q is the maximum (or minimal) value allowed for the specific variable.

$$(\max\{Q' - Q, 0\}/Q)^2 \times M$$

The constant M is calculated by multiplying the total driving distance with the summation of costs per kilometre per vehicle. This will ensure that the penalty is significant for larger problems in which the weight of one violating of the restrictions may be insignificant in terms of costs but should be prevented when possible. The penalty constant is not visible in the solver yet, but will be added solution spreadsheet, see Figure 7.

Total net profit:	-778,92	**Penalty value**	244652,00					
Vehicle:	**V1**	**Stops:**	14	**Net profit:**	-258,93			
Stop count	**Location name**	**Distance travelled**	**Driving time**	**Arrival time**	**Departure time**	**Working time**	**Profit collected**	**Load**
0	8601 WC	0,00	0:00		05:00	0:00	0	14
1	9364 PG	61,40	0:42	05:42	07:10	2:09	0	13
2	9821 PD	71,20	0:54	07:21	07:31	2:31	0	12
3	9801 HD	77,60	1:04	07:41	07:51	2:51	0	11
4	9977 TE	99,00	1:38	08:26	08:36	3:36	0	10
5	9981 BC	119,40	2:06	09:03	09:13	4:13	0	9
6	9951 TE	137,20	2:29	09:36	09:46	4:46	0	8
7	9737 HN	152,40	2:50	10:07	10:17	5:17	0	7
8	9741 CB	158,10	3:02	10:30	10:40	5:40	0	6
9	9743 AD	161,40	3:14	10:51	11:01	6:01	0	5
10	9745 DE	164,90	3:22	11:09	11:19	6:19	0	4
11	9711 JS	170,50	3:39	11:37	11:47	6:47	0	3
12	9722 EJ	173,60	3:53	12:00	12:10	7:10	0	2
13	9723 TH	176,40	4:01	12:18	12:28	7:28	0	1
14	9621 AN	194,10	4:16	12:43	12:53	7:53	0	0
15								

Figure 7: Penalty constant displayed next to the total net profit in the solution spreadsheet

Lower bound penalty

The model does not calculate a penalty for arriving earlier at locations than the time window starts. Therefore, when running the model often waiting/idle time occurs in the solution. This is against the company demands and the perspective in Section 3.1.4. In the coding the same penalty for finishing service X minutes too late is applied for when a vehicle arrives X minutes earlier at a location.

To apply this change properly the arrival time at the first location has to be changed. Initially the arrival time at stop 1 is the EDP + driving time from depot to this customer. This would lead to enormous penalties since EDP is 05:00:01 and the driving time to most regions is 1,5 hours. This would lead by default to large penalties and unrealistic total costs of transport. Therefore, the departure time is changed in such way that the first customer will be visited at the start of its time window. For example, when the driving time to customer 1 is one hour and the time window starts at 07:00, then the departure time from depot will be 06:00 and not 05:00.

4.3.2 Data setup

In this section will be discussed how the data gathered from Hoekstra will be used as input for the solver. For each of the sheets the variables will be stated and their values, if they are not yet mentioned in Section 2 than the calculation will be described. The whole generation of setup data can be found in Appendix C.

4.3.2.1 Solver setup sheet

The initial sheet in the solver is there to set-up the other sheets correctly and to give the primary input for the model.

Number of depots; The number of depots will be by default 1, see Section 2.3.3

Number of customers; The number of customers will be calculated dependent on the region which will be modelled. The value will be the average number of unloading addresses in that specific region per day. How this value is calculated can be seen in Appendix C-4.

Distance and duration computation method; The distance and duration computation will be done manually. This will be further explained in Section 4.3.2.3.

Number of vehicle types; This value will be by default 1, because of a simplification explained in Section 2.3.3.

Do the vehicle return to their depot(s)?; The answer to this question is by default no. In Section 2.2 is discussed that the pick-up route will be unprogrammable, so therefore the vehicle does not return to depot in this model. This is mainly because the direct route from last customer to depot does not match the pickup route performed after the last customer before the depot, in terms of time and distance.

Time window type; The time window can either be a hard time window or soft time windows. As discussed in Section 3.1.4 the time windows will be soft.

Backhauls; Backhauls (Section 4.3.1.) will not be studied in this model, because of the stochastic demand in pickups. Therefore, in the model no pickup route will be driven, so the value will be set to no on this question.

Warm start; Warm start is the fact that the solver will try to adapt the best-known solution from earlier runs as initial solution in the new run. This may affect the performance of the second run unwillingly and therefore be unreliable. Therefore, the value will be by default no.

Show progress on the status bar?; The progress bar shows the number of iterations and the best know solution so far. This can be useful to detect mistakes and to indicate the performance of the run. Therefore, this value will be set to yes.

CPU time limit (seconds); The CPU time limit is the time the model will run to find the best solution, at least one instance must be finished otherwise the limit will be exceeded. The CPU limit time is largely affected by the number of customers, since that increases calculation time exponentially (Section 3.3). Therefore, the solver gives a recommendation of the minimum time. The recommended time in seconds is calculated with the following formula:

$$60 * Rounded\ up(\frac{Number\ of\ Customers^3}{100000})$$

This number will be doubled in this research to ensure a reasonable calculation time. So, if the recommendation is at least 120 second, the CPU limit will be 240 seconds.

4.3.2.2 Locations

Address; The address will be the generated postal code for a customer in the modelled region. How this postal code is generated can be seen in Appendix C-5.

Coordinates; The coordinates are used to calculate distances using other methods the manual entry method as chosen in Section 4.3.2.1. Therefore, these fields can remain empty.

Time window start/end; The window start and end time will be determined according to the following procedure for each of the generated postal codes: First of all will be determined if the customer is an SME or individual, which determines if they can choose a time window if it is assigned. In Section 2.3.4 is the reasoning explained. According to the percentage displayed in the digital dashboard (Appendix A) will randomly be determined which customer type it is. If the customer is an SME then the time window be the absolute lower bound (07:00) and the absolute upper bound (15:00) as described in Section 2.5.1. When the customer is an individual, they can choose their own time window. The requested time window will be randomly assigned to each customer according to a Uniform distribution (Section 4.2.1). For the depot the lower bound will be the earliest departure time (Section 2.5.4) and the upper bound will be the end of the day, 23:59. Figure 8 shows an example on how the time windows may look in an experiment. The generation of these time windows can be seen in Appendix C-6.

	A	B	F	G
1	Location ID	Name	Time window start	Time window end
2	0	Depot	05:00	23:59
3	1	Customer 1	07:00	09:00
4	2	Customer 2	07:00	15:00
5	3	Customer 3	13:00	15:00
6	4	Customer 4	11:00	13:00
7	5	Customer 5	07:00	15:00
8	6	Customer 6	10:00	12:00
9	7	Customer 7	08:00	10:00
10	8	Customer 8	07:00	15:00
11	9	Customer 9	07:00	15:00
12	10	Customer 10	10:00	12:00

Figure 8: Possible Location sheet with 10 customer and 60% individuals customer type

Other Constants; In the location sheet other constants are also stated but have default values which are already stated in Chapter 2 or are empty because they will not be used. These constants with their value and the reference to the explanation of the meaning are stated in Table 9.

Table 9: Other location constants

Constant	Value	Reference
Address	Customer postal code	Appendix C-5
Coordinates	Not needed	Section 4.3.2.1
Service time	10 minutes	Section 2.3.5
Pick up amount	0	Section 2.2
Delivery amount	1	Section 2.5.2
Profit	0	Section 4.3.1

4.3.2.3 Distances

As stated in Section 4.3.2.1 the distances will be manually calculated. This is chosen because the Bing maps key method and OpenStreetMap does not handle Dutch zip codes properly. The usage of Google maps via a key for large request requires additional costs. Large requests are easily made since the request size is since the number of routes is approximately the number of customers squared divided by 2. For 10 customer this is 50, but for 20 customers this is 205, 50 customers have 1270 unique routes and for 100 even 5045. The costs for these 5000 requests are €100,- (Google, sd). Therefore, this option is not investigated further and a more time consuming code is written in Visual Basic (VBA) to retrieve distance and time data from the ANWB route scheduler, an equivalent to routing option tool for of google maps (for individuals). For the travel time is an assumption made which is that the travel time is calculated with a car instead of a truck (Section 4.2.2). The route and distance generation can be seen in Appendix C-7,C-8.

4.3.2.4 Vehicles

Number of vehicles; The number of vehicles in the region will be calculated according to the average number of vehicles present in the selected region, the average number of deliveries for this region per vehicle and the average number of deliveries per vehicle. Afterwards the value will be rounded up and that will be the number of vehicles. The following formula is used.

$$Rounded\ up\left(\frac{Average\ \#\ deliveries\ region}{Average\ \#\ deliveries\ total} * Average\ \#\ vehicles\ region\right)$$

Capacity; The capacity will be restricted to a maximum of 20 (Section 2.5.2). However, the value is often lowered since the average number of customers divided the number of vehicles results in that with a capacity of 20 one of the vehicles remains empty and thus not travel to the region, whereas this vehicle may is needed for pick up route in practise. Therefore, the capacity is restricted manually to ensure that all vehicles will be used. The value of this parameter will be described in the experiment.

Distance limit; The distance limit is not a limit mentioned by Hoekstra as a constraint in Section 2.5. After a further investigation Hoekstra confirms that there is no distance limit for the vehicles used. Therefore, a large number is used such that solution will not infeasible because of this limit.

Duration multiplier; To compensate for the assumption that the vehicle driving speed of a truck is equal to the driving speed of a car, a multiplier can be used to lengthen the driving time (Section 4.2.2). To determine the value of this constant, literature is searched with only one useful outcome (Hallmark & Isebrands, 2004). This study shows a speed difference between cars and trucks of 13 km/h on routes and 4,4 km/h on certain spots. However, this study in performed in the United States. The United States has different truck regulations and a completely different road network. Therefore, the speed difference could not be applied directly as duration multiplier. From this study, we can conclude that truck speed is on all occasions lower than car speed. Together with the company is concluded that an assumption on this constant is the best approach to compensate for the speed difference between cars and trucks. The value of the duration multiplier is set 1.15, resulting in that the travel time of trucks will be 15% longer than the travel time of a car.

An example route which will be used in the experiments in Chapter 5 is the possible route between a customer (1424 EB) and a customer (1251 JX). The distance of this route is 49.2 kilometres with a travel time (uncorrected) of 32 minutes. This would cause this route to have an average travel speed of 92 km/h. The duration multiplier corrects the travel time from 32 to 32 x 1,15 = 37 minutes, which is more representative for a truck. The average travel speed is reduced to a more realistic value of 80 km/h.

Other constants; In the vehicle sheet other constants are also stated but have default values which are earlier covered in Chapter 2. These constants with their value and the reference to the explanation of the meaning are stated in Table 10.

Table 10: Other vehicle constants

Constant	Value	Reference
Fixed costs per trip	0	Section 2.4.1
Costs per unit distance	1,3340	Section 2.4.1
Work Start time	05:00:01	Section 2.5.4
Driving time limit	10:00	Section 2.5.3
Working time limit	15:00	Section 2.5.3

4.4 Summary

This chapter covered the creation of a model suited for the situation at Hoekstra. Firstly, an optimization model has been described with all factors to be considered. Afterwards, some assumptions have been described which are needed for the modelling of the old and new situation at Hoekstra. Lastly, the environment in which the experiments (Chapter 5) are going to be executed is shown. To this end, changes are being made to the model of Erdoğan (2017) and the data from Hoekstra is implemented.

5 Experiments

In this chapter experiments will be performed. Before any of the experiments are discussed, different input variables dependent on the experiment are discussed. This will be done in Section 5.1. Section 5.2 discusses the region experiment. Sections 5.3 and 5.4 will discuss the experiments on time window size and individuals percentage respectively. Afterwards, a comparison analysis between all time windows and individuals percentages is discussed in Section 5.5. Lastly in Section 5.6, the validation of the experiments is discussed.

The layout of an experiment section will be as followed. Firstly, the experiment dependent variables (Section 5.1) are stated in a table. Afterwards, a result table is displayed in which the old situation is always stated together with the results in the new situation. The result sheet will display the experiment name, the number of iterations and the KPIs. The number of iterations is an indicator for the performance, which will be discussed in Section 5.5. Below the table, a short explanation on the results is given. Lastly, a section is used to interpret the results with the conclusions of the experiment.

5.1 Experiment dependent variables

In this section, variables will be discussed which influence the results of the experiment or are different per experiment because for example these variables are changed in experiments.

Running time

The experiments are run on a ThinkPad P51 with a 7th generation Intel Core i7 processor. This processor is on par with the CPUs used in the experiments compared in Chapter 3. Therefore, the determination of running time (Section 4.3.2.1) does not have to be revaluated for receiving reasonable solutions when performing experiments.

For finding the solutions in the different regions, different running times are used. As explained in Section 4.3.2.1. The length of the run depends on the number of customers in the region, when there are more customers, the model will get more time to find the solution. This is the same for scheduling at Hoekstra. The more addresses to visit, the longer scheduling takes for the scheduling department. Therefore, per region the running time will be stated.

The effect of the running time and CPU performance on the solution finding process can be seen in the number of iterations, which will be presented in the results sheet. This number is the number of time step 4 of the solution method is performed (Section 4.3.1). When the number is higher than from another experiment then it means that the model found it easier to created alternative solution, which indicates that this problem is easier to solve than the problem in which a lower number of iterations has been performed.

Region accuracy

The first variable is the region accuracy. This variable is already described in Section 2.3.1. The region accuracy indicates in which degree the vehicles are loaded with deliveries for the selected region in reality. A region accuracy of 80% means that 80% of the load of all vehicles, performing at least one delivery in the region, will be delivered to an address in the selected region. This variable does not influence the results as input, it is a result of the region selection performed in Section 5.2.

Individuals percentage

This variable determines the number of customer chosen time windows in the experiment. The higher the value, the more customers will have a chosen time windows (Section 2.3.4). Each region has a different value of this variable. For the experiments this value will not be used since when using this regional value, a difference in KPIs can have two reasons. The first being the regional difference in terms of location and customer density and the other one being the difference in number of chosen time windows. This last one will be an experiment of itself in Section 5.3. The region experiment (Section 5.2) and the time window size experiment (Section 5.3) therefore uses the general individuals percentage on the selected weekday.

Number of customers

The number of customers is one of the experiment characteristics and is dependent on the region and the weekday. More explanation of the variable can be found in Section 2.5.5. This number is tied to region and will not change with the different experiments. The customers visit will neither change with the different experiments.

Capacity

The fourth variable is the capacity of the vehicle, explained in Section 4.3.2.4. This number may vary to ensure the usage of all available vehicles, therefore this variable is stated in each experiment.

Number of vehicles

This variable is explained in Section 4.3.2.4. It will be tied to the region and does only change if the region is changed.

Time window size

The time window size is the variable which will be experimented with in Section 5.2. The value will be a number of hours with this value the time windows will be calculated according to the description in Appendix C-6.

Replications

The last variable is the number of new situations tested. Since the customer will choose their time window randomly, time windows which will be chosen by customer can result in an outlier in the experiment. Therefore, the new situation will be performed 5 times, resulting in less randomness in the comparison with the old situation. The average value of the KPIs will be used for comparison and the same customers will be used in each experiment.

5.2 Regions

In this experiment regions will be compared based on their costs when implementing customer chosen time windows. Firstly, the regions have to be determined, afterwards the results of the model will be shown for each region. The region experiment serves the goal to evaluate the hypothesis that customer chosen time windows is more beneficial in city regions (with more customer close to each other) than in rural region. Therefore, two city regions have been defined and three rural regions (Figure 9).

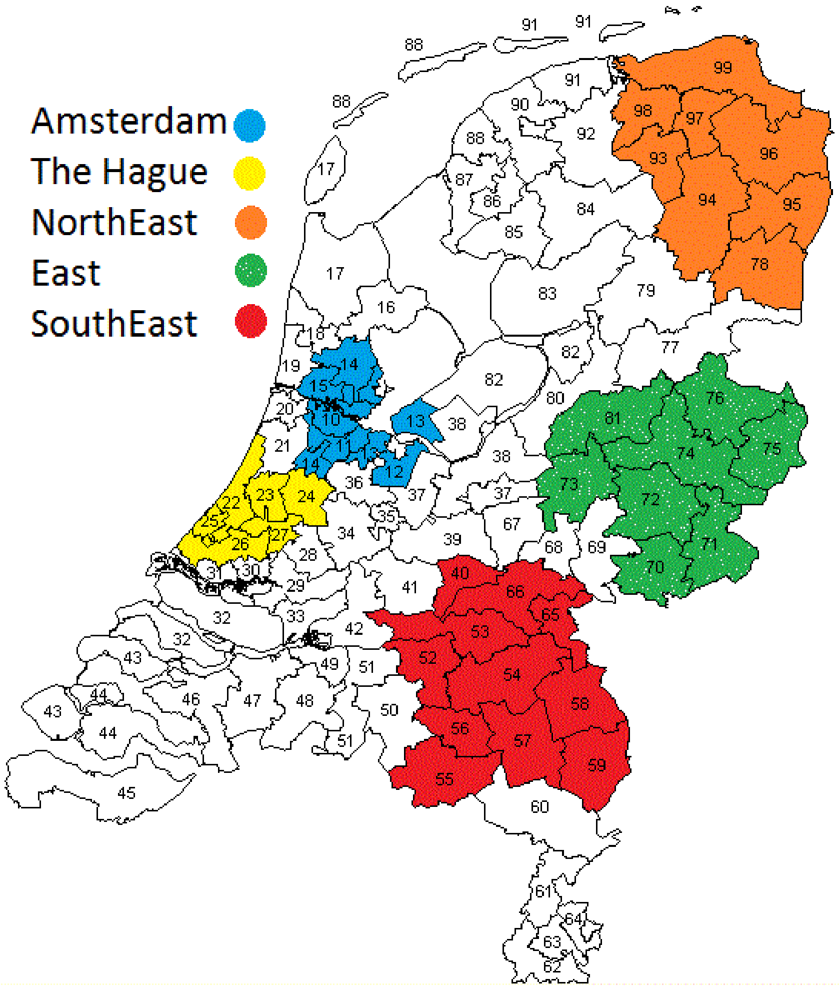

Figure 9: Map of the location of the regions chosen for the experiment

The selection procedure for the city region is as follows. The cities are chosen from the four big cities (Amsterdam, Rotterdam, The Hague and Utrecht) in the Randstad. The dashboard showed that Amsterdam (zip code 10) and The Hague (zip code 25) are the most suitable. These two cities are the most visited with 2,98% of all deliveries at Hoekstra (Amsterdam) and 1,59% (The Hague), therefore these cities are chosen. To accurate define the region in which the city operates the zip code who has the most outer selection percentage is added (except 86, the depot zip code) until the inner percentage of the regions does not increase. For Amsterdam this results in the zip codes: 10,11,12,13,14,15 and for The Hague: 22,23,24,25,26,27.

The selection procedure for rural regions differs a from the city selection procedure. For the North East region the goal was to define a region in the northeast of the Netherlands with an as high as possible inner percentage, therefore zip codes are swapped out of the region for other to find the optimal mix, resulting in the following zip codes: 78,93,94,95,96,97,98,99. The same approach applied for the region East in which the goal was to capture the regions Achterhoek and Twente which define the eastern part of Netherlands as well as possible. This resulted in the following zip code for this region: 70,71,72,73,74,75,76,81. For the South East region the same approach applied except the region in South-Limburg (61,62,63,64) are excluded, since the often are part of a two day drive in combination with deliveries in eastern Belgium. This resulted in the zip codes: 40,52,53,54,55,56,57,58,59,65,66.

To fairly compare the performance of all regions, the same weekday will be used. This is done to so daily demand per region is not influencing the experiments unnecessary. The weekday that will be used in the experiments is Wednesday. Across all regions the demand on Wednesday is the second largest, only Friday is has more orders. In general, the demand of 2019 is lower than the demand in 2020, so therefore a weekday which has slightly more than average demand on all weekdays represent the current situation best. The individual percentage of a Wednesday at Hoekstra will be used.

To gain more insights in the regional performance, 4 more indicators will be used to value the regions more on their geographical position. The first two being the average distance and travel time from depot to customer, the last two are the average distance and travel time between customers. The exact calculation of these indicators will be stated in Appendix C-10. These will be used in the comparisons in Section 5.2.6.

The region experiment will be performed in the following way. The experiment dependent variables will be used as input for the model. Firstly, the old situation is run in which no customers have a time window. Afterwards, 5 new situations will be executed, in which certain customers do have a time window. These 5 new situations will be averaged and compared with the old situation below the result sheet. Section 5.2.6 will discuss the results between the regions.

5.2.1 Region Amsterdam

The region Amsterdam is the closest city region for Hoekstra from their depot. Besides being the closest one it is also one of the densest ones. The experiment dependent variables are stated in Table 11 below.

Table 11: Variables region Amsterdam

Variable	**Value**
Running time	480 seconds
Region accuracy	62,73%
Individuals percentage	51,46%
Number of customers	68
Capacity	15
Number of vehicles	5
Time window size (customer chosen)	2 hours
Number of new situations tested	5

Table 12: Results region Amsterdam

Experiment	**Number of iterations**	**KPI total cost of transport**	**Percentage achieved time windows**

Old situation	938	-1112,50	-
New situation 1	95	-1310,37	100%
New situation 2	84	-1313,11	100%
New situation 3	84	-1338,08	98,5% (67/68)
New situation 4	88	-1390,15	100%
New situation 5	97	-1420,80	98,5% (67/68)
Average new situation	89,6	-1354,50	99,40%

This region has on average 21,75% more costs in the situation with customer chosen time windows than without. Two of the new situation solutions have violated the time windows by 1 of their visits. In both cases they were 1 minute to early at location, which violating the constraint of the company.

5.2.2 Region The Hague

The region around the city of The Hague is less dense city than Amsterdam. It is further away from Amsterdam which results higher initial costs to arrive in the region itself. The experiment dependent variables are stated in Table 13 below.

Table 13: Variables region The Hague

Variable	Value
Running time	240 seconds
Region accuracy	61,91%
Individuals percentage	51,46%
Number of customers	49
Capacity	15
Number of vehicles	4
Time window size (customer chosen)	2 hours
Number of new situations tested	5

Table 14: Results region The Hague

Experiment	Number of iterations	KPI total cost of transport	Percentage achieved time windows
Old situation	971	-1158,29	-
New situation 1	125	-1303,02	100%
New situation 2	183	-1273,94	100%
New situation 3	164	-1256,20	100%

New situation 4	141	-1317,30	100%
New situation 5	137	-1253,80	97,96% (48/49)
Average new situation	150	-1280,85	99,59%

This region has more costs when performing customer chosen time windows, namely 10,58%. On the other KPI the score of 4 out of the 5 runs of the new situation is 100%, the experiment with violates the time windows does this one time with being 8 minutes too late to complete service within the time window.

5.2.3 Region North East

The first rural region tested is the region of the North-East in the Netherlands. It is the closest rural region from the depot, with the least number of customers. Other experiment dependent variables are shown in Table 15 below.

Table 15: Variables region North East

Variable	**Value**
Running time	120 seconds
Region accuracy	64,54%
Individuals percentage	51,46%
Number of customers	37
Capacity	15
Number of vehicles	3
Time window size (customer chosen)	2 hours
Number of new situations tested	5

Table 16: Results region North East

Experiment	**Number of iterations**	**KPI total cost of transport**	**Percentage achieved time windows**
Old situation	841	-760,78	-
New situation 1	160	-859,50	100%
New situation 2	173	-1129,23	100%
New situation 3	145	-963,82	100%
New situation 4	144	-937,53	100%
New situation 5	137	-985,43	100%
Average new situation	151,8	-975,10	100%

The first rural region shows a 28,17% higher costs value than in the old situation. All of the new solutions do not violate any time windows.

5.2.4 Region East

The Region east is the second rural region in this experiment. It is the region with the highest accuracy and the lowest percentage of individuals of all region. The other details are presented in Table 17 on the next page.

Table 17: Variables region East

Variable	**Value**
Running time	240 seconds
Region accuracy	71,85%
Individuals percentage	51,46%
Number of customers	47
Capacity	15
Number of vehicles	4
Time window size (customer chosen)	2 hours
Number of new situations tested	5

Table 18: Results region East

Experiment	**Number of iterations**	**KPI total cost of transport**	**Percentage achieved time windows**
Old situation	1013	-1077,87	-
New situation 1	152	-1282,64	97,88% (46/47)
New situation 2	196	-1375,89	97,88% (46/47)
New situation 3	153	-1461,00	97,88% (46/47)
New situation 4	158	-1493,41	97,88% (46/47)
New situation 5	176	-1524,36	95,74% (45/47)
Average new situation	167	-1427,46	97,45%

The eastern region has to cope with a 32,43% cost increase when implementing customer chosen time window in this way. In all new situation simulated at least 1-time window is violated. In new situation 5, 2-time windows are violated. However, the violations are within the constraints and are being either 1 or 2 minutes too early or too late.

5.2.5 Region South East

The last region is the third rural region defined and is the most distant region from the depot. With the most customers of all region it will have the most vehicles deployed. All variables are stated in table 19 below.

Table 19: Variables region South East

Variable	Value
Running time	480 seconds
Region accuracy	66,74%
Individuals percentage	51,46%
Number of customers	72
Capacity	15 and 14
Number of vehicles	6
Time window size (customer chosen)	2 hours
Number of new situations tested	5

Table 20: Results region South East (15)

Experiment	Number of iterations	KPI total cost of transport	Percentage achieved time windows
Old situation	660	-1812,39	-
New situation 1	78	-2515,60	97,22% (70 out 72)
New situation 2	77	-2456,44	100%
New situation 3	75	-2447,90	100%
New situation 4	72	-2535,24	98,61% (71 out 72)
New situation 5	84	-2395,74	100%
Average new situation	77,2	-2470,18	99,17%

The result of the biggest and most distant region is a cost increase with 36,29%. In the found solution for the new situation 1 not all time windows are met. One of the 72-time windows is violated with departing 10 minutes late and another one is violated with arriving 1 minute to early. In situation 4 1-time window is violated by being 1 minute to early. This is a score within the constraint and therefore will these solutions not be rejected. With the chosen capacity is this the only schedule to not use all 6 vehicles for this region. Therefore, a second run will be performed in which a capacity of 14 will be used, to find out if the saving of a vehicle in the old situation does affect the region disproportionally, for each of the comparisons the same time window set will be used.

Table 21: Results region South East (14)

Experiment	**Number of iterations**	**KPI total cost of transport**	**Percentage achieved time windows**
Old situation	713	-1997,32	-
New situation 1	60	-2723,24	95,83% (69 out 72)
New situation 2	81	-2469,65	100%
New situation 3	78	-2622,44	98,61% (71 out 72)
New situation 4	70	-2474,64	100%
New situation 5	95	-2370,26	97,22% (70 out 72)
Average new situation	76,8	-2532,05	98,33%

The results of the second run show that the higher capacity was mainly advantageous for the old situation rather than the new situation. The cost increase was 26,77% instead of the 36,29% in the situation with a capacity of 14. With the lower capacity more violations of the time windows happen. These violations are between being served 7 minutes too early and 15 minutes too late. The violations are not outside the constraints to reject the solutions.

Both of the experiments in this region will be used in the analysis in Section 5.1.6 although the 14-capacity experiment for this region gives the most representative image of the costs increase, the main KPI.

5.2.6 Comparative analysis regions

To determine whether or not on how the regions score a graph is made to compare the performance on the KPI total costs (Figure 10). The achieved time window KPI is not plotted since the performance of all regions is very high and the performance of this KPI is also part of the total costs of transport because of the implementation of a penalty when violating. Two things can be seen in the results of these experiments, which will be elaborated upon next.

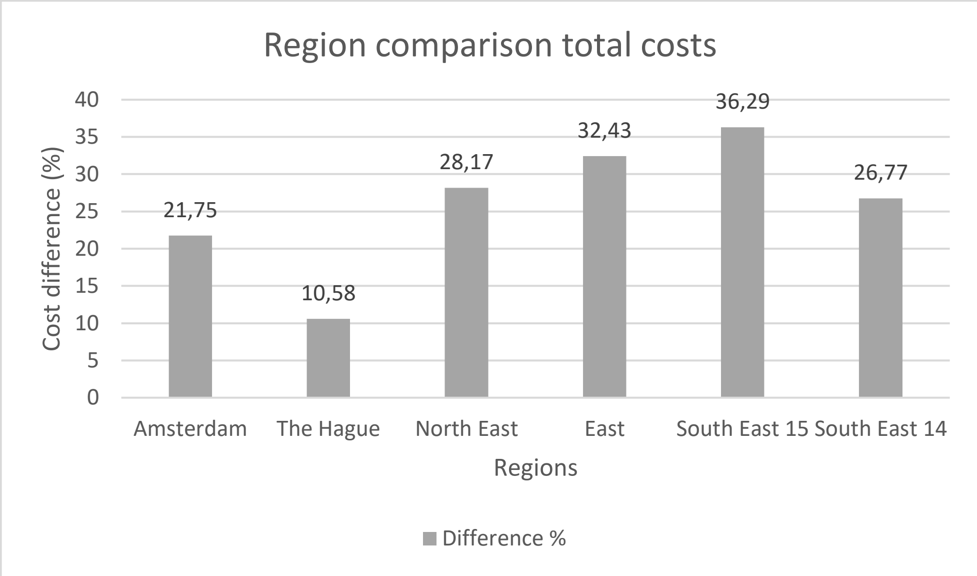

Figure 10: Regional comparison of cost difference

Dense Regions have less costs increase

The first conclusion which can be drawn is that dense regions have a less costs increase when implementing customer chosen time window than region with more distance between customers. This is plotted in Figure 11. This confirms the expectation of the company that denser regions are more beneficial to implement customer chosen time window than rural regions.

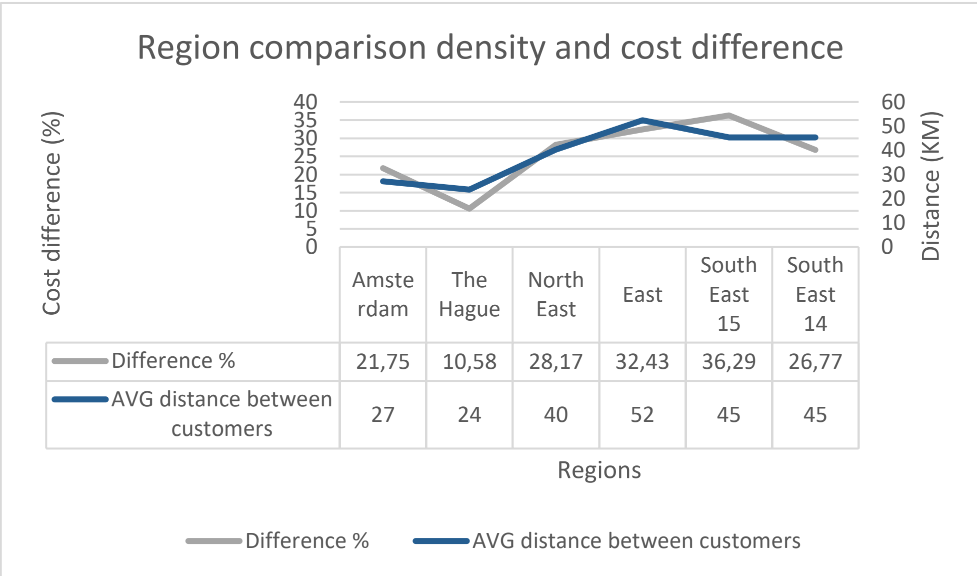

Figure 11: Region density compared with the costs increase

Distant regions do not perform worse than close regions

The second conclusion is that distant regions do not perform worse than region close by the depot in Sneek. That close regions do not perform better can be seen in Figure 12. While The Hague and South East (14) are the most distant regions they do outperform Amsterdam and the Northeast respectively, more than on the fact of the average distance between customer can be assumed.

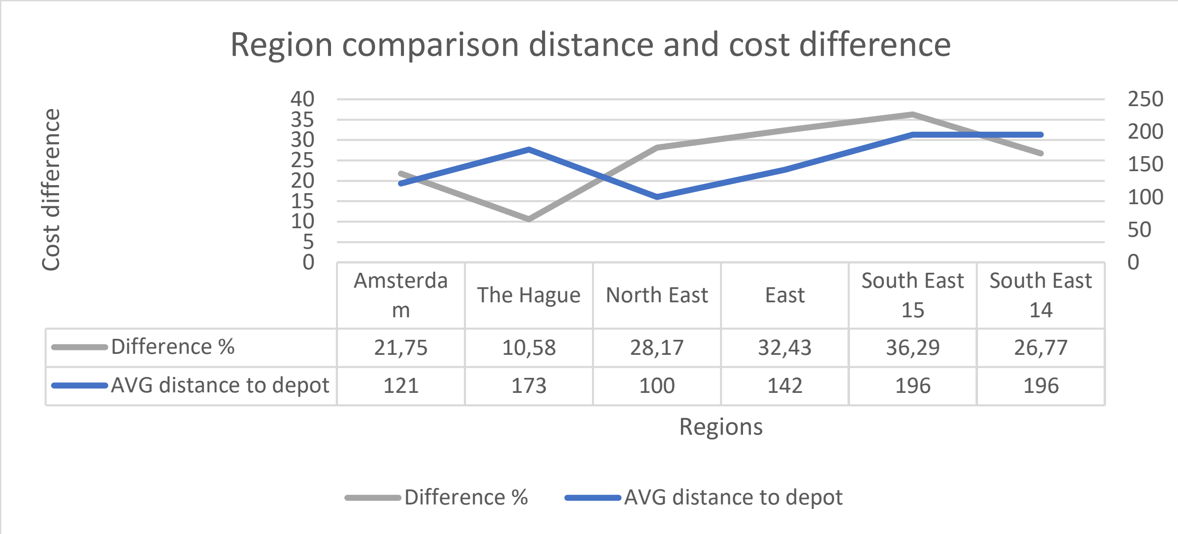

Figure 12: Region distance to depot compared with the cost increase

5.3 Time window size

For the experiment of time windows all the regions will be used. For each of the region the same customers will be chosen as in the region which have a chosen time window.4 time windows will be considered: 1 hour,2 hours, 3 hours and 4-hour time windows. The new situation will be compared with the old situation of the specific region, which is already simulated in Section 5.2. The time windows can be chosen on each hour of which the time window does completely fit, the possibilities will be mentioned per experiment.

5.3.1 1-hour time windows

The first experiment will be that customers can choose time windows of 1 hour. The hour starts only on the exact hour, which will mean that there are 8 options for customers to choose from. The time windows options and other variables are stated in Table 22.

Table 22: Variables 1-hour time windows

Variable	Value
Running times	480, 240, 120, 240, 480
Regions	Amsterdam, The Hague, North East, East, South East (14) respectively.
Individuals percentage	51,46%
Number of customers	Region dependent (68,49,38,47,72)
Capacity	15 and 14
Number of vehicles	Region dependent
Time window size (customer chosen)	1 hour (7-8, 8-9, 9-10, 10-11, 11-12, 12-13, 13-14, 14-15)
Number of new situations tested	1 per region

Table 23: Results 1-hour time windows

Experiment	Number of iterations	KPI total cost of transport	Percentage achieved time windows
Old situation Amsterdam	938	-1112,50	-
New situation Amsterdam	69	-1607,40	97,06% (66/68)
Old situation The Hague	971	-1158,29	-
New situation The Hague	109	-1452,19	97,96% (48/49)
Old situation North East	841	-760,78	-
New situation North East	144	-1067,20	97,37% (37/38)
Old situation East	1013	-1077,87	-
New situation East	151	-1814,91	97,88% (46/47)
Old situation South East (14)	713	-1997,32	-
New situation South East (14)	66	-2778,37	94,44% (68/72)
Old situation accumulated	4476	-6106,76	-
New situation accumulated	539	-8906,16	96,72%

The results show that across all regions the costs increase is 45.84% The time windows are the narrowest of all the test which results in that none of the new situation score 100% on achieving the time windows. In the regions except South East (14), all violations are because of arriving 1 minute to early. In the South East there are more violations than number of customers served within time window constraint allows. However, the solution accepted because 2 out of the 4 violations are being one minute too early and the two large violation are only being 4 and 5 minutes too late, which is not too large to reject the solution.

5.3.2 2-hour time windows

The second experiment will be time windows of 2 hours. Customer can only choose time windows which start on the exact hour which will open up 7 possible time windows. These time windows and other variables are stated in Table 24.

Table 24: Variables 2-hour time windows

Variable	Value
Running times	480, 240, 120, 240, 480
Regions	Amsterdam, The Hague, North East, East, South East (14)
Individuals percentage	51,46%
Number of customers	Region dependent (68,49,38,47,72)
Capacity	15 and 14
Number of vehicles	Region dependent

Time window size (customer chosen)	2 hours (7-9, 8-10, 9-11, 10-12, 11-13, 12-14, 13-15)
Number of new situations tested	1 per region

Table 25: Results 2-hour time windows

Experiment	**Number of iterations**	**KPI total cost of transport**	**Percentage achieved time windows**
Old situation Amsterdam	938	-1112,50	-
New situation Amsterdam	69	-1305,65	100%
Old situation The Hague	971	-1158,29	-
New situation The Hague	108	-1284,11	100%
Old situation North East	841	-760,78	-
New situation North East	165	-912,86	100%
Old situation East	1013	-1077,87	-
New situation East	158	-1309,19	97,88% (46/47)
Old situation South East (14)	713	-1997,32	-
New situation South East (14)	74	-2495,57	95,83% (69/72)
Old situation accumulated	4476	-6106,76	-
New situation accumulated	574	-7307,38	98,54%

The results show that over all region the costs are 19,66% higher than in the old situation. Only 2 regions have violated the time windows. Region East has 1 violation, which is being two minutes to early at a customer. Region South East has 3 violations one of being 12 minutes to late, another one being 6 minutes to late and the last violation is being 3 minutes to late. The violations in South East are still within the constraint, so the solution is valid.

5.3.3 3-hour time windows

The third experiment will look into the possibility for customers to choose from time window of three hours. The time windows start on exact hour, which results in 6 available option to choose from. All the relevant variables are stated in Table 26.

Table 26: Variables 3-hour time windows

Variable	**Value**
Running times	480, 240, 120, 240, 480
Regions	Amsterdam, The Hague, North East, East, South East (14)
Individuals percentage	51,46%

Number of customers	Region dependent (68,49,38,47,72)
Capacity	15 and 14
Number of vehicles	Region dependent
Time window size (customer chosen)	3 hours (7-10, 8-11, 9-12, 10-13, 11-14, 12-15)
Number of new situations tested	1 per region

Table 27: Results 3-hour time windows

Experiment	Number of iterations	KPI total cost of transport	Percentage achieved time windows
Old situation Amsterdam	938	-1112,50	-
New situation Amsterdam	85	-1264,35	100%
Old situation The Hague	971	-1158,29	-
New situation The Hague	302	-1205,11	100%
Old situation North East	841	-760,78	-
New situation North East	186	-853,49	100%
Old situation East	1013	-1077,87	-
New situation East	208	-1215,94	100%
Old situation South East (14)	713	-1997,32	-
New situation South East (14)	93	-2272,08	98,61% (71/72)
Old situation accumulated	4476	-6106,76	-
New situation accumulated	874	-6810,97	99,63%

The results show that the costs are 11,53% higher overall than in the old situation. In this experiment only 1 region violates a time window. In the South East region 1 customers is visited 1 minutes to early.

5.3.4 4-hour time windows

The last experiment to test the time window size will be that customers can choose time windows of 4 hours. The time windows start in this experiment as well on the exact hour which results in 5 available options. These and the other relevant variables are stated in Table 28.

Table 28: Variables 4-hour time windows

Variable	Value
Running times	480, 240, 120, 240, 480
Regions	Amsterdam, The Hague, North East, East, South East (14)

Individuals percentage	51,46%
Number of customers	Region dependent (68,49,38,47,72)
Capacity	15 and 14
Number of vehicles	Region dependent
Time window size (customer chosen)	4 hours (7-11, 8-12, 9-13, 10-14, 11-15)
Number of new situations tested	1 per region

Table 29: Results 4-hour time windows

Experiment	**Number of iterations**	**KPI total cost of transport**	**Percentage achieved time windows**
Old situation Amsterdam	938	-1112,50	-
New situation Amsterdam	201	-1189,65	100%
Old situation The Hague	971	-1158,29	-
New situation The Hague	214	-1185,63	100%
Old situation North East	841	-760,78	-
New situation North East	276	-828,95	100%
Old situation East	1013	-1077,87	-
New situation East	397	-1159,25	100%
Old situation South East (14)	713	-1997,32	-
New situation South East (14)	145	-2093,06	100%
Old situation accumulated	4476	-6106,76	-
New situation accumulated	1233	-6456,54	100%

The results for the 4-hour time windows are that there is a cost increase of 5,73% compared to the old situation. In this experiment no of the large time windows is violated so the score is 100% on that KPI.

5.3.5 Comparative analysis time windows

The results on this experiment show an expect image that when the time windows are smaller the costs increase. However, the relative cost increase of the smallest time windows of 1 hour is 8 times as high as relative cost increase compared with 4-hour time windows. Overall, an exponential pattern is visible in terms of decrease costs difference compared to time window size (Figure 13). The costs increase of 1-hour time windows seems not worth the increase in customer satisfaction, but whether 2-hour time windows is a better option than the 3-hour time windows is dependent if the relative increase of costs with 7,28% can be earned back.

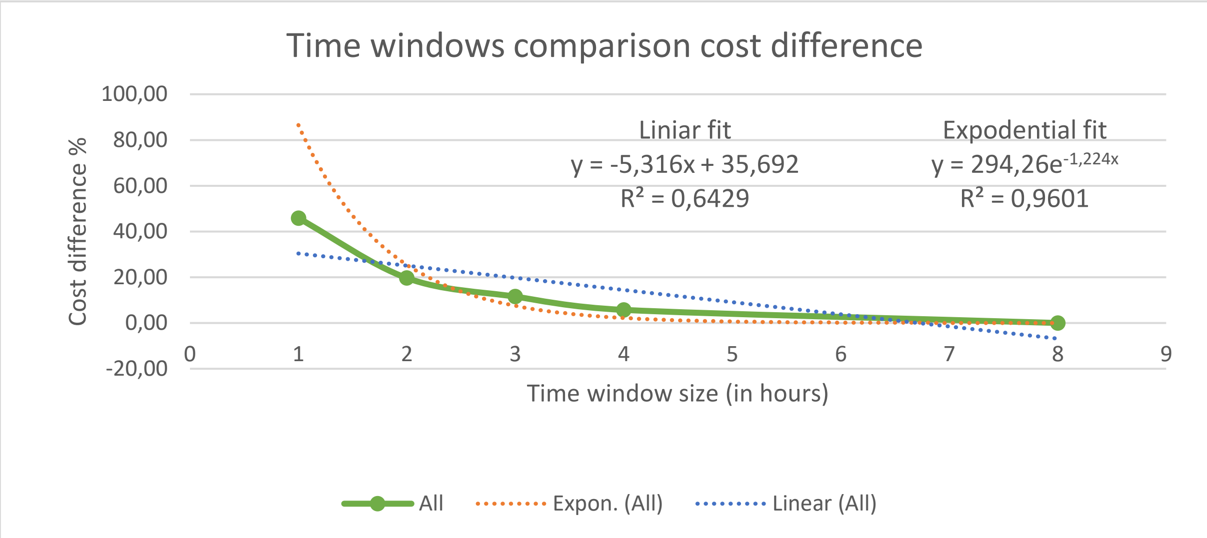

Figure 13: Cost difference compared with the time window size

5.4 Individuals percentage

The last experiment is about the individuals percentage, the number of customers that will be able to choose a time window. In Section 2.3.4 is the current situation discussed about the number of individuals within the customer total. However, this percentage is balanced over all regions during the previous experiments. This is done, because when implementing the time window in Hoekstra not all SME who serve individuals will use this option offered by Hoekstra. Therefore, it is important to test if there is a critical mass of time windows the routes in the different regions can cope with. Therefore, for each region the old situation will be compared with 10% customer chosen time window, 30%, 50% and 70%. Which customer will have the time window will be random. The time window in this experiment will be 2 hours, the same as in the region experiment in Section 5.2.

5.4.1 10% customer chosen time windows

The first experiment will be that only 10% of the customers will have chosen time windows. The number of customers which will have a chosen time window in the experiment will be displayed in Table 30, besides this value other variables will be stated.

Table 30: Variables 10% customer chosen time windows

Variable	**Value**
Running times	480, 240, 120, 240, 480
Regions	Amsterdam, The Hague, North East, East, South East (14)
Individuals percentage	10% (7,5,4,5,7)

Number of customers	Region dependent (68,49,38,47,72)
Capacity	15 and 14
Number of vehicles	Region dependent
Time window size (customer chosen)	2 hours
Number of new situations tested	1 per region

Table 31: Results 10% customer chosen time windows

Experiment	Number of iterations	KPI total cost of transport	Percentage achieved time windows
Old situation Amsterdam	938	-1112,50	-
New situation Amsterdam	251	-1157,23	100%
Old situation The Hague	971	-1158,29	-
New situation The Hague	331	-1162,29	100%
Old situation North East	841	-760,78	-
New situation North East	351	-746,51	100%
Old situation East	1013	-1077,87	-
New situation East	481	-1097,88	100%
Old situation South East (14)	713	-1997,32	-
New situation South East (14)	170	-2058,91	100%
Old situation accumulated	4476	-6106,76	-
New situation accumulated	1587	-6222,26	100%

The results for 10% customer chosen time windows is a cost increase of 1,89%. The test in the north east region shows even a cheaper route is found than in the old situation. In this experiment all time windows of the customers are met.

5.4.2 30% customer chosen time windows

The second experiment will have 30% of the customer with chosen time windows. The amount of chosen time window will be together visible with other variables in Table 32.

Table 32: Variables 30% customer chosen time windows

Variable	Value
Running times	480, 240, 120, 240, 480
Regions	Amsterdam, The Hague, North East, East, South East (14)

Individuals percentage	30% (20,15,11,14,22)
Number of customers	Region dependent (68,49,38,47,72)
Capacity	15 and 14
Number of vehicles	Region dependent
Time window size (customer chosen)	2 hours
Number of new situations tested	1 per region

Table 33: Results 30% customer chosen time windows

Experiment	**Number of iterations**	**KPI total cost of transport**	**Percentage achieved time windows**
Old situation Amsterdam	938	-1112,50	-
New situation Amsterdam	127	-1217,21	100%
Old situation The Hague	971	-1158,29	-
New situation The Hague	205	-1223,54	95,92% (47/49)
Old situation North East	841	-760,78	-
New situation North East	215	-836,95	100%
Old situation East	1013	-1077,87	-
New situation East	194	-1307,98	100%
Old situation South East (14)	713	-1997,32	-
New situation South East (14)	110	-2293,25	97,22% (70/72)
Old situation accumulated	4476	-6106,76	-
New situation accumulated	851	-6878,80	98,54%

30% customer chosen time windows results in a cost increase of 12,64%. In 2 regions 2 customers did not receive their delivery in the time windows. For the region The Hague 2 customers got served 15 and 16 minutes late. In the South East the 2 customers are served 26 and 17 minutes late.

5.4.3 50% customer chosen time windows

The third experiment will have 50% of the customer with chosen time windows. The amount of chosen time window will be together visible with other variables in Table 34.

Table 34: Variables 50% customer chosen time windows

Variable	**Value**
Running times	480, 240, 120, 240, 480

Regions	Amsterdam, The Hague, North East, East, South East (14)
Individuals percentage	50% (34,25,19,24,36)
Number of customers	Region dependent (68,49,38,47,72)
Capacity	15 and 14
Number of vehicles	Region dependent
Time window size (customer chosen)	2 hours
Number of new situations tested	1 per region

Table 35: Results 50% customer chosen time windows

Experiment	**Number of iterations**	**KPI total cost of transport**	**Percentage achieved time windows**
Old situation Amsterdam	938	-1112,50	-
New situation Amsterdam	86	-1300,48	100%
Old situation The Hague	971	-1158,29	-
New situation The Hague	133	-1277,71	100%
Old situation North East	841	-760,78	-
New situation North East	181	-964,88	97,37% (37/38)
Old situation East	1013	-1077,87	-
New situation East	179	-1391,63	97,88% (46/47)
Old situation South East (14)	713	-1997,32	-
New situation South East (14)	81	-2505,40	98,61% (71/72)
Old situation accumulated	4476	-6106,76	-
New situation accumulated	660	-7440,10	98,91%

According to this experiment if half of the customer get to choose a time window of two hours the costs increase with 21,83%. For 1 customer in three regions the delivery is not within the window. 1 customer got visited 1 minute too early in the North East. In the East, 1 customer is served 1 minute too late and in the south east 1 customer 2 minutes late.

5.4.4 70% customer chosen time windows

The last experiment will have 70% of the customer with chosen time windows. The amount of chosen time window will be together visible with other variables in Table 36.

Table 36: Variables 70% customer chosen time windows

Variable	**Value**

Running times	480, 240, 120, 240, 480
Regions	Amsterdam, The Hague, North East, East, South East (14)
Individuals percentage	70% (48,34,27,33,50)
Number of customers	Region dependent (68,49,38,47,72)
Capacity	15 and 14
Number of vehicles	Region dependent
Time window size (customer chosen)	2 hours
Number of new situations tested	1 per region

Table 37: Results 70% customer chosen time windows

Experiment	Number of iterations	KPI total cost of transport	Percentage achieved time windows
Old situation Amsterdam	938	-1112,50	-
New situation Amsterdam	90	-1390,29	100%
Old situation The Hague	971	-1158,29	-
New situation The Hague	159	-1339,04	97,96% (48/49)
Old situation North East	841	-760,78	-
New situation North East	185	-989,43	100%
Old situation East	1013	-1077,87	-
New situation East	197	-1547,31	100%
Old situation South East (14)	713	-1997,32	-
New situation South East (14)	77	-2671,54	100%
Old situation accumulated	4476	-6106,76	-
New situation accumulated	708	-7937,61	99,64%

The last experiment results show a cost increase of 29,98% compared to the old situation. The violations of time windows were very low with only 1 violated in the region The Hague, the vehicle arrived there at a customer 1 minute too early.

5.3.5 Comparative analysis individuals percentage

The results of the comparison of individuals percentage show a linear pattern with costs increase and the percentage of customers who choose a time window (Figure 14). When looking into the regions the same conclusions can be drawn as in Section 5.1.6. The regions with close customer distance can have more customers chosen time windows for the same costs increase (Figure 15). For example, the region Amsterdam can have 70% customer chosen time windows for 24,97% cost increase whereas the region North East has the 26,83% costs increase for 50% customer chosen time windows.

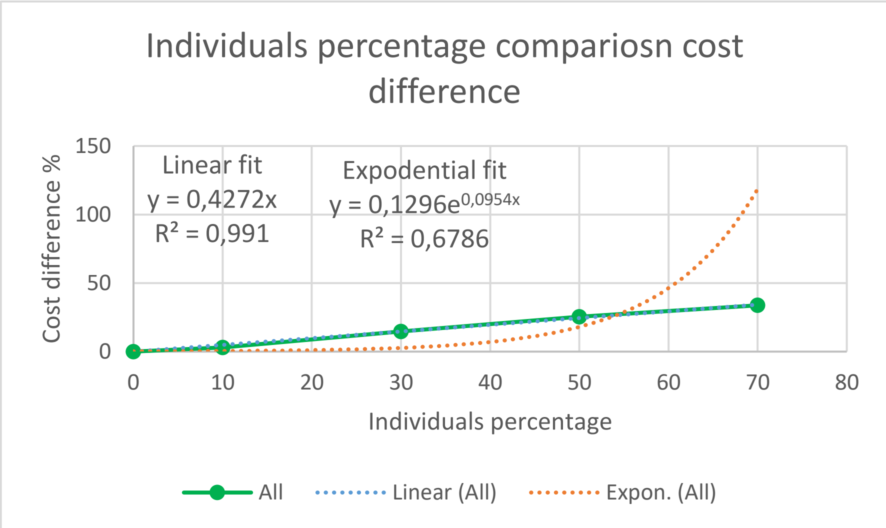

Figure 14: Cost difference compared with the individuals percentage (all regions)

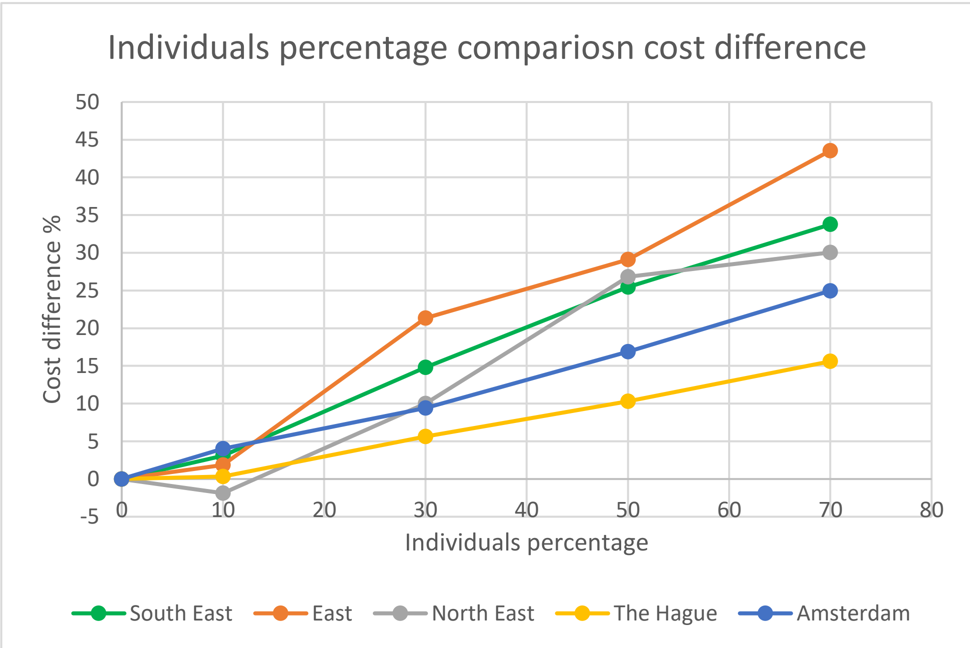

Figure 15: Cost difference compared with the individuals percentage (per region)

5.4 Comparative analysis

In this section, all the combinations of time windows and individuals percentage will be analysed. This will be done in the following way. The costs of all combinations with time window sizes and individuals percentages will be listed (Table 38). With these values, a comparison cannot yet be made because, the benefits of having smaller time windows and more chosen time windows are not accounted for in the cost KPI. Therefore, a formula is constructed with company approval to evaluate each scenario fairly.

$$Benefits\ formula = \ C + N \times A \ \times \ 2^{4-T}$$

The formula is build op out of the following variables. C: Costs of the routing expressed as in Table 38. N: Number of customers who achieved a time window. A: Additional payment by the customer for the ability to choose their own time window. The value of this will be 10% of the costs per customer in the old situation (6106,76 / 274 * 0,1 = 2,23). The last term is the exponential function with variable T, which stands for the time window size in hours. The values of this will be as follows. For 1-hour time windows, the value will be 8; For 2 hours 4; 3 hours 2 and 4-hour time windows will be 1. This is according to the trend seen in Section 5.3.5. This would mean for example when a customer signs on a 2-hour time window, they pay 140% of the costs that would be charged in the old situation. This would not necessarily mean that the price for transport increase with 40%, because the revenue is 100% on transport costs in reality. The values of Benefits formula will be shown in Table 39.

Table 38: Results KPIs for each time window size and individuals percentage

Time window size/Individuals percentage	10%	30%	50%	70%
1 hour	-6205,95/ 100% (1462)	-7598,37/ 98,91% (744)	-8683,93/ 97,91% (743)	-10804,74/ 93,43% (912)*
2 hours	-6222,26/ 100% (1587)	-6878,80/ 98,54% (851)	-7440,10/ 98,91% (660)	-7937,61/ 99,64% (708)
3 hours	-6227,32 / 100% (3577)	-6530,86/ 99,64% (1653)	-6940,66/ 98,91% (1114)	-7187,48/ 100% (1101)
4 hours	-6174,35 / 100% (4056)	-6318,87/ 99,27% (2366)	-6492,50 / 100% (1846)	-6562,42/ 98,91% (1427)

*Percentage achieved time windows constraint in region South East could not be satisfied.

Table 39: Costs when benefits formula is applied

Time window size/Individuals percentage	10% (28)	30% (82)	50% (138)	70% (192)
1 hour	-5706,43	-6135,49	-6222,01	-7379,46
2 hours	-5972,50	-6147,36	-6209,14	-6224,97
3 hours	-6102,44	-6165,14	-6325,18	-6331,16
4 hours	-6111,91	-6136,01	-6184,76	-6134,26

Relative to the old situation with 6106,76 costs this would give the following table (Table 40). These percentages indicate how beneficial the policy is compared with the old situation if the additional costs are (partly) paid by the customers. A negative percentage indicates that profit can be made, a positive number indicates that the costs despite compensation are still larger than in the old situation. The following conclusion can be drawn out of this analysis.

Table 40: Comparison benefits formula with old situation results

Time window size/Individuals percentage	10%	30%	50%	70%
1 hour	-6,56%	0,47%	1,89%	20,84%
2 hours	-2,20%	0,66%	1,68%	1,94%
3 hours	-0,07%	0,96%	3,58%	3,67%
4 hours	-0,08%	0,48%	1,28%	0,45%

Extreme values cause the most cost differences

When the values of Table 40 are plotted in Figure 16 and 17 then it becomes clear that certain time window size or individuals percentage cause far more fluctuation in cost difference than others. With 1-hour time windows a lot more service will be achieved which can be profitable at low individuals percentages. However, when the number becomes too high the schedule cannot be made efficiently anymore and the costs increase more than the additional income generated (Figure 16). This can be clearly seen in the 1-hour time windows with 70% individuals percentage. In this scenario the demand of very narrow time window is too high, resulting in difficult and inefficient routing. In general, the fluctuation between the different individuals percentage is lower when the time window size is larger.

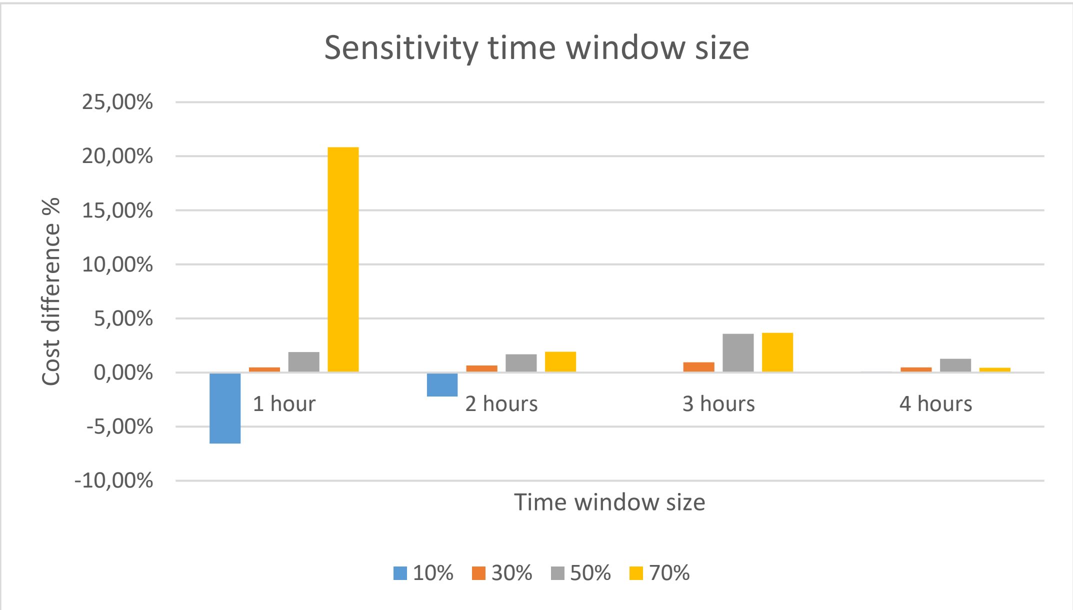

Figure 16: Cost difference per time window size compared with the individuals percentage

Something similar can be seen in Figure 17 where the individuals percentages are compared with each other. The two extreme values of 70% and in lesser degree the 10% chosen time windows are way more sensitive for the time window size. The 70% individuals percentage has an absolute costs difference of 20,39%, whereas 30% only has an absolute difference of 0,49%.

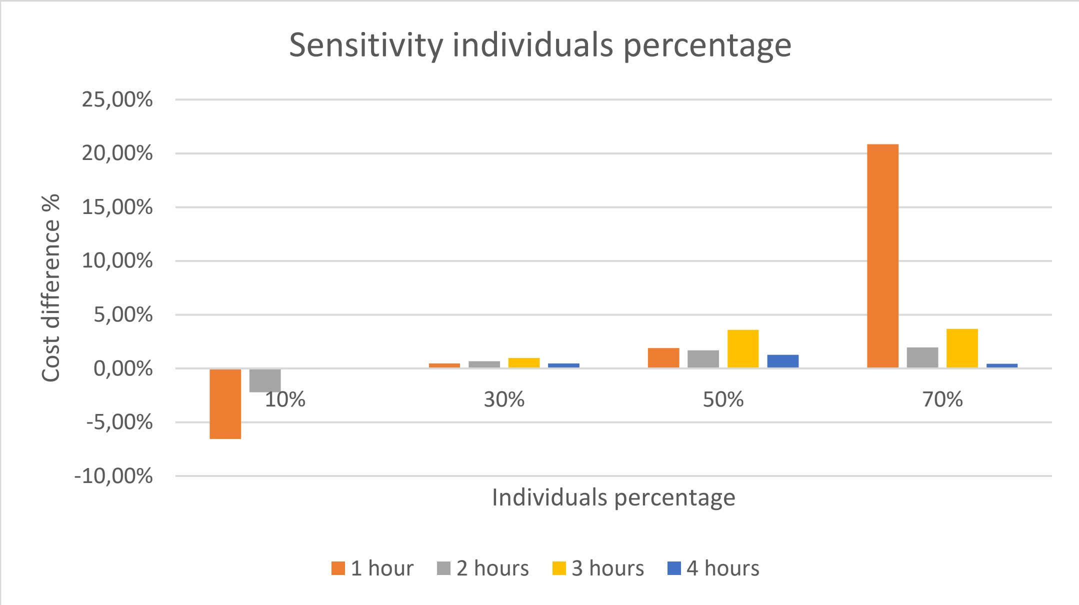

Figure 17: Cost difference per individuals percentage compared with time window size

No restriction or severe restrictions makes solving easier

When looking into the number of iterations made to calculate the total costs of transport (Table 38), a trend can be spotted in terms of how difficult it is to find the optimal solution. When the individuals percentages are lower and the time windows size, solving the problem is easier (Figure 18). The more severe restrictions of in the upper right quadrant of Table 38 show that the 1-hour time windows with 70% chosen time windows has found more solutions in total than the other, less restricted cases. It can also be seen in Figure 18 where the 1 and 2-hour time window show an upwards trend from 50% onwards. This can be explained by the fact that when restricting the possible solutions more, the decision between improvements is less difficult. For example, when two customers are close located to each other and in the severe case customer A has the time window 10:00-11:00 and customer B 11:00-12:00, then route between is always from A to B. However, when customer A has no time window, then the order route can go from A to B or from B to A or even from A to C to B. In the last situations more, difficult evaluations have to be done to find improvement, which cause a lower number of generated solutions within the given computation times.

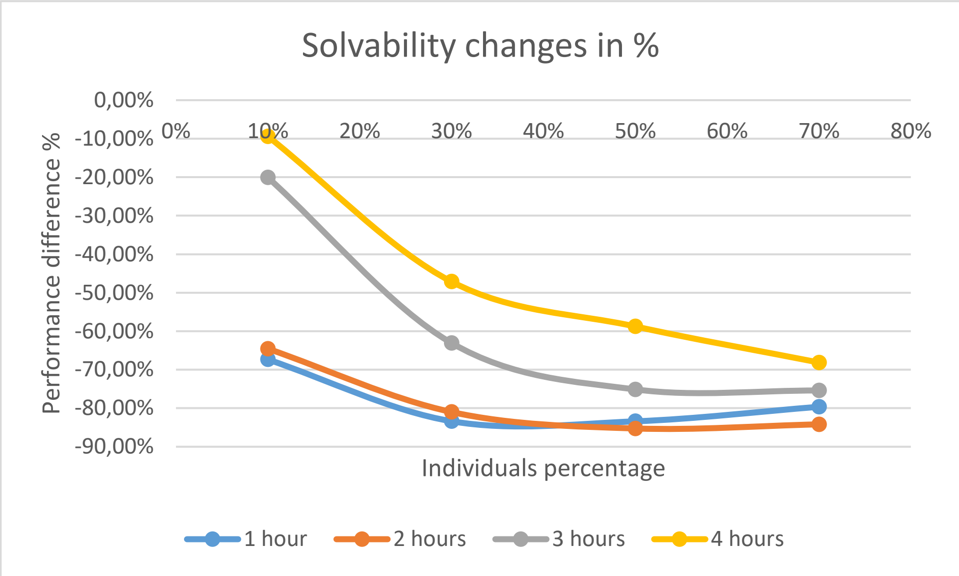

Figure 18: Decrease in performance % in comparison with the old situation

5.5 Validation

In this section the validation of the research will be discussed. After presenting the results to the management, a validation interview has been conducted which discussed the following topics: assumptions, constraints, experiments and conclusions. There were only two topics which require further explanation on the impact in reality. Firstly, the driving time limit (Section 2.5.3) is discussed in Section 5.5.1. Secondly, the sensitivity of the benefits formula (Section 5.4) is discussed in Section 5.5.2.

5.5.1 Driving time limit

The driving time limit is a constraint to ensure that the law on maximum driving time is not violated (Section 2.5.3). The value of the constraint is set to 10 hours, the maximum stated in the law. However, the models are only run on the delivery route and not on the pickup route. This is done because the demand on pickups is stochastic. Consequently, the time spend on driving back to the depot is not taken into account. So therefore, an analysis on the impact of the possible route back is requested by the company.

The driving time limit is reached way earlier in distant regions than in close region. When a vehicle has to drive 2 hours to a region and back, 6 hours remain for driving between customers. For region on 1-hour distance, 8 hours remain which allows way more driving time between customers. For investigating the consequences on driving time limit. The region South East is investigated first, since it is the most distant and has also second largest driving time between customers (Table 41).

Table 41: Average distance to depot and between customers per region

Region	**AVG travel time to depot (min)**	**AVG travel time between customers (min)**
Amsterdam	85,79	31,1
The Hague	125,6	32,2
North East	72,2	39,4
East	107,1	50,5
South East	135,7	43,0

To investigate whether the driving time limit would be violated because of the driving back to the depot, each simulation of the new situation in South East from the comparative analysis in Section 5.4 (Table 38) is checked on the total driving time. The results are summarized in Table 42.

Table 42: Number of vehicles categorised on total driving time

Total driving time	**Number of vehicles**
Less than 6 hours	76
Between 6 and 7 hours	14
Between 7-8 hours	6
More than 8 hours	0

The results of Table 42 show that no vehicles will break the driving time limit without doubt. In the category 7-8 hours driving time it is doubtful if the vehicle will reach the depot with an average driving time of 2 hours and 15 minutes to the depot. Therefore, a more in-depth analysis on those 6 routes is necessary.

The possible violations of this restrictions are in 2 of the experiments. 5 of the 6 are in the scenario of 70% customer chosen time windows with 1-hour time windows. This experiment was in Section 5.4 the only experiment in which the percentage achieved time windows constraint could not be satisfied because of the complexity of serving 70% of the customers in time windows of 1 hour. Therefore, for this solution it is acceptable that driving time limits maybe violated, when performing a pickup route.

The other violation is also in an experiment with 1-hour time windows, but with only 30% customer chosen time windows. When looking into this scenario, the driving time of the route is 7 hours and 8 minutes. On average, there should be enough time to reach Sneek in 2:52 minutes. When investigating the distance from the last stop to Sneek, the travel time is only 113 minutes (1:53). For this specific route a detour to a SME for pickup of 59 minutes is still possible to not violate the driving time limit. So therefore, this possible violation can only happen if a large detour is needed for the pickup, whilst 5 other vehicles are also present in the region.

In the end we can conclude that driving time limit is not a treat to the violation of the 10-hour limit when the pickup route is taken into account. Only a few routes have the risk of violating this limit in reality in the most likely region it to happen. All of the possible risks of violation are explainable and no rerun of simulations with a different limit seems necessary, since the scenario of 70% chosen time windows of 1 hour is hardly plausible already.

5.5.2 Sensitivity benefits formula

The benefits formula proposed in Section 5.4 was the second topic which required some additional attention by the company. Hoekstra requested to check the sensitivity on the exponential part of the formula which used a base value of 2. The result of this base value is that 1-hour time windows require 8 times more additional payment than 4-hour time windows. The company would like to see the scenario in which 1-hour time windows are 10 times as expensive as 4-hour time windows. Before comparing the alternate benefits formula with the old one, the new value of the ground number has to be determined. Therefore, a number X to the power needs to equal 10 instead of 8 in the old scenario. Which results in that X equals 2,15 ($\sqrt[3]{10}$), instead of 2 in the old formula. The changes in comparison are shown in Figures 19 and 20, Figure 21 shows the relative difference between the old and alternate benefits formula.

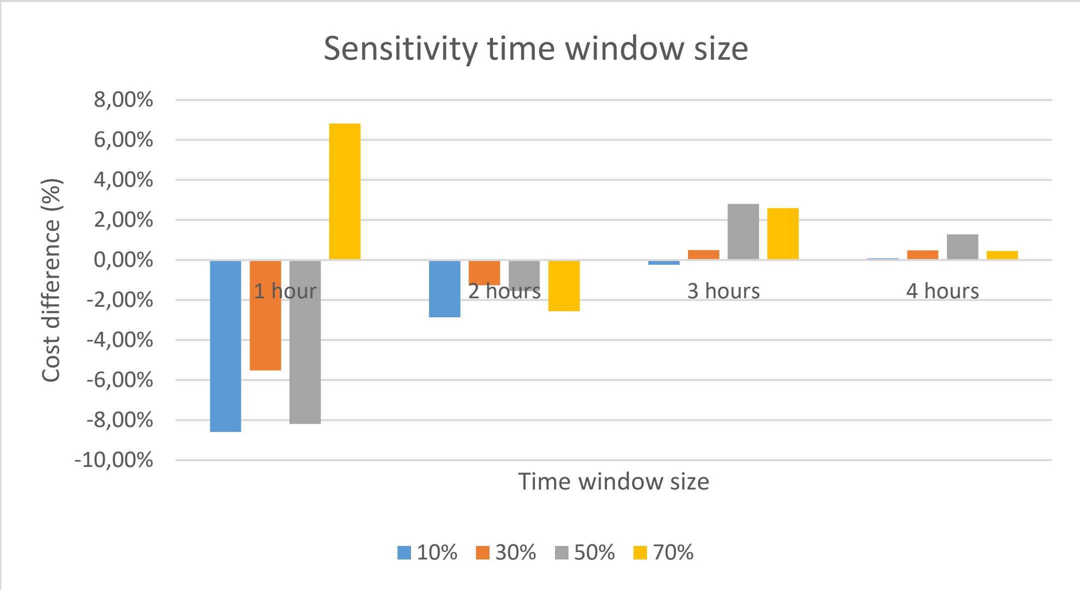

Figure 19: Cost difference per time window size compared with the individuals percentage

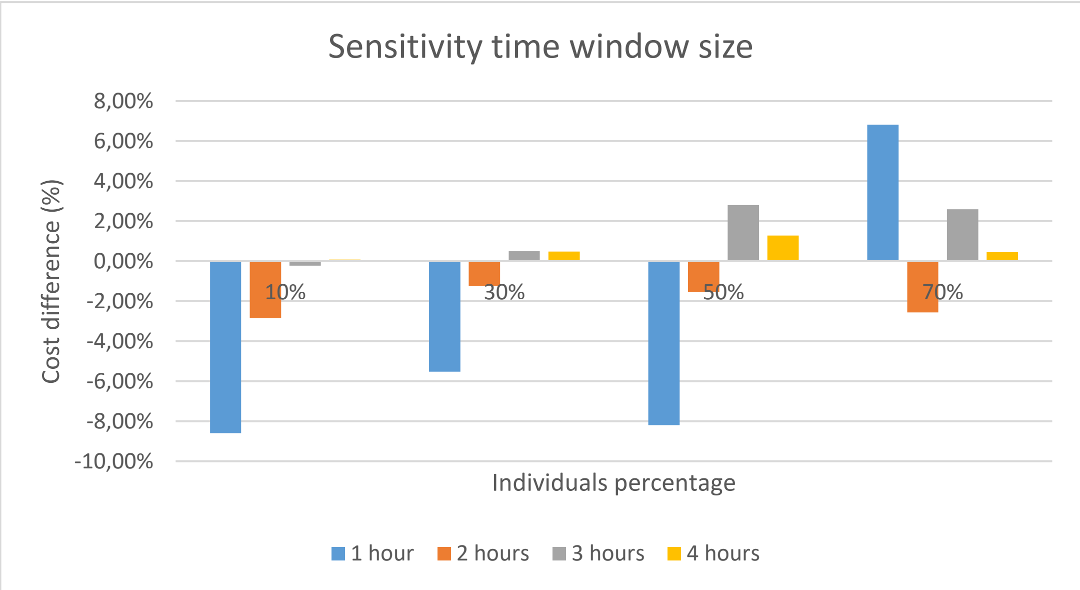

Figure 20: Cost difference per individuals percentage compared with the time window size

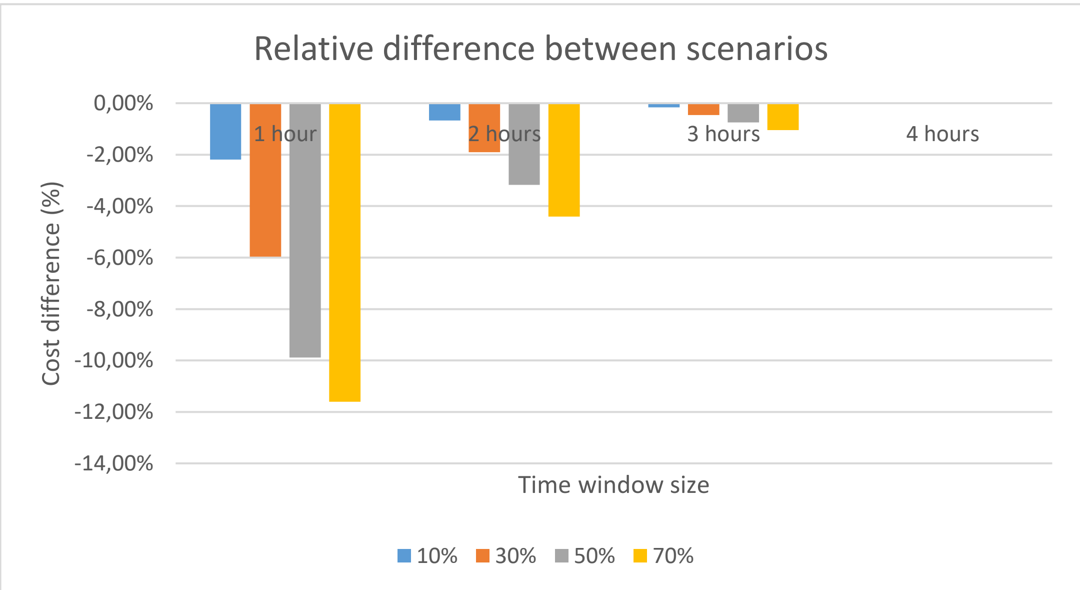

Figure 21: Relative cost difference between the alternate and old benefits formula

The difference in performance are most visible in the 1-hour and 2-hour time windows (Figure 20). This is explained by the fact that the difference in multiplication factor for the time window size is larger for the small-time windows than for the large time windows (Table 43). The effect of this change is logically that the smaller time windows are performing better than with the old benefits formula. From this benefits formula the conclusion would still be that the extreme values cause the most cost difference, in this mainly the 1-hour time window. This time window seems under this formula consistently beneficial until the number of chosen time window becomes too high to make plausible routes, resulting in a cost increase, instead of cost decrease with lower number of chosen time windows.

Table 43: Multiplication factor in benefits formula for the time window size

Time window size	Old benefits formula	Alternate benefits formula
1 hour	8	10
2 hours	4	4,64
3 hours	2	2,15
4 hours	1	1

The 2-hour time window seems to benefit very consistently from this change in multiplication factor. Originally, the 2-hour time window performed stable between -3% and 3% cost difference compared with no time windows. In this alternate scenario the 2-hour time window performs consistently below 0%, which indicates profit could be made if customers are willing to pay in this case 146% of the transportation price in the old situation. The consistency of beneficial 2-hour time window size on every amount of customer chosen time windows seems the best option for Hoekstra when able to charge this to their customers.

5.6 Summary

In this chapter, multiple experiments are performed together with an analysis of each experiment and a general analysis on all possible cases between experiments. Lastly, the validation interview is discussed. The experiments resulted in multiple findings: the most important ones being that dense region are beneficial for customer chosen time windows. Time window costs increase exponential when the time window size is decreased, resulting in the smallest time window of 1 hour is sensitive to changes in the number of customers. The individuals percentage shows a linear trend with a cost increase. The last conclusion from the experiments is that no or severe restrictions make scheduling easier. The validation shows that driving time limits are not violated when pick up routes are taken into account and that when the base increases the small time window profit the most and the two hour time window becomes the best option for Hoekstra to implement.

6 Conclusion

The final chapter presents all the findings of this study and how Hoekstra can use these findings . The first section will discuss how this research is perceived by the company. In Section 6.2, the answers on the different research questions of Section 1.6.2 will be used to answering the main research question described in Section 1.6.1. Afterwards, recommendations for the company will be stated and explained based upon the findings in this research. The last section discusses further research, which can be performed at Hoekstra.

Before the conclusion and recommendations can be drawn, it is important to understand that the conclusions are based on experiments as described in Chapter 5. The reality at Hoekstra is far more complex than any model can describe. Therefore, the results may not be met as in the conclusion described when it is implemented in reality.

6.1 Discussion

In this section will be other points will be discussed which may not be proven in this study or are related to the contribution in practice for other companies.

Firstly, other benefits may occur when implementing customer chosen time windows. The most intuitive one being that the number of failed deliveries will possibly drop. This due to the fact that customers are more likely to be add home at a chosen time window than an assigned one. Therefore, the costs of failed deliveries that have to be rescheduled the next day will likely decrease.

Secondly, it is important to know that time window choosing option does not have to replace other services Hoekstra provides at this moment for their customers. For example, when customers can choose for time windows of 4 hours, it is still possible to send a mail with the 2-hour time window they are assigned to and to receive a text message 30 minutes before delivery. Whether or not this may still be necessary is another question, especially if the time window size is 2 or 3 hours.

Lastly, the application of this research on other companies will be discussed. However, the models and the input data is fully adapted to the situation at Hoekstra, Other companies can also use the knowledge of VRPTW to find out whether or not time windows chosen by customer can be (partly) implemented in their scheduling. Therefore, the model of Erdoğan (2017) can be used or another tool has to be found or created. Before modelling, first all input data has to be identified and determined for the specific situation at the company. This has to be done with caution; otherwise, the results may be too positive or too negative for the possibilities for customer preferred time windows.

6.2 Conclusion

Throughout the whole research, the answer to the different research questions will help to answer the main research question:

"How can Hoekstra implement customer preferred time window scheduling without decreasing profitability?"

Therefore, the sub research questions will be answered. Firstly, the current situation can be concluded too complex for modelling in this research and therefore a more theoretical approach is chosen, for enabling experimentation options.

From literature, we could conclude that soft time windows can be used, which is the option preferred by Hoekstra. Another source provided the insight in the usage of partly chosen time windows, a solution approach which will be closest to a new reality at Hoekstra. After literature analysis, the best suited solution method for Hoekstra is a metaheuristic.

Chapter 4, concludes that a model for the situation at Hoekstra is an adaptation of the spreadsheet solver from Erdoğan (2017). From the conceptual model, assumptions are needed for modelling Hoekstra's situation. Hoekstra's data is successfully implemented in the solver for experimenting.

The experiments performed to find are covering the geographical region, from which can be concluded that dense regions are more suitable for customer chosen time windows. Experiments on the time window size show an exponential relation between the time window size and the cost difference with no time windows, whereas the number of chosen time windows has a linear relation with the cost difference.

For answering the main research question, the key is in the part '… **without decreasing profitability?'** The experiments have shown that costs will increase when implementing customer chosen time windows. This is because, when you restrict your schedules, your costs will not decrease; in fact, they will be higher in all situations (Chapter 5). However, when the additional service is priced correctly then this implementation is possible to gain profit or to at least be equal profitable. So, Hoekstra can implement customer chosen time windows when the time windows are charged.

6.3 Recommendations

For the implementation of the customer chosen time windows, some recommendations can be stated out of the result and conclusion in this research. These will be listed and discussed below.

Start implementation with small number of customers

In the conclusion we have stated that a complex situation will cause that the time windows will not be profitable anymore, therefore it is recommendable to start the implementation on a small group of customers and not open up subscription of time windows directly on all individuals. A test group should be selected on the customers of one or a few SMEs, preferably with most of their customers in a dense region. The sensitivity of individuals percentage larger than 50% becomes instable and therefore starting large can be risky. In addition, how the increased difficulty will affect the scheduling department at Hoekstra is unknown. Therefore, when, customer chosen time windows is directly implemented the increased difficulty in the schedule may cause problems with later finishing the schedules.

Choose a time window size larger than 1 hour

From the experiments, it seems that 1-hour time windows can achieve a lot of additional profit for the company especially if used for the small instance as recommended above. However, in large instances, the additional revenue does not outweigh the increased total transport costs and it is only viable with the assumption that the customers are willing to pay 8 times as much extra for time windows of 4 hours or 2 times as much extra for a time window of 2 hours. Since these values are based upon the additional costs for smaller time windows it is not sure if that is the case. Therefore, further research (Section 6.3) is necessary, but time windows of 1 hour seem not appropriate in the case of Hoekstra.

Conduct further research

This is not a recommendation often given in a research project, however the limited scope and time available for this research causes that further research can be useful. These limitations caused that not all aspects which could be important for Hoekstra are researched. Therefore, it is important to further investigate customer chosen time windows, before implementing it at larger scales. All recommended research for Hoekstra will be stated in Section 6.4.

6.4 Further research

This research has covered the theoretical side of the implementation of customer chosen time windows at Hoekstra. However, more research can or even should be performed before the implementation on large scale should start. Therefore, further research is listed below.

Time window (size) demand distribution

One of the assumption is this research was that the demand for time windows by individuals is uniform, this is mainly done because when in practice the demand exceeds the capacity of that time window the company could block the time window, which results that the spread could be equalized over the day. The research suggested is to find the demand distribution of customers together with the size of the time windows they would like to see. These results could be implemented in the assignment of time windows to investigate in which degree another demand distribution affects the profitability of customer preferred time window scheduling.

Time window charge

The second advised research for the company is how Hoekstra want to charge the additional costs for this system to the customers. The implementation of customer chosen time windows has additional costs in every instance, someone has to pay for this feature. One option is that customers who choose their time window will pay X euro for this service. Otherwise, the general costs of transport have to be raised, or the margin will be lower. For time window charge, a research is necessary to find a fair price for the chosen time window size, such that this can be implemented for all SMEs who wants their customers to be able to choose their time window.

Large-scale model with pick up route

In this research, the model used was suitable on a regional scale. The unknown demand for pickups when the scheduling caused that pick up routes have not been included. However, customer chosen time windows may affect the times on how late pick up routes can start and may cause driving/working time limit problems. Another problem which may be caused if customers prefer afternoon scheduling is that the pickup route will start late. To check whether this may be a problem, a new research has to be conducted with another scope with another model, which is suitable for large-scale vehicle routing problems. The results and methods of this research could be the start of that large research.

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Appendices

Appendix A: Region accuracy

For the analysation of the region, the dashboard on the page 73 is used.

The main table used for the determination of the accuracy for a region is the table in the upper right corner. On the x-axis is the postal code presented in two digits. The y-axis gives the trip numbers (unique identification number for a route of a vehicle) of vehicle, which perform at least one unloading action in the selection. The values represent the number of unloading actions done. The green colour indicates postal codes within in the selected region.

Out of this information the table can be constructed which determines the region accuracy. The table in the bottom left displays on the y-axis the postal code (2) and on the y-axis the inner selection and outer selection. The values are number of unloading actions performed within the postal code as percentage of the total number of unloading actions. The left value of the top row represents the percentage of unloading actions performed within the selection (region accuracy), whereas the right value the number outside the selection.

The other table (top left) and graph (bottom right) present additional information. The top left table shows two values. The left number is the number of selected postal codes. The right number is the number of different postal codes, which have at least one unloading action of the vehicles in the main table. This value indicates the spread of the locations, which can also be visited by vehicles visiting the selection. If the number is low than the selection is not often combined with other postal codes within the route. The graph shows the number of unloading actions per hour of the vehicles visiting the selected postal codes. In colours is differentiated between postal codes within and outside the selection. The graph is an indication of how the region is defined. If the curve looks normal distributed skewed to the left than it means that the trips within the region on average follow the standard routing within Hoekstra. First, they drive to the region to arrive at around 08:00 at their first location. Some of the first deliveries will be done before 8 o'clock so the graph starts low. The hours 8, 9 and 10 are the peak hours. In these hours the trucks only empty their vehicles and the unload action are at their peak. Afterwards the first vehicles are moving towards pickups at SMEs and the number of unload action almost reach zero after 16:00. The other scenario is that the curve resembles a uniform distribution within the region. This can indicate two things. The region is close to Sneek, this is because trips start later in the morning or even during the day, which cause deliveries to be more spread out, since driving times are longer because the population density is lower. Secondly, because deliveries can be done at the end of a certain route. The other possibility is that the region is too far away of Sneek that the route is done in multiple days, because of the driving time limitations. This happens for example with regions in the south of the Netherlands. Then deliveries will start much later during the day and will continue during the afternoon and then start again in the morning.

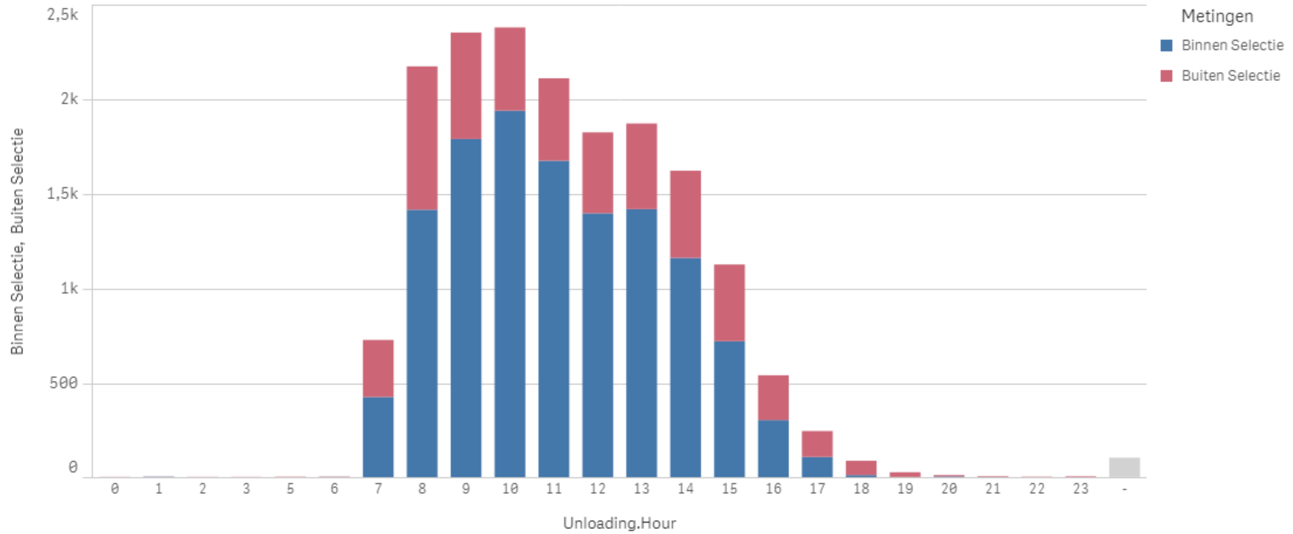
OrderTrip.Unloa... Nederland | Year 2019 | Postcode.2 8 van 98 | Selecties | Inzichten

My new sheet (2)

# Geselecteerde postcodes	# Postcodes
8	81

TripNumber \ Postcode.2	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
Totals	**17**	**49**	**118**	**195**	**665**	**1265**	**1020**	**884**	**2274**	**2553**	**2005**	**1416**	**435**	**22**	**176**	**1174**	**951**	**253**	**129**	**35**	**12**
2224270000	-	-	-	-	-	-	-	-	-	4	2	2	-	-	-	-	2	-	-	-	-
2224280000	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	1	-	-	-	-
2224290000	-	-	-	-	1	3	2	2	-	2	-	-	-	-	-	-	-	-	-	-	-
2224960000	-	-	-	-	-	-	-	-	-	7	6	4	-	-	-	-	-	-	-	-	-
2224980000	-	-	-	-	1	5	1	2	-	2	-	-	-	-	-	2	1	-	-	-	-
2225150000	-	-	-	7	4	-	-	-	6	-	-	-	-	-	-	1	-	-	-	-	-
2225240000	-	-	-	-	-	-	-	-	-	-	-	4	4	-	3	-	-	-	-	-	-
2225610000	-	-	-	-	-	-	-	-	-	-	8	8	-	-	-	-	-	-	-	-	-
2225630000	-	-	-	-	-	-	-	1	11	5	-	-	-	-	-	-	2	-	-	-	-
2225690000	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
2225890000	-	-	-	3	3	-	-	1	-	6	-	-	-	-	-	-	-	-	-	-	-
2225900000	-	-	-	-	2	5	5	1	1	-	-	-	-	-	-	-	-	-	-	-	-
2225920000	-	-	-	-	-	-	-	-	-	-	-	1	8	-	4	-	-	-	-	-	-
2226080000	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	1	-	-	-
2226160000	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
2226320000	-	-	-	-	-	-	-	-	-	5	2	2	1	-	-	2	2	-	-	-	-
2226330000	-	-	-	-	-	-	-	-	7	3	-	-	-	-	-	-	2	-	-	-	-

Postcode.2	Binnen Selectie	Buiten Selectie
Totals	**71,85%**	**28,15%**
74	14,83%	0,00%
73	13,21%	0,00%
75	11,65%	0,00%
76	8,23%	0,00%
70	7,35%	0,00%
71	5,93%	0,00%
81	5,52%	0,00%
72	5,14%	0,00%
80	0,00%	6,82%
86	0,00%	3,89%
69	0,00%	3,86%
77	0,00%	2,53%
82	0,00%	1,47%
38	0,00%	1,24%
68	0,00%	1,13%
79	0,00%	1,02%
83	0,00%	0,75%
67	0,00%	0,60%



Appendix B: Schedule inputs

For the gathering of region data, the dashboard on the page 75 is used.

The top row contains the following filter options: Year, Month, Week, Weekday, ZIP Code, Date, Country and 2 digits zip code. Below the filter is the main table with on the x-axis the weekdays and the total. On the y-axis are the zip codes (on two digits) displayed, which can be further investigated into three and four digits. The data fields show the following data.

#orders

This number represents the total number of orders Hoekstra processes in the certain postal code on a certain weekday.

#routes

The number of routes represent the total number of vehicles that have at least one delivery in the selected region

#days

The number of days states the amount of day deliveries are performed in the selected region.

Average # of vehicles present in the region

The average number of vehicles present in the region is calculated in the following way. It is the number of trips having at least one order in that region divided by the number of days.

#count (of delivery addresses)

This number is closely related to the number of orders but distinguish itself by counting multiple orders on the same delivery address once.

Average # of orders in a vehicle for this region

This average is calculated by summing the orders, which have to be delivered in this region, present in the selected trips (which have an order in the region), and taking the average of that value.

Average # of orders in a vehicle

This value is calculated by summing the orders (within or outside the selected region) which are present in the selected trips (which have an order in the region) and taking the average of that value.

Percentage individual customers

The percentage of individual customers is calculated by summing the orders of companies, which are listed as company who only serve individuals (P companies) and dividing that with the sum of orders within the selected region.

Year 2019 | OrderTrip.Unloa... Nederland | Postcode.2 6 van 98 | Selecties | Inzichten

Dashboard parameters

Year	Month	Week	WeekDay	OrderTrip.UnloadingLocat...	Date	OrderTrip.UnloadingLocat...	Postcode.2
2019 ✓	jan.	1	ma	1011 AB	02-01-2019	Nederland ✓	10 ✓
2017	feb.	2	di	1011 AJ	03-01-2019	België	11 ✓
2018	mrt.	3	wo	1011 CP	04-01-2019	Noorwegen	12 ✓
2020	apr.	4	do	1011 CV	07-01-2019	Duitsland	13 ✓

left(OrderTrip.U...
left(OrderTrip.U...
left(OrderTrip.U...
left(OrderTrip.U...

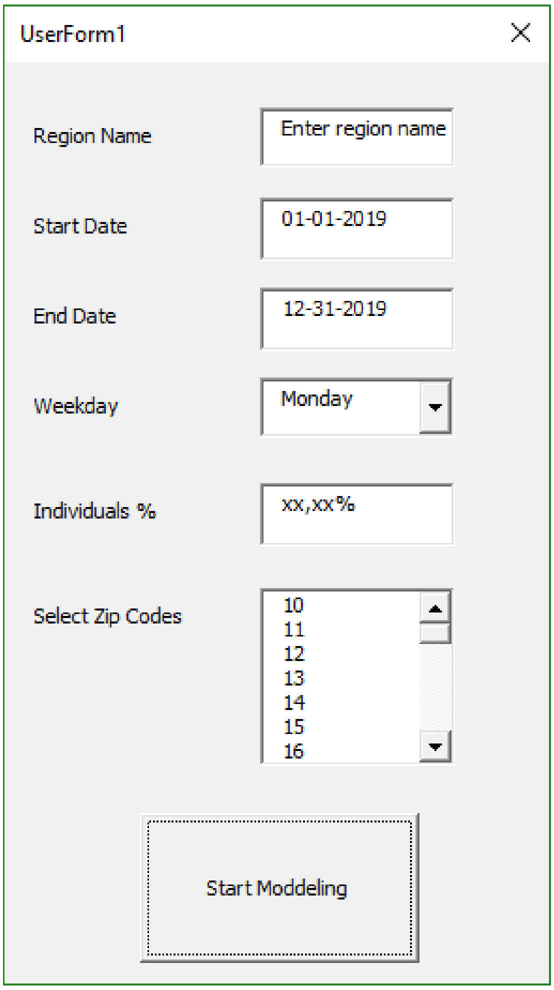
WeekDay | Waarden

	Totals								ma								di				
	# Orders	# Ritten	# Dagen	AVG	Aantal	AVG - Losacties per rit	AVG - Losacties per rit	% particuliere leveringen	# Orders	# Ritten	# Dagen	AVG	Aantal	AVG - Losacties per rit	AVG - Losacties per rit	% particuliere leveringen	# Orders	# Ritten	# Dagen	AVG	Aantal
	16623	1806	258	7,00	16240	9,20	14,67	62,97%	2604	307	50	6,14	2553	8,48	14,15	63,48%	3278	378	52	7,27	3204
⊕ 10	5204	779	255	3,05	5108	11,28	14,25	56,07%	904	142	50	2,84	893	11,08	13,89	57,08%	958	137	51	2,69	948
⊕ 11	2252	831	256	3,25	2226	8,43	13,71	62,48%	322	143	49	2,92	320	6,51	11,71	65,84%	420	166	52	3,19	418
⊕ 12	1307	322	240	1,34	1302	8,57	15,60	78,58%	196	49	45	1,09	196	8,30	15,65	85,20%	274	80	49	1,63	273
⊕ 13	2333	497	253	1,96	2328	9,33	15,44	77,71%	358	88	50	1,76	357	7,59	14,70	75,42%	441	97	52	1,87	441
⊕ 14	3004	956	257	3,72	2826	6,97	14,82	54,79%	431	150	50	3,00	407	6,82	15,16	58,24%	688	232	52	4,46	648
⊕ 15	2523	445	255	1,75	2450	10,13	14,82	65,64%	393	83	50	1,66	380	8,42	14,42	60,31%	497	93	52	1,79	476

Appendix C: Data setup sheet

Appendix C-1: Data input

Before starting the simulation input variables have to be given in order to start the generating the simulation data. This is done in the form below. The region name is the name the user can give for each identification of a region in a list of regions that can be created. The start and end date are there to determine the length of the selection period of the data to use as input (Appendix C-3). The weekday is the day of the week, which will be simulated (Appendix C-3). The individuals percentage is number of chosen time window generated (Appendix B and C-6). In the Select Zip Codes box 2 digits zip codes can be selected. These will be used in the model, the more zip codes selected, the large the region becomes and the large the computation time.



Appendix C-2: Orders per Zip code

In order to determine the number of deliveries per Zip code the pivot table of Appendix D has to be compromised to a table with only the zip codes of the selected region. This is done by determining each 4 digits postal code within the region and placing those value in column A. Afterwards, a lookup is used for each weekday (Monday to Sunday) to determine the number of deliveries in that postal code. These values are display in column B (Monday) to column H (Sunday). Column I represents the number of total number of deliveries for the postal code calculated with the sum of the deliveries per day. The last row of the table represents the deliveries per day for the whole selected region and in column I the total number of deliveries in the region.

	A	B	C	D	E	F	G	H	I
1	Postcodes Regio	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Zipcode Total
46	7961	3	5	5	4	3	0	0	20
47	7963	2	7	4	4	3	0	0	20
48	7964	1	1	0	0	1	0	0	3
49	7971	1	2	5	3	4	0	0	15
50	7973	2	0	2	0	4	0	0	8
51	7974	1	0	0	0	1	0	0	2
52	7975	1	1	1	2	0	0	0	5
53	7981	3	4	8	6	7	0	0	28
54	7983	2	4	3	2	2	0	0	13
55	7984	0	1	1	0	1	0	0	3
56	7991	9	7	6	3	9	0	0	34
57	Totals	232	285	273	255	359	11	0	1415

Appendix C-3: Basic Data list

Appendix C-3 is a list of modelling constant which are created by the code itself. It presented in the middle of the sheet in column K and L to be visible most of the time. Below the values are explained

Number of deliveries

The number of deliveries is the total number of deliveries performed by Hoekstra in the selected region in the selected time period (2019). This number comes from the table in Appendix C-2, specifically Cell(I57).

Period (days)

The period in days shows the length of the selected period (2019) in days. In this example it is one year so 365 days. This value is used to determine the average deliveries per day value below.

AVG deliveries per day

The average deliveries per day is the fraction between the number of deliveries and the period. This value is not representative for testing since most of the deliveries are performed between Monday and Friday and only a few on Saturday and Sunday.

Total Addresses

The total number of Addresses represent the amount of Zip codes (with letters) in the region. These addresses are found by filtering out unique zip codes from the list of zip codes in the general data (Appendix D). These addresses are used for the generation of delivery addresses (see Appendix C-5).

Number of deliveries in test

The number of deliveries in test represents the number of addresses generated for modelling. This value is a rounded value of the average deliveries per weekday (Appendix C-4). This rounding is partly random. A random number between 0 and 1 is compared with the decimals of the average. When the random number is lower than the decimal number the rounding will be down. When the random number is larger the number will be rounded up.

Chosen weekday

This field displays the chosen weekday of the experiment.

First day

This field represents the first day of the selected data. For the data chosen, the year 2019, it is the first of January.

Last day

This field shows the last day of the period chosen. For this study this is 31 December 2019.

K	L
Number of deliveries:	1415
Period (days):	365
AVG deliveries per day:	3,887362637
Total Addresses:	717
Number of deliveries in test:	6
Chosen Weekday:	Tuesday
First day:	1-1-2019
Last day:	31-12-2019

Appendix C-4: Delivery statistic per day

To determine the number of deliveries per weekday the number of working days has to be determined. This is not simply the number of weekdays within the selected period since on most of the holiday there are no deliveries performed by Hoekstra. Therefore, these days are subtracted from the total number of working days. Two Mondays, Easter Monday and Pentecost Monday; One Tuesday, New year; one Wednesdays, (1st) Christmas day; two Thursdays, Ascension Day and 2nd Christmas day; one Friday, Good Friday; One Saturday, Kings day; Three Sundays: Easter, Pentecost and Liberation day. To calculate the average deliveries performed per weekday the total number of deliveries per weekday is divided by the number of working days. The deliveries per weekday can be found in the total column in the table of Appendix C-2 (row 57 in this case). The standard deviation is a value calculated for only the chosen weekday. Therefore, a new pivot table is created in the columns X and Y (Appendix C-9). This value is not further used in the calculation but is purely informative to show the spread in deliveries in the region on the different weekdays.

Day	Working days in period	AVG deliveries per weekday	St. Dev deliveries
Monday	50	4,64	
Tuesday	52	5,480769231	2,450130049
Wednesday	51	5,352941176	
Thursday	50	5,1	
Friday	51	7,039215686	
Saturday	51	0,215686275	
Sunday	49	0	

Appendix C-5: Addresses generation

The addresses which will be used in the experiment are generated randomly. Firstly, the number of addresses generated is the number of deliveries in test (Appendix C-3). Secondly, a random number X between 1 and the total number of addresses (Appendix C-3) is retrieved. With this number X, the Xth item in the list of possible addresses (within the region) is retrieved. This Zip code is placed in column P.

P
Random Zipcode
7942 NZ
7943 SN
7916 VH
7916 VG
7954 GG
7901 LA

Appendix C-6: Time window generation

For the time window generation multiple factors have to be take into account before generating the time window. The first factor is to determine whether the generated address is for an individual, or for an SME. This is randomly generated with the percentage given as input. If the random number is lower than the percentage, this address will be an individual, otherwise it will be an SME. When this is defined the windows can be determined, for SMEs the lower bound is 07:00 and the upper bound is 15:00. For the individuals a random number between the lower bound (7) and the upper bound minus the time window size, in this case 15-2 = 13. This random number x represents the lower bound of the time window and the upper bound is X hours later. For example, the time window of row 3 (2^{nd} address) is 12:00 as lower bound and the upper bound is 2 hours later (time window size in this example), at 14:00.

Q	R
StartTime	EndTime
08:00	10:00
07:00	15:00
12:00	14:00
11:00	13:00

Appendix C-7: Route generation

The routes are generated in all direction, so from every location the route is generated to all other instances. This is done between all customers but also between the depot (Sneek) to all customers. The depot is shown in the range from K20 to M21.

20	Depot	StartTime	EndTime
21	8601 WC	05:00	20:00

Together with the Addresses generated before the routes are determined. For 6 customers there are 49 routes, of which are 21 are unique. An example of the route list can be seen in below.

T	U	V
Departure + Arrival Zipcode	Departure Zipcode	Arrival Zipcode
7904 EL8601 WC	7904 EL	8601 WC
7904 EL7901 TA	7904 EL	7901 TA
7904 EL7943 RW	7904 EL	7943 RW
7904 EL7904 EL	7904 EL	7904 EL
7904 EL7904 JE	7904 EL	7904 JE
7904 EL7955 PX	7904 EL	7955 PX
7904 EL7915 AB	7904 EL	7915 AB
7904 JE8601 WC	7904 JE	8601 WC
7904 JE7901 TA	7904 JE	7901 TA
7904 JE7943 RW	7904 JE	7943 RW
7904 JE7904 EL	7904 JE	7904 EL
7904 JE7904 JE	7904 JE	7904 JE
7904 JE7955 PX	7904 JE	7955 PX
7904 JE7915 AB	7904 JE	7915 AB
7955 PX8601 WC	7955 PX	8601 WC
7955 PX7901 TA	7955 PX	7901 TA
7955 PX7943 RW	7955 PX	7943 RW
7955 PX7904 EL	7955 PX	7904 EL
7955 PX7904 JE	7955 PX	7904 JE
7955 PX7955 PX	7955 PX	7955 PX
7955 PX7915 AB	7955 PX	7915 AB
7915 AB8601 WC	7915 AB	8601 WC
7915 AB7901 TA	7915 AB	7901 TA
7915 AB7943 RW	7915 AB	7943 RW
7915 AB7904 EL	7915 AB	7904 EL
7915 AB7904 JE	7915 AB	7904 JE
7915 AB7955 PX	7915 AB	7955 PX
7915 AB7915 AB	7915 AB	7915 AB

Appendix C-8: Distance generation

The distances and travel time are generated with the ANWB route scheduler. The departure zip code (column U) and the arrival zip code (column V) are filled in the route scheduler which determines the fastest route for the vehicle. After the route determination, the scheduler shows the travel distance and time. Those values are retrieved and converted to travel distance in kilometres (column W) and travel time in minutes (Column X). With those two the average speed in km/h is calculated in column Y. Not all routes are retrieved from the ANWB scheduler. The routes for which the arrival place equal departure place is always 0 in terms of distance, travel time and speed. Secondly the routes are checked if there opposite route is already determined. If that is not the case than the values of the Route A → B are placed at the fields for the route B → A. The reason behind this assumption are stated in Section 4.2.3.

T	U	V	W	X	Y
Departure + Arrival Zipcode	Departure Zipcode	Arrival Zipcode	Distance (km)	Travel Time (minutes)	Average travel speed (km/h)
8601 WC8601 WC	8601 WC	8601 WC	0	0	0
8601 WC7901 TA	8601 WC	7901 TA	88,6	53	100
8601 WC7943 RW	8601 WC	7943 RW	69,9	41	102
8601 WC7904 EL	8601 WC	7904 EL	89,7	54	100
8601 WC7904 JE	8601 WC	7904 JE	90,2	56	97
8601 WC7955 PX	8601 WC	7955 PX	74,9	51	88
8601 WC7915 AB	8601 WC	7915 AB	92,6	57	97
7901 TA8601 WC	7901 TA	8601 WC	88,6	53	100
7901 TA7901 TA	7901 TA	7901 TA	0	0	0
7901 TA7943 RW	7901 TA	7943 RW	23	17	81
7901 TA7904 EL	7901 TA	7904 EL	3,9	7	33
7901 TA7904 JE	7901 TA	7904 JE	4,9	10	29
7901 TA7955 PX	7901 TA	7955 PX	24,1	23	63
7901 TA7915 AB	7901 TA	7915 AB	9,2	11	50
7943 RW8601 WC	7943 RW	8601 WC	69,9	41	102
7943 RW7901 TA	7943 RW	7901 TA	23	17	81
7943 RW7943 RW	7943 RW	7943 RW	0	0	0
7943 RW7904 EL	7943 RW	7904 EL	24,7	19	78

Appendix C-9: Standard deviation calculation

To determine the standard deviation for the specific weekday selected a new pivot table has to be created from the general data in the 2019 Data setup (Appendix D). The first column (AA) shows the date (in this case Tuesday) of the week. The second column (AB) displays the number of orders delivered in the selected region on that day. Below the end total the manual calculated standard deviation is show.

AA	AB
2 digits zip code	(Meerdere items)
13-8-2019	3
20-8-2019	4
27-8-2019	9
3-9-2019	11
10-9-2019	6
17-9-2019	7
24-9-2019	8
1-10-2019	5
8-10-2019	4
15-10-2019	3
22-10-2019	2
29-10-2019	8
5-11-2019	1
12-11-2019	8
19-11-2019	4
26-11-2019	1
3-12-2019	9
10-12-2019	5
17-12-2019	3
24-12-2019	4
31-12-2019	3
Eindtotaal	**275**
st. dev. Tuesday	2,450130049

Appendix C-10: Regional performance indicators

There are two sets of variables in the figure below. The first set is about distances and time to the depot. The second set is about the distance and travel time between customers of the specific region.

The average distance and travel time to depot is calculated as follows. The sum of distances and travel times is taken between all customers and depot. Afterwards, the total is divided by the total number of customers in this region.

For the distance and travel time between customers a similar approach is used. The sum of distances and travel times between unique customers is summed and divided by the unique number of routes between customer in that region. In Appendix C-7 is more stated about unique routes.

	K	L
1	Number of deliveries:	17803
23	AVG distance to depot	195,7777778
24	AVG travel time to depot	117,9861111
25	AVG distance between customers	45,38405321
26	AVG travel time between customers	37,36776213

Appendix D: 2019 Data setup

In the model the general data is adjusted to be able for applying into the analysis of the selected region and the selected date. Column A and Column B are the input fields of from the data source at Hoekstra, which are the unloading location of a delivery (as zip code) and the unloading date (as date). From the first column the first two digits are retrieved in column C and the four digits are displayed in Column D. Those are used for analysing zip code areas (column C) and for demand in the region (column D). The unloading date is used for determining the demand per weekday and the weekday of the delivery is shown in column E.

	A	B	C	D	E
1	OrderTrip.UnloadingLocation.ZIPcode	Order.Unloading.Date	2 digits zip code	4 digits zip code	Weekday
2	1011 AB	9-4-2019	10	1011	di
3	1011 AJ	14-2-2019	10	1011	do
4	1011 CP	12-4-2019	10	1011	vr
5	1011 CV	14-5-2019	10	1011	di
6	1011 CV	3-7-2019	10	1011	wo
7	1011 CV	12-11-2019	10	1011	di
8	1011 DD	9-9-2019	10	1011	ma
9	1011 DG	23-5-2019	10	1011	do
10	1011 DL	26-6-2019	10	1011	wo
11	1011 DL	10-7-2019	10	1011	wo
12	1011 DL	16-10-2019	10	1011	wo
13	1011 JV	18-2-2019	10	1011	ma
14	1011 KB	13-6-2019	10	1011	do
15	1011 NH	11-11-2019	10	1011	ma
16	1011 NH	22-11-2019	10	1011	vr
17	1011 PG	30-8-2019	10	1011	vr
18	1011 PG	18-12-2019	10	1011	wo
19	1011 PN	13-2-2019	10	1011	wo
20	1011 PN	15-4-2019	10	1011	ma

With these 5 columns of data a pivot table is created which represents the data more structured for analysis. On the row the 4 digits of the postal code are shown. In the columns the weekday is presented. The data fields display the number of deliveries performed in this zip code area on the specific day. The last row and column show the totals per row and column.

G	H	I	J	K	L	M	N	O
Order.Unloading.Date	(Alle)							
Aantal van OrderTrip.UnloadingLocation.ZIPcode	**Kolomlabels**							
Rijlabels	**ma**	**di**	**wo**	**do**	**vr**	**za**	**zo**	**Eindtotaal**
1011	14	11	16	12	11			64
1012	11	10	13	12	13			59
1013	27	25	36	29	41			158
1014	19	16	27	21	36			119
1015	5	8	15	13	19			60
1016	13	13	17	12	22			77
1017	16	26	24	19	20			105
1018	25	21	21	18	35			120
1019	16	26	31	20	25			118
1021	14	9	15	10	10			58
1022	8	11	7	6	10			42
1023	5	6	1	3	3			18
1024	13	8	20	4	11			56
1025	10	7	13	22	15			67
1026	1	1	3	2	2			9
1027	2		2	1	1			6
1028	1	2			2			5
1031	7	18	17	9	20			71
1032	10	24	24	20	62			140
1033	25	21	34	30	44			154
1034	11	4	11	13	14			53
1035	9	14	15	16	11			65
1036	6	2	11	2	9			30
1037		1						1
1041	1	4	5	3	1			14