IEM bachelor thesis

'Creating a planning tool for company X'

Enschede, 2021

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Preface

Dear reader,

In front of you lies my bachelor thesis 'Creating a planning tool for company X'. For this thesis the inventory routing problem of supplying the service engineers of company X is researched. To be able to gain more information about this problem, I worked from March 2021 to June 2021 at company X.

I would like to thank Matthieu van der Heijden, my first supervisor from the university, for his time, guidance and elaborate feedback. He helped me to successfully complete this bachelor thesis. Also I want to thank my second supervisor, Ipek Seyran Topan, for her time and effort. Furthermore, I would like to thank the company for making it possible to complete my bachelor with an enjoyable and challenging assignment. Working with the company went without any problems and I am grateful for the time they took to help me with my thesis.

I hope you enjoy reading my thesis.

Kind regards,

Kasper van Ekeris

Enschede 2021

Management Summary

This thesis is conducted at a technical service company, in the centre of the Netherlands. The main activity of the company is conducting maintenance. The 50 service engineers who conduct this maintenance are spread around the Netherlands. In order for them to do their jobs, they need certain products. These products are supplied from a central depot to all the storage boxes of the service engineers. The goal of this thesis is to create a planning tool, which provides an optimal planning to supply the service engineers.

First, the problem is examined by creating a problem cluster. From this it can be derived that the supplying is not efficient. This has two main causes, (non-optimal) fixed routes and an inefficient inventory strategy. A target has been set to accomplish a reduction of at least 25% in kilometres driven in a four-week period. The variable ‘kilometres driven in a four-week period’ provides a good indication on the improvement of a future supply planning. After a literature study, it became possible to establish a model to solve the problem. This model consists of two parts, an inventory part and a routing part. First a delivery frequency of a location (place where one or more service engineers have a storage box) is established. This is done by evaluating the expected demand and storage capacity of six products which are in ‘high’ demand. The delivery frequencies are calculated in such a way that storage capacity would not be an issue. All of this is done in cooperation with the company to assure that the model is accurate. When the delivery frequencies are known, two Vehicle Routing Problems (VRP) are solved, one for each delivery frequency. The goal is to minimize the total distance of the routes for each VRP. However, this includes taking certain constraints into account, these are with regard to the maximum allowed distance of a single route and the truck capacity. Different heuristics are tested and used to solve the VRPs and these are implemented in a planning tool.

To conclude, the model is used with the help of the planning tool, to create a near-optimal solution. The tool calculated a total distance of 3267 kilometres driven in a four-week period. This is a decrease in total distance of 35,6% compared to the current situation (also estimated by the tool). Because the model looks at two delivery frequencies, once every four weeks and once every two weeks, it becomes possible to supply certain locations less frequent. 15% of the locations needs to be supplied once every two weeks, in the current situation this is 100%. This is based on historical data, the data shows that certain locations could be supplied less frequently. The data of products per service engineer was used to come to this conclusion. The estimation of the expected demand per product resulted in more insights in the number of products to bring in the truck. Currently the number of items in the truck are mainly the same for all the routes, because it is not specified for the route. By taking the expected demand per service engineer into account, the truck will be filled more efficiently, which contributes to better routes. However, not only the lower delivery frequencies contributed to the solution, the new routes also helped. The heuristics create routes which are near-optimal, many options are evaluated to come up with the final solution. The current routes are created with the idea to created equally long routes. However, the tool takes more variables into account and uses good heuristics to find a solution, a decrease of 12,8% in total distance is found solely by the improve routing. This information is obtained by using the tool for the situation where all locations have a delivery frequency of once every two weeks (such as the original situation). It is also good to notice that in the model it is assumed that 8 of the 12 truck areas can be used as truck capacity for the six products in question. A test on truck capacity shows, that being able to use only 7 areas instead of 8 resulted in an increase of total distance of 8,2%. This is quite a lot, especially compared to small decrease of 0,4% if one would go from 8 truck areas to 9. Thus, increasing the truck capacity a bit would be that beneficial. However, only using 7 truck areas will have more serious impact, but it must be stated that 7 truck areas will still result in an improvement of 29,8% compared to the current situation. Finally, the tool which is used to create the planning is adapted in such a way that the company can also use it in the future.

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Table of abbreviations

Abbreviation	Definition
API	Application Programming Interface
GUI	Graphical User Interface
IRP	Inventory Routing Problem
LP	Linear Programming
NNH	Nearest Neighbour Heuristic
SKU	Stock Keeping Unit
TSP	Traveling Salesman Problem
VRP	Vehicle Routing Problem

1. Introduction

In this chapter an introduction is provided about the company and the problem the company encounters. It will be explained what types of problems the company has, and which will be solved. Moreover, this includes a plan on how this problem will be approached.

1.1. The company

The company is a technical service company, with its office located in the centre of the Netherlands. The main activity of the company is maintenance, this is done for more than 20.000 customers throughout the Netherlands. Maintenance is done for companies ranging from small and medium-sized enterprises to multinational companies. Furthermore, the service engineers, who provide this maintenance, need to be supplied. As there are over 50 service engineers throughout the Netherlands, they get supplied in groups. Every group of service engineers get supplied once every two weeks in their individual storage boxes. Currently every group has its own route, this is shown in figure 1 below. The supplies involve all the parts needed to conduct proper maintenance.

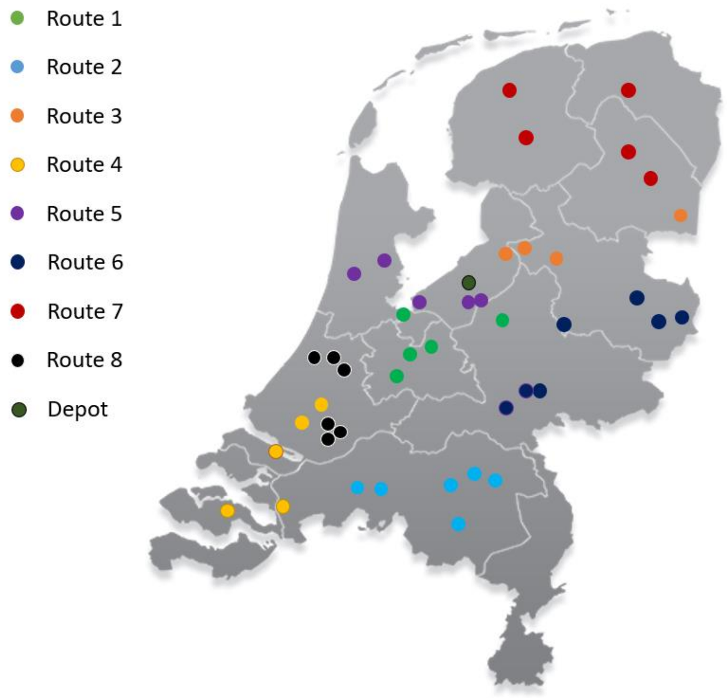

Figure 1, current supplying routes at company X

In order to be able to understand the core of the problem, it is useful to have an insight in the current supplying method. As shown in the figure above there are eight different routes. Every route is driven once every two weeks. Because there are eight routes this means four supply moments in a week, four in the even weeks and four in the odd weeks. A truck full of different supplies will departure from a central storage point and will drive the route along the storage boxes (see figure 1, above). The supplier is able to access the storage box. Only in the storage box he is able to see the level to which the inventories need to be filled. This means that he has no insight in the boxes from outside the box. The service engineers will write how much he or she will need per Stock Keeping Unit (SKU), there are around the 15 different SKUs. The supplier fills the storage box to the desired levels and continues its route. The service engineers also collected waste which are retrieved from the used products, these goods will be recycled or reused, that is why the supplier will take them back to the central point. After the route is completed, the supplier will go back to the central point. And prepares the truck for the next day. The next day he will do the exact same, but then with another route.

1.2. Problem identification

The assignment for my thesis is to improve the supplying process of the service engineers by lowering the costs. To analyse this problem a problem cluster with all the relations of the problems is formed, because this assignment is very broad. The problem cluster can be found below (figure 2). The action problem is the high costs of supplying the service engineers. This problem has three main causes: Inefficient supplying, high transportation costs and non-optimal storage boxes.
The inefficient supply method can be due to the low delivery rate of the truck, inefficient inventory management and/or inefficient waste management (waste consists of a.o. packaging materials and materials of other used supplies). The current 50+ service engineers are divided in eight areas and every area has its own route. The routes are currently based on just the locations of the boxes. And the routes are fixed. All areas should be covered once every two weeks. In order to make a special extra supply in the region possible, routes are divided in more or less equal daily distances as the largest route on a day can have a maximum of ten working hours based on the Dutch transport regulations. This is controlled by a formal approved automatic track & trace system built in the truck. Since the delivery truck drives on a time bases, every two weeks, instead of a demand basis, when supplies are needed. It can happen that the truck will not deliver many supplies. Since the demand in two weeks can be on the low side. This means that it can be unnecessary to drive the route, since it would result in such a low delivery rate. Therefore, it is not optimal to have this supplying system with possible low delivery rates.
Besides the routes, the inventory management is currently managed via a fixed reorder period system. This fixed reorder point is set by the service engineer him-/herself. But not only the delivery of supplies is important, the garbage of the used supplies also needs to be collected. Large equipment can be delivered to the boxes. They all result in waste, it is important to collect this because the waste needs to be recycled and it takes up space in the box, which could be used to store more inventory.
The second cause is the high transportation cost. Currently a small fuel-using truck is driven, the reason for this small truck is that it should be big enough for the supplies and still be drivable with a B-driver license. However, besides it not being eco-friendly it is also expensive in taxes and fuel.
The final cause is about the storage boxes. In the current situation, most service engineers have their boxes nearby. This way the service engineers do not have to drive far for their supplies, but the supplier needs to drive further to supply all the individual boxes. So, the locations might not be ideal. Another reason why the boxes can cause higher costs, is the layout of the current storage box. Because the boxes are so small it is very important that the space is used as efficiently as possible. Currently they have one rack standing against the wall. The other supplies are dropped in front of the rack.

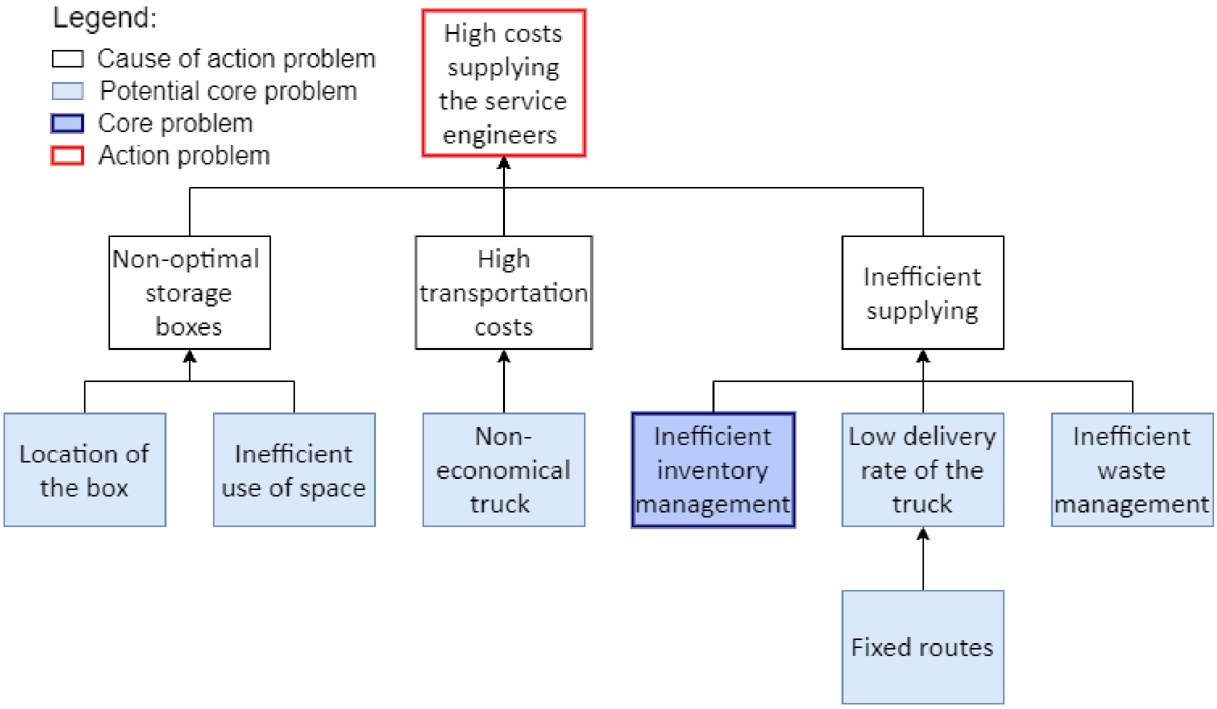

Figure 2, The problem cluster

1.2.1. Core problem

When looking at the problem cluster there are many core problems. Fixed routes, inefficient inventory management, inefficient waste management, the non-economical truck, the high rent prices for the storage boxes and its inefficient use of space. Now the question remains, which solution of the problem will have the most impact for the least amount of money invested? In terms of costs the truck and boxes are the most expensive. The purchases of a truck or new storage boxes are high with respect to the costs of rearranging the routes and inventory management. By changing the inventory or routes there is no large investment necessary, except the time that needs to be invested. Therefore, it would be the obvious choice to start with either the inventory or routes. The bad inventory management is one of the causes of the inefficient supplying, because the inventory strategy decides when to deliver the supplies. In the current situation the inventory strategy results in an inefficient supplying. This will be explained in more detail in the next paragraph. Next to that, the fixed routes are also indirectly the cause of the inefficient supplying. Because there are fixed routes, the supplier/company does not take the needs of the service engineers into account. Therefore, it can happen that the supplier will end up with a lot of goods still in his truck, since he did not deliver a lot of supplies, meaning a low delivery rate. Getting rid of the fixed routes will improve this low delivery rate but is quite complex. However even improving the current fixed route will contribute to a better low delivery rate and thus a more efficient supplying. Since the inventory plan can have influence on the routes it is an understandable option to start with the inventory management as the core problem.
The company believes that the core problem is the fixed routes. There is a lot to gain in getting rid of the fixed routes. Because your routes are fixed it means that even if the service engineer only used one screw in the past two weeks the delivery man has to drive by the storage box for just this one screw. Obviously, this is not efficient, that is why in order to lower the costs it would be the right move to start looking at how to change those fixed routes. However, the routes have a strong relation with the inventory model. Because the current inventory model is a fixed reorder period system. Meaning that every two weeks the inventory will be filled to a certain point. If the routes need to be more flexible, then the inventory model should allow this. The opposite system is the fixed reorder quantity system, this means that the inventory (in the storage boxes) will be filled when the inventory drops below a certain point.
The inventory strategy decides when the supply moments are. And because the supply moments are

not optimal the way to optimize the supply moments is by changing the inventory strategy in such a way that less delivery moments are needed. With the company it is discussed that by changing the inventory strategy the supply moments will decrease and therefore a different routing plan will be established. Since that is the desire of the company, they agree on the current choice of the core problem.

To give a better insight in the problem, I created a graph of the inventory level with the supply moments, see figure 3 below. The graph shows the inventory level of one particular SKU from one service engineer. It can be seen that the inventory level is all over the place. The first blue circle shows that even though the inventory is already relatively high, it is still supplied. Later on in the year, see second blue circle, it shows that for a period of almost three months not a lot of traffic of this particular SKU is going on. Therefore, it is interesting to think about the relevance of supplying in those three months. Since there are more situations such as this one, the goal is to reduce the number of deliveries. This can result in higher cycle stocks, however for most SKUs this will not form any issues. Next to the cycle stock, the safety stock is hard to determine. When we look at the graph again, no obvious safety stock can be derived. This is mainly because the service engineers themselves decide on how many products they need. Some engineers like to keep a lot of extra supplies, others only want a bit more than they need. However, for the company it is important that they can conduct the maintenance without any shortages. The goal will be to find the balance between less delivery, but still being able to handle all the demand.

Figure 3, Current inventory level, one SKU, one engineer

1.2.2. Target

As explained above, the focus will be on trying to adjust the cycle stock in such a way that less delivery moments are needed. Because there are less delivery moments, less kilometres will be driven. This results in the following core problem: there are 5256 kilometres driven every four weeks, and this should be reduced by 25%. Thus, the target is 3942 kilometres driven in a four-week period. When less kilometres are driven, less hours needs to be paid to the supplier and less fuel is needed. Therefore, less costs will be achieved by saving on supplying and fuel. Nevertheless, the amount of shortage should not occur significantly more. The company has different approaches to prevent shortages, however these approaches cost money. If these costs get too high, the costs saved by a new planning would be reduced.

1.3. Problem solving approach

1.3.1. Goal

The goal of this research is, to lower the total costs of supplying the service engineers. This will be achieved by optimizing the supplying, by changing the delivery frequency and cycle stock, and by adapting the current routes so they fit the newly made changes. By trying to estimate the demand and creating a planning tool, the supplying should become more optimal.

1.3.2. Deliverables

In order to reach this goal and substantiate what I have done, I will deliver certain documentation of my research to the company.
- The first deliverable will obviously be the thesis itself. This will include all the information and explanation of my research.
- The second deliverable will be an Excel model; this will include the inventory levels and planned routes. The company can use this for more research on their own and to use it for their planning in their next years.
- The final deliverable will be the recommendation. The recommendation will explain in detail, what needs to change and why. Where the focus lays on the delivery frequency with the optimal order quantities and the adapted routes. This will be in the form of a supply planning.

1.3.3. Research questions

In order to solve the inefficient supplying, a research question formulated. The research question is as follows:

What is the optimal supply strategy for company X?

To answer this question a set of sub-questions is established. These questions should give me a step-by-step approach to the answer of the research question. Moreover, it should help me achieve the deliverables.

The first sub-question is about the current situation.

1. *What are the current working method and limitations at company X?*

In order to answer this question data needs to be gathered of the previous year(s). This should give insights in the demand, inventory levels and order quantities of that year. This will not be a perfect resemblance for current year, however with the knowledge of the company, an estimation can be made on what the demand will be in the upcoming year. Thus, this estimation will be based on previous years data and knowledge of the company. When I know the current situation and have the Excel model, I can set a reference point. The data should in theory give enough information to base a planning tool on. Besides the data it is also of interest what the constraints are with respect to the availability of the SKUs in the central delivery point. In addition to the quantitative information, I will communicate with different parties within the company to get an understanding of their perspective. Next to that I will also analyse the current routes and supply limitations. A part of this analysis will also be having a meeting with the supplier and the creator of the routes. Finally in order to get an idea on how to approach such a problem a literature study will be conducted to improve the planning tool.

The second question looks at the most optimal delivery frequencies with their optimal order quantities.

2. *What are the optimal delivery frequencies and optimal order quantities?*

When I have a better understanding of the current situation, I can optimize the supply strategy. This will be done by means of an Excel tool/model. This should in theory give the optimal delivery frequencies with the order quantities. The optimal values will be obtained by conducting an analysis on the variables. With the forecasted demand it is possible to create a theoretical supply planning.

The final sub-question is all about the adaption of the new routes.
3. What are the optimal routes for the planning?
If the data is analysed and a theoretical planning is created, the next task is to analyse the routing situation. To start with that I will take another look at the current routes and conduct a literature study on routing problems. After that I should be able to find the best implementation of the new supply strategy with the knowledge of the previously defined theoretical planning from question two. Together with the company and the tool, I will make a plan on how the implementation needs to happen. This will most likely result in a new schedule with optimal order quantities which will replace the old strategy.

1.3.4. Scope & validity

Since there is limited time to complete the thesis, there are parts which cannot be finished in this time span. Therefore, it is important to think about which parts are important and which simplifications need to be made in order for the project to be feasible. The first simplification is the type of maintenance. The company provides mainly preventive maintenance, as well as corrective maintenance to some extent. Because corrective maintenance is only a small part of the total maintenance, the company and I decided not to take this into account. However, since it cannot be left out, an assumption can be made on the average level of corrective maintenance, which can then be added to the optimal inventory levels. The next simplification point is the demand. The demand is not exactly deterministic, however it can be easily forecasted. This is the case, because the company has an idea on when preventive maintenance should be conducted, on a monthly level. Thus, by forecasting the demand, it can be seen as deterministic, which makes it easier to calculate the desired delivery quantities and frequencies. Another point on which time should be spared, is the implementation of the new inventory strategy. After selecting the best strategy, it can be difficult to implement it exactly as the theoretical plan. Because there is a limited time the implementation will most likely not be ideal. Moreover, a possible solution can be a fully dynamic routing strategy, since this can turn out to be very difficult it is likely this will not be implemented. However, the company is free to use my research to find a better implementation themselves. Nevertheless, there will be an implementation, because just the theoretical plan will not give an immediate result. There are two more simplifications with respect to the supply strategy. This has to do with big orders and waste management. When there are big orders for either preventive, or corrective maintenance, it is common to send the supplies directly to the customer, instead of going to the storage boxes first. Since this activity does not involve supplying the storage boxes, it is not included in the thesis. Finally, there is the waste management. The service engineers collect the waste from used/broken products, and this waste then needs to be collected by the supplier. The supplier first delivers the supplies and collects the waste afterwards. It is difficult to track the amount of waste in a planning tool, therefore the waste management will not be included in the thesis either. This means the waste will be collected in the same way they do it now, namely by collecting it after delivering the goods.
Lastly in order to make sure my research is valid I will ensure internal and external validity. I can ensure my internal validity by making sure that no other factors will influence my work. I want the best for the company and assignment, this is only possible by assessing all relevant articles in the same way. The external validity might be more difficult to prove, after using the Excel tool it should give an insight in the numbers, the goal of course, is to make an estimate as close to reality as possible, however this might not be fully achieved. This is all because it is possible that certain factors are not included in the Excel model.

1.3.5. Solution planning

In order to solve the questions and create the deliverables, a well-defined plan is needed. A step-by-step approach will contribute to the work efficiency of this project. Therefor a more detailed explanation on how the sub-questions will be answered is provided below.

Starting with the first sub-question, "What are the current working method and limitations at company X?". In order to fully analyse the current working method, data is needed. The finance department has access to all the invoices from the last years, with those invoices the demand can be deduced. Moreover, the demand will be estimated with the expertise of the company and the invoices. The company can export a excel file from their system with all the data in and out per service engineer. Which means that when looking at the previous years an estimation can be made of the next year, but with some additional information of the company we can improve the accuracy to a monthly level. Since the inventory per service engineer is of interest, the data per service engineer will be generated. Furthermore, the managing director will provide a list with all the service engineers and locations of their boxes. Moreover, the SKU levels, every service engineer has his/her own inventory restock level. To gather all that data, the supervisors will check all the restock levels by visiting the storage boxes, since the refill levels are written in the storage boxes. Of course, at the end, when all the data is collected, it should be in a structured sheet. So, it will be easy to export it to a table. Besides collecting the data, this is also a great moment to go to one of the boxes to see the space the service engineers are dealing with. This will give a better view of the current problem and what limitations there are. The last action that needs to be taken is the literature study about the problem. By conducting a literature study, it should become more understandable how to tackle such a problem.

In order to answer the next question "What are the most optimal delivery frequencies and optimal order quantities?", some additional steps are needed. First of all, it is important to determine the inventory levels. This in combination with the demand should make it possible to estimate the delivery frequencies and the corresponding order quantities. These values will be implemented in the excel tool. If the tool works accordingly, it can use this data to test different supplying options. After testing the model thoroughly, an optimal planning can be created.

Finally, when all the data is gathered and the best values are chosen, the last sub-question to answer is: "What are the optimal routes for the planning?". A lot of information is already gained from the analyses conducted in my first sub-question, however I will need to take another good look at it and with some additional literature I should be able to improve the routes according to the new planning. Moreover, after I know what is important for the company and service engineers regarding new routes, I can start a literature study. When looking at similar scenarios, I will be able to use that information to optimize the routes. The literature in combination with the data gathered should results in a more optimized supplying for the company. Finally, when the plan is created it will be shown in the recommendation. Moreover, it will include a map with the routes (might be new routes, but can also be the old ones), a yearly scheme which indicates when to drive which routes with the ideal quantities and recommendations for the future years. So, what needs to change after one yearly scheme is completed and how to use the excel tool in the future?

2. Current system analysis

In order to improve the supplying of the service engineers, there should be full understanding of the current situation. To achieve this, conversations were held, data was gathered, and field experience has been gained. First, the current supplying method will be explained from different perspectives. After that, certain exceptions will be discussed, data analysis will be explained and finally an overview of the current problems will be shown.

2.1. Current supplying method

To get a better understanding of the current situation, different perspectives are discussed. First the service engineer's perspective will be discussed, after that the company's and lastly the perspective from the supplier himself.

2.1.1. A service engineer's perspective

A service engineer will mainly conduct maintenance in his or her area. All the service engineers have a van in which they can transport the supplies needed for maintenance. The van can also be used as a temporary storage unit. However, since the vans are not large enough to be filled with weeks of supplies, they also have access to a storage box. This storage box is close to their home, this way they do not waste that much time filling their vans with supplies. Currently this storage box is supplied every two weeks. The service engineer will communicate to the supplier, via notes in the storage box, how much supplies he or she needs. When the supplier visits the storage box and reads the note, the storage box will be filled up to the indicated levels. Ideally service engineers will fill their vans as much as possible, so there is more room for inventory storage in the box. Service engineers can also request more supplies when they expect a shortage, this will be in addition to the indicated levels. Moreover, it can happen that a service engineer has a large project which means a large number of supplies are needed at once. If this is the case, a service engineer can request the supplies to be delivered directly to the customer. However, this is only possible if the location of the customer allows it. This has two main advantages, one being that the service engineer knows that he or she has enough supplies for the customers. The second advantage is that this way, the storage box should have enough supplies left to conduct other maintenance as well, since the large order of supplies does not have to go through the storage box first. Obviously, it costs a bit to send the supplies directly, however this only happens for big projects and it ensures that no further supplies will be used from the storage box. That is the reason why it is profitable to send large supply orders directly. Besides it being more profitable, it is also more convenient for the service engineer to have the supplies on location, since this saves the time and effort of moving the supplies.

In order to gain a better understanding of the problems that the service engineers bump into, a couple of questions were asked to service engineers from different expertise. In this case, different expertise means service engineers with different types of customers. For instance, there are service engineers who conduct maintenance for companies with many units and service engineers who conduct the maintenance for smaller customers. First of all, none of the service engineers experienced a lot of shortages. It only happened between the one and five times a year and when a shortage occurred, they were able to fix it quite easily. They either borrow items from other service engineers close by, request an urgent delivery, or drive to the central point themselves to get the supplies. Next to that, most service engineers know which products are in high demand, so they make sure that they have enough of this product in stock. That is why most of the time when there is a shortage, it is of a product that is not used often and thus is not always in stock. Another question was to what extent they are able to forecast their demand. Almost all of them answered that it is very much possible to forecast the demand of an entire month. Only one answered that forecasting a period of two weeks is possible, but that this is because he conducts a lot of unique corrective maintenance. Because of the nature of this corrective maintenance, he always needs to be available when needed, since corrective maintenance has a priority over preventive maintenance. The service engineers also pointed out that they do not experience any form of stress about their inventory levels. They do point out that sometimes the delivery is not exactly what they expected to get. However, most of the time this will not form a problem, since they will contact the central point and make sure they will get the right amount with additional products when needed next time. The last point which sometimes forms an issue are the unused products. Service engineers can have items in stock which are not used that frequently. Because some items have an expiration date, it can happen that products will be thrown away or returned because they cannot be used any more.

2.1.2. A company's perspective

The service engineers are supplied by the company, which is all done by means of a truck that departs from a central point in the Netherlands. There are eight different routes which need to be driven every two weeks. This means that the truck will drive four routes a week. The work method is as follows: after a route is finished the truck will be refilled at the central point and prepared for the next day. In the morning of this next day, the truck will drive the route for that day and go back to the central point to be prepared for the following day. At the central point it is decided what goes into the truck. This is done in two parts, the first part is the general part which holds that there is a fixed amount for every product which will always be in the truck. The second part is the specific route part, this includes all the extra supplies needed for that route. Service engineers are able to order extra supplies when they expect to need more supplies than usually. When the service engineers order something extra, an employee at the central point will put the needed supplies in the separate space for that specific route. When the standard supplies for that route are loaded into the truck, the extra supplies will also be taken in the truck with a note to which service engineer it has to go. How many supplies are needed for the general part is derived from experience. Since the quantities are not based on calculated numbers, the following two things happen too often. On the one hand it, it happens that some supplies cannot be delivered due to a shortage of that supply in the truck. On the other hand, it also happens that the truck returns with a lot of the items remaining in the truck. Generally, an employee at the central point estimates a very roughly 60% delivery rate, which means that roughly 40% of the supplies is not delivered. This is not always on the same product but differs per SKU. For example, one product is by far the most selling product, see figure 4 on page 16. However sometimes other products are not available in the truck because of sudden demand, so there is not one obvious SKU where it goes wrong. Another point which needs attention is about the constraints with regards to the shelf life. A product can get too old, to the point where it cannot be used anymore. This makes it important to ensure there is enough flow in the products. If this is not the case, old products need to be returned, which results in unnecessary waste. These returned products will not be used elsewhere, since the service engineers send the products back when they are already expired. Nevertheless, there are also some advantages of the current system. For instance, the efficiency of (un)loading the truck at the central point. Every day the general part is made ready and in the central point there are eight areas, one area for each route. If the new planning will be less static it can be more challenging and time consuming to load the truck. Another advantage is that the routes are currently arranged in such a way that a second round of supplies the week after the original round is possible if needed. For instance, in the even weeks there is a route supplying the East of the Netherlands, and in the odd weeks the route supplies a different area which is nearby. If a service engineer thus suddenly needs supplies as quickly as possible, it might be possible to drive by him or her, because the supplier is already more or less nearby. The disadvantage of this simplistic and static supplying method is that it happens that the supplier cannot deliver everything or that the supplier has too many supplies still in the truck which makes it inefficient.

2.1.3. A supplier's perspective

The supplier is a freelancer who is hired by the company to deliver the products throughout the country. He will start his day early in the morning with a full truck to drive to the first storage box. At the box he starts with taking the crate of waste to create some room in the box. After that is done, he will get the products from his truck and fill all the products to the desired levels. Next to that, he will place a new crate with possible extra supplies requested by the service engineer. This crate can be used to store waste for the next time the supplier arrives. When the old crate and the remaining products are back in the truck, the supplier will write down the number of products he delivered from the general part and continues his route. After the route is completed, he will arrive at the central point. At the central point new products are available to be loaded. He first empties the entire truck, then he fills the truck again with the new products.

2.2. Exceptions

There are some exceptions to the standard supplying method. Sometimes it can occur that a service engineer has a project were he or she needs a large number of supplies. Then it can be delivered directly to the customer, this can only happen under two conditions. First, the order should be large enough, which means that it should be profitable, this can differ per situation and is decided by the employee at the central point. The second condition is that it should be possible to store the supplies safely at the customer. If both conditions are applicable, supplies can be sent to customer directly. This is either done by the supplier or by a third party. This process does not include the supplies going through the box. Another exception to the fixed routes is another additional delivery. Sometimes it can happen that a service engineer needs a certain product within a week. If that happens in a week in which he or she is not supplied, it would be a loss. It can be requested to deliver the product in a week in which the engineer is not supposed to be supplied. If the supplier will drive a route which is close to the box of the service engineer, he can drive by that storage box as well. However, this is only possible if the box is nearby and if there is time for that. When this is not the case, the supplies can also be sent by the third-party suppling company. In this way the service engineer will receive the products in time. Nevertheless, it should be mentioned that both options will cost extra money, but the company is willing to pay that extra money if this will guarantee that the service engineer can do his or her work.

2.3. Current data analysis

In order to get an understanding of the performance and demand of the current method in the past, a data analysis is conducted. The raw data, provide by the company, is cleaned and analysed to get useful information about the current method. Graphs with the demand per product and demand per service engineers will be provided to support the analysis.

2.3.1. Data gathering

To get a better insight in the demand and inventory, data from the previous year needs to be analysed. In order to make that happen, data first needs to be gathered and cleaned. The company provided an Excel sheet with raw data of all the streams of the products per service engineer. The advantage of using this primary data is that the data is up-to-date, relevant and specific to this research. (*Primary Market Research | Start Up Loans*, n.d.). On the other hand, primary data tends to be time consuming because of all the noise that is within this raw data. To ensure a high-quality analysis it is necessary to carefully clean the raw primary data (*Data Cleaning - DIME Wiki*, n.d.). In this case it meant that a lot of data needed to be removed since retired service engineers were still in the system. These retired service engineers thus do not have any inventory or demand. Another reason why they have been removed, is that they are not part of the current routes. As explained above in section 2.2, it can also happen that there are large orders which will not go through the storage box, but directly to the customer. These orders are included in the data, but they do not influence the supply through the boxes. They are therefore not of interest and need to be removed. The last action to clean the data was to remove the items which were not involved in the weekly delivering of the storage boxes. These are the items in the data which are only available by request. Besides the noise there is another problem with the data, namely that the time is not always in line with reality. This has to do with the moment the data is processed, namely the data gets invoiced later than the supplies actually arrive. This makes it difficult to estimate the inventory levels, since it is unclear when products arrive at the storage box and when products leave the storage box. For the estimation of the demand this problem is not crucial, since the monthly data is more important for the analysis than daily data because the solution will be based on expected monthly demand.

2.3.2. Data analysis

After the data was filtered it was ready to be sorted. The Excel file consisted of a single sheet of data. The data then was grouped per service engineer. This resulted in an Excel file with multiple worksheets of service engineers. The raw data of items out (products used by the service engineer) was displayed per service engineer and was shown in a table. This table consist of all the different items with their quantities of the year 2020. From those tables' graphs were made to give quick overview of the items with their yearly quantities. Next to the quantities per service engineer, there is also a sheet with the total data of the items. This data is very useful to get an overview of the importance of the individual products. Below are the two graphs of the items from a service engineer and the total product distribution (see figures 4&5).

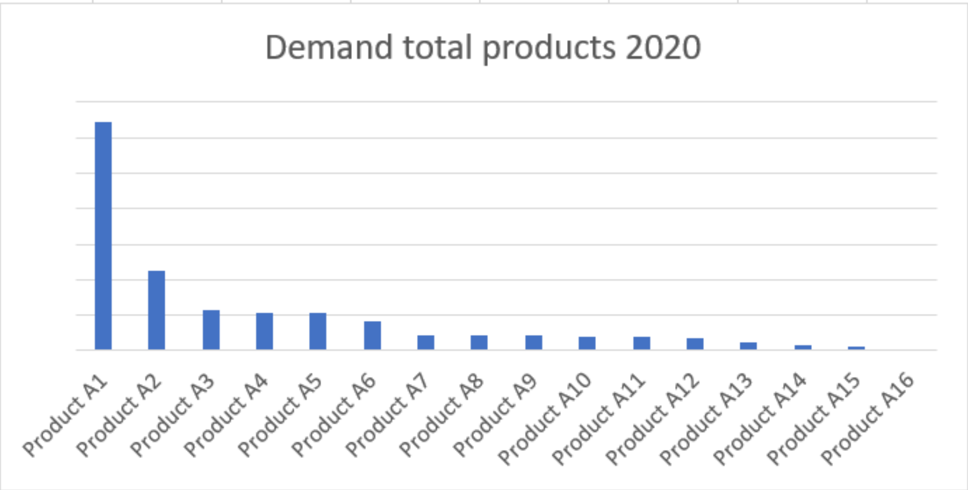

Figure 4, Total demand in 2020, in pieces

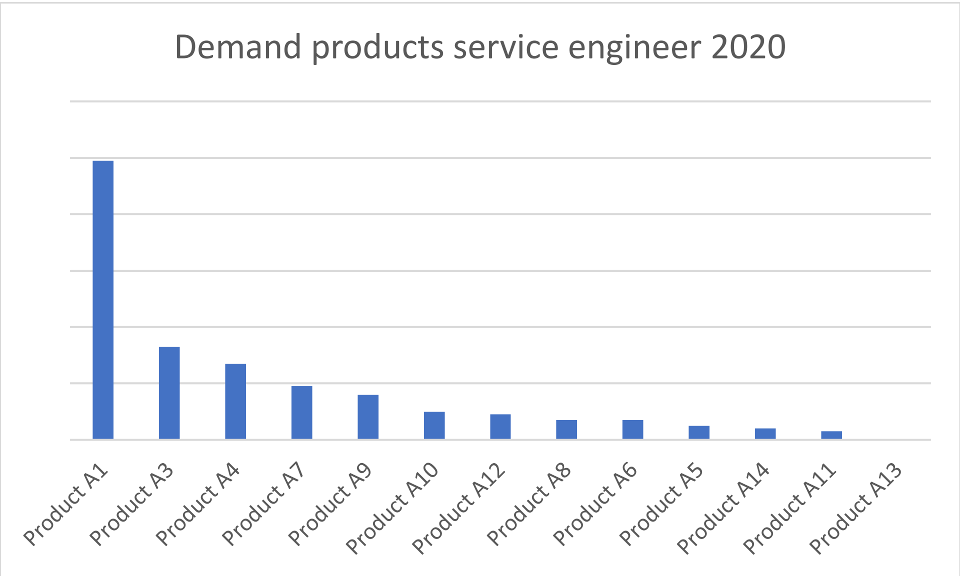

Figure 5, Demand for products in pieces, from a representative service engineer

Right away it becomes clear that one product is by far the most popular, with almost three times as much demand as the second most popular product. In figure 4, it is shown that after product A6, the demand becomes little in comparison to the products A1 to A6. This immediately shows that, if you look at the numbers, the focus of the optimization should be on the first six products. The first six products result in more than 80% of the total demand and 80% of the revenue.

The numbers above only say what the demand was of the year 2020. In order to make an estimation on what needs to be delivered when it is better to look at the monthly numbers. As said before the dates are not always accurate, however the invoices are always accurate on a monthly level. Therefore, the monthly demand per service engineer is of interest. When this information is known, it becomes possible to estimate the order quantities.

The demand per service engineer varies a lot since it depends on the type of customers the service engineer has. The company divides the customers in two groups, the “smaller” and the “larger” customers. Which group a customer is part of, depends on the number of maintainable units. The service engineers are also divided, there are service engineers who focus only on the “larger” customers and ones who focus only on the “smaller” customers. There are no similarities in demand between two random service engineers. However, if you compare the monthly demand of the “smaller” customers in the year 2018, 2019 and 2020, there is a certain correlation. This correlation is shown in figures 6 & 7 below. In both figures the years are more or less the same. Some of the events can be explained, for example, in the summer and December there are fewer working days, because of the holidays. Other small fluctuations however are not directly explainable. Besides those small fluctuations there are no major spikes or deviations. This means that the monthly demand is relatively stable, which is good, since this will result in less overall safety stock (Chopra & Meindl, 2013). Although the overall demand seems relatively stable, the demand per product per service engineer is not. This is stochastic without any obvious pattern, mainly because the service engineers plan their own work. So, the only way to be certain of future demand is to ask the service engineers for their needs for the next month. Otherwise, the future demand will always be an estimation.

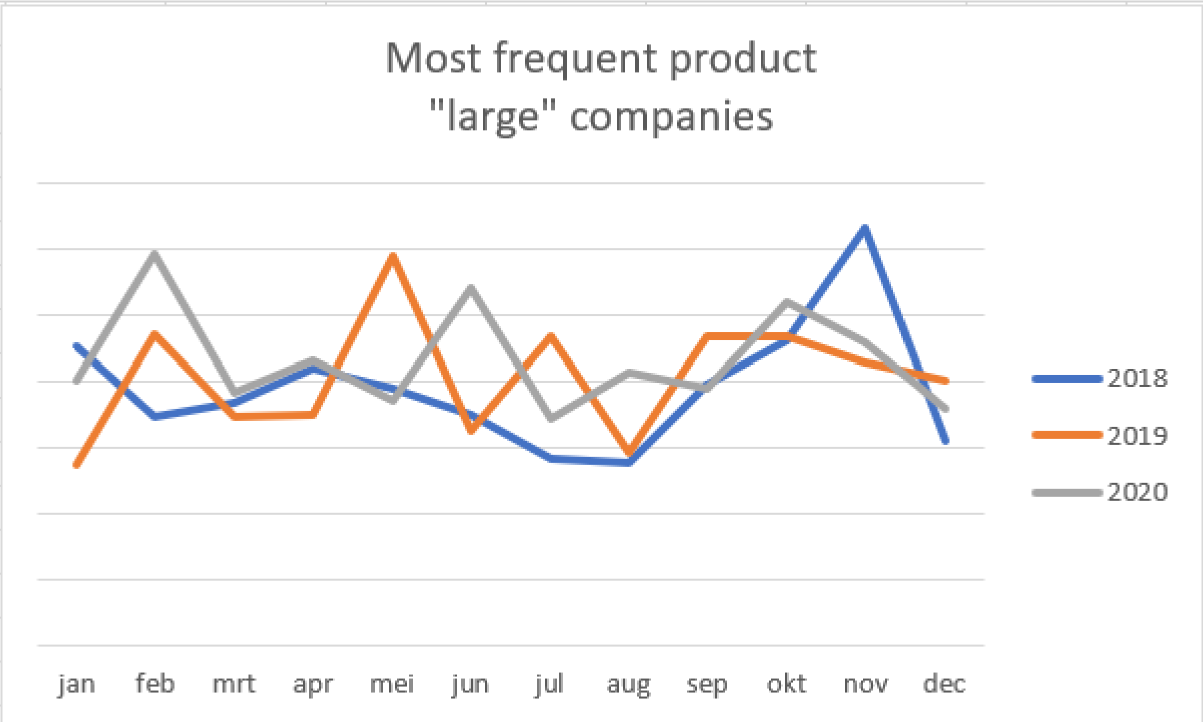

Figure 6, Demand most frequent product “large” companies.

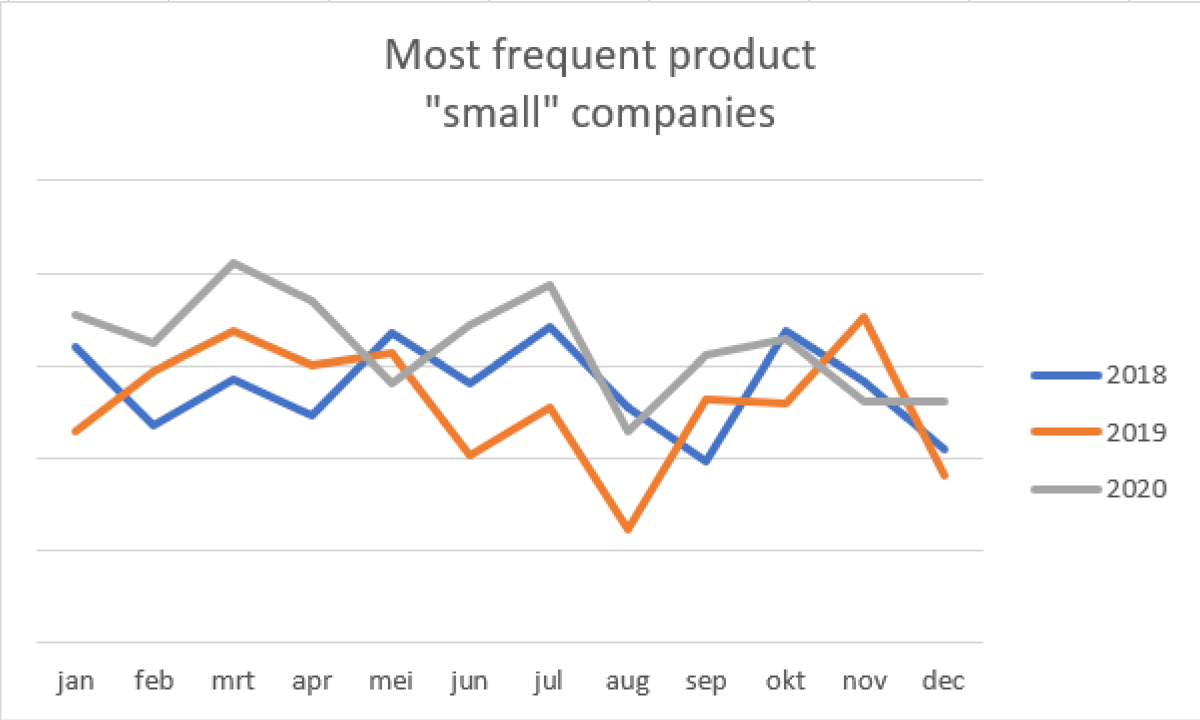

Figure 7, Demand most frequent product "small" companies.

2.3.3. Restock levels service engineers

The company currently works with a (T, S)-policy, where 'T' is the time in between the supply moments and 'S' the order-up-to level. The order up to level is the level to which amount the products needs to be filled, this is currently decided by the service engineer. This policy contributes to the simplicity of the supplying method, that is why this for this thesis the (T,S)-policy will be used.

As said before, the service engineers control their own order-up-to levels, this is done with a note in the storage box to indicate the restock levels. Below in figure 8 it is shown for a couple of service engineers what the restock levels are for the top six products. The figure shows that there are a lot of differences between the restock levels of the service engineers. Some might have optimal or close to optimal values already. However, it will be better if the data will be analysed and the restock levels will follow from that analysis. This way everyone will have the optimal values and the company/supplier get a better overview of the restock levels. Because currently the restock levels can be adapted every day by the service engineers. And because this is only communicated via notes in the storage box, the company/supplier will not know that it changed before the supplier gets to the storage box.

	Product A1	Product A2	Product A4	Product A5	Product A3	Product A6
Service engineer 1	2	6	1	1	1	2
Service engineer 2	6	4	2	1	1	1
Service engineer 3	9	9	6	1	3	2
Service engineer 4	1	8	1	2	1	1
Service engineer 5	2	6	1	1	1	1
Service engineer 6	1	9	1	2	1	1
Service engineer 7	2	9	1	1	1	1
Service engineer 8	2	6	1	2	2	2
Service engineer 9	2	6	2	2	1	1

Figure 8, Overview restock levels per service engineer

2.4. Delivery analysis

With previous data we obtained knowledge about the demands of the products per service engineer. However, to get a full analysis on the supplying it is also important to get an insight in how the service engineers are being delivered. How are the current routes arranged and why are they arranged like that? And also, what are the constraints regarding the supplier's vehicle?

2.4.1. The routing

In the introduction it already showed how the locations are divided (figure 1). Right away it can be concluded that the routes are currently based on their geographical locations. However, there is more to the routes than just the locations. The company did consider the option that a service engineer might be in a sudden need for a certain product. Normally this would mean that the service engineer would have to wait two weeks, if the supplier already delivered the items in that week. However, the routes are arranged in such a way, that every week they will come in every part of the Netherlands. This means if they are in the north of the Netherlands in week one, then they will be also in the north in week two. This is shown by the overview below, route 3 is in the north as is route 8. Route 1 till 4 are the even weeks and 5 till 8 in the odd weeks. This gives more flexibility to the service engineers and the company. Although it is not optimal to drive extra, if the supplier has to already be in that area, it is much cheaper driving by than sending a third party company to go there. The last point the company took into consideration is the total distance of a route. The company tried to divide the routes as equally as possible, with regards to the total distance.

The main disadvantage of this current routing system is that it is fixed and does not take the demand into account. There are eight routes purely based on their geographical properties. Since the demand is not completely deterministic, this is not taken into account. That is the reason why it happens often that products cannot be delivered or that certain products are not even supplied to a single service engineer. This last point is a waste of space in the truck, which can be better used for other goods which are in higher demand. As said multiple times before, it is not optimal that the routes are fixed. However, what makes matters worse is that the supplies in the truck are not fully based on the needs of the service engineers. Due to experience, there is a small difference in the delivery sizes between the routes, but not close to optimal. Besides the routes themselves, there are also some challenges with regards to the truck. Due to Dutch and European regulations, a person cannot drive more than nine hours a day, with the exception of two days in a week where ten hours are allowed. This regulation limits the amount of routing options, since total driving time needs to be taken into account. Possibly even more important is the truck's capacity. The supplier is limited on what he can bring with him. This forces the company to make difficult decisions on what to bring. Section 2.3.2. showed that certain products are in significantly higher demand than the others. So obviously these products are always in a large amount in the truck. Nevertheless, if a product is not needed frequently, it does not mean that you do not have to bring it with you. Since all of these constraints are difficult to take into account at once, the company chose for a simple approach of fixed routes with more or less fixed quantities. Moreover, because the company is considered a high-quality company it is very important that they have a high availability of products. That is why they choose to send products where needed and have fixed routes with high quantities.

2.4.2. Truck and storage box constraints

To analyse the constraints regarding the truck, a conversation with the employee of the central point has been conducted. He helped to make the capacity of the truck measurable. Moreover, the truck can be divided in twelve areas, this could be a maximum of sixteen, but when there are twelve spots it is still possible to walk to the back of the truck. With sixteen it would not be possible to reach the end of the truck, this will form an issue because products from multiple boxes are needed. Not being able to reach the end of the truck will result in higher (un)loading times. Below in figure 10 it is schematically shown how the space in the truck is divided in multiple areas. Figure 11 shows how many items can fit in one area. Moreover, the maximum number of areas for the most frequent items (Products A1 till

A6) is nine. There is one area reserved for all the items which are not delivered that frequent (Products A7 till A15). Another area is reserved for the moveable drawer and there is one spot left for additional items, but this spot is also used to store additional collected waste. Product A16 does not use an area, but a separate place in the truck. Next to the capacity of the truck, there is also the capacity of the storage boxes. These capacities are a bit harder to estimate, because all the storage boxes are different in size. The boxes do have the same drawers and marked areas for the components. However, the extra space in the box cannot be measured for all the boxes, since it varies quite a bit. This extra space can be used to store extra products outside the drawers, this means that some service engineers are able to store more products than others.

Opening truck	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6
	Movable drawer	Area 11	Area 10	Area 9	Area 8	Area 7

Figure 9, schematic view of the deviation of areas in the truck

Item:	Product A1	Product A2	Product A3	Product A4	Product A5	Product A6	Product A7	Product A8	Product A9	Product A10	Product A11	Product A12	Product A13	Product A14	Product A15	Product A16
Maximum amount of items:	**~20**	**~20**	**~20**	**~20**	**~20**	**~20**	**All combined in one area**									**Seperate space in the truck**

Figure 10, maximum number of items per area

2.5. Conclusion current system

The way the supplying is currently handled is simplistic and does not form too many problems for the service engineers. However, the current system is far from optimal since the delivering rate is low, meaning that only 60% of the product in the truck will be delivered to a storage box. Also, certain inventory levels can be on the high side, while others experience some shortages. In short, the current system has advantages and disadvantages. In the bullet list below the main advantages and disadvantages are stated.

Advantages:

- Service engineers experience few shortages
- Service engineers have multiple solutions when a shortage occurs
- Supplying is made simple for supplier and the employee of the central point
- Big orders do not have to go through the storage box

Disadvantages:

- In the current situation only 60% of the products in the truck are delivered to the storage box (rough estimate)
- Service engineers decide on restock levels, this results in high and variable inventory levels
- Routes are mainly based on geographical locations and route length, meaning that demand does not play a role in the current planning.

To conclude, the simplistic strategy results in a low delivery rate and a non-optimal routing solution. From the data we gathered, it is shown that the six most used items are the items of interest. These items result in more than 80% of the total demand. This means that the optimization will take these six products into account. The other products can be easily fitted in the truck (in comparison to the six products), that is why these six products are of importance. Together with the analysis of the route, truck and storage boxes it becomes possible to establish new optimal delivery frequencies and order quantities. To create such a planning a literature study first needs to be conducted on these types of problems, which should give a better insight in the solution to this problem. The literature study can be found in the next chapter.

3. Literature study

With a clear overview of the current situation, it is now time to conduct research on how these types of problems are approached. First, knowledge is gained by diving into a type of problem called, the inventory routing problem. Next to that, more knowledge is gained about the vehicle routing problem in order to get more information on how to establish the best routes possible.

3.1. The inventory routing problem

3.1.1. Introduction

The inventory-routing problem (IRP) integrates inventory management, vehicle routing, and delivery scheduling decisions (Coelho et al., 2014). All of this applies to the problem of this assignment. The goal to find the ideal deliver frequencies, which can be achieved by solving this IRP. Since there is not a "standard approach" to the IRP, it is important to find a variant that works or only needs minimal adaption to work. Therefore, the objective of the IRP approach is to minimize cost while meeting the demand. However, there are also some constraints to the "basic version" as Coelho calls it. These are: The inventory level of each customer (in this case, the service engineers) can never exceed its maximum capacity. Inventory levels are not allowed to be negative. The supplier's vehicles can perform at most one route per time period, each starting and ending at the supplier. And lastly, vehicle capacities cannot be exceeded. Moreover, there are seven criteria to specify a IRP, these are: Time horizon, structure, routing, inventory policy, inventory decisions, fleet composition and fleet size. The time horizon is the time included in the IRP. Next to that the structure tells something about the supplier to customer ratio, this is either; one-to-one, one-to-many or many-to-many. The routing is also divided in three options, option "one" means there is one customer on the route, option "multiple" means multiple customers on one route and option "continuously" means there is no central depot. Then there is the inventory level, the IRP only considers two inventory policies. There is the maximum level, fill to the max capacity of the customer. And there is the order up to level, where the levels of the are indicated rather than filled to the max. Moreover, the inventory decisions are based on whether or not back-logging is allowed. However, if the demand is deterministic then no negative values are allowed, so neither with nor without back-logging. Lastly the fleet can be either homogeneous or heterogenous (fleet composition) and the fleet has a number of vehicles (fleet size). Besides these criteria, there is another criterion which is about the possibility to forecast the demand. If the demand is deterministic for the period of the IRP this will result in another model than if the demand would be dependent on a possibility (stochastic) (Coelho et al., 2014).

3.1.2. The basic IRP

In the article "Inventory routing problems: an introduction" from L. Bertazzi and M. Speranza (2012) an example is provided of a simple IRP from Bell et al. (1983). This article shows the relation between the logistic costs and the delivering possibilities. The problem is very simple but provides a clear explanation of the relation and how a simple IRP is defined. In this example time is discrete, there is one supplier and multiple customers with a limited storage capacity, also there are no limitations on the availability of the products at the supplier. To solve this type of problem, the first step is to define the relevant variables. In this example, M is referred to as the set of customers, C as the capacity of the truck, q_s as the daily demand of customer s, U_s as the maximum inventory level at customer s and I_{st} as the inventory level of customer s on day t. Since this example looks at the logistic costs it does not take the inventory costs into account. Furthermore, with these variables, the goal is to find a periodic distribution policy, meaning a plan on who to serve when, how much and via which routes. This goal should be achieved with taking a set of constraints into account. Some of these constraints are rather obvious, for instance, the vehicle or inventory capacity cannot be exceeded. Other constraints might be more situation based, these are constraints such as, shortages are not allowed. This example does not show a model to calculate the optimal solution, since it is quite basic. However, it shows all the basics of an IRP, it consists of (decision) variables, an objective function and constraints. These components are also major components for a linear program (LP).

Next to the fixed variables there are also the decision variables. The objective function depends on the value of these decision variables. A part of the IRP is the Vehicle Routing Problem (VRP), these problems involve deciding when to visit who and how much should be delivered. These decisions influence the routes. These decisions with respect to the routing are called "over space". Next to that, there are decisions with respect to the inventory management. These decisions include the timing and quantities of the deliveries, which is called "over time". An IRP always includes decisions "over time", but "over space" is optional. That is why the article (Bertazzi & Speranza, 2012) divides the decisions of an IRP into two classes. Either, decisions are only made over time, where the routes are already decided on and only the times and quantities need to be decided on. Or decisions over time and space, where the times, quantities and routes are all decided on at the same time.
In addition to the simple example, Bertazzi and Speranza (2012) provided a more advanced example. It is what they call a Single Link Shipping Problem, which involves decisions over time only and introduces a set of new variables compared to the simple example. Some features of this problem have a lot in common with the current problem of this study, which is why this problem is of interest. This new problem introduces the concept of a periodic policy. This periodic policy is defined with a period P and quantities s_{it} where t=0,1,…p-1 (if the time is discrete). Next, are the number of vehicles at time t, defined by y_t, when there is a maximum of one vehicle per day, $y_t \leq 1$. Finally, the initial inventory levels, d_i, need to be given (Bertazzi & Speranza, 2012). Although this approach has many similarities, it is still not enough to formulate a concrete model with multiple customers. Therefore, more information should be obtained.

3.1.3. The two-phase algorithm approach

Since my IRP is not as simple as the example given in section 3.1.2., an approach is needed to solve this more complex problem. A problem where multiple items should be handled instead of one, and 50 locations rather than four. An interesting approach of the IRP is provided by Campbell et al. (1997), who proposed an integer programming solution. It is a two-phase algorithm. In short, the first phase results in an overview with when to deliver how much to a customer. The second phase establishes a set of possible delivery routes. First, a lower and an upper bound should be established for the integer program. Where the lower bound L_i^t represents the minimal amount that should be delivered to customer i on day t. And the upper bound U_i^t is the maximum amount that should be delivered to customer i on day t. Moreover, the variable d_i^t should always be in between the lower and upper bound and represents the delivery volume to customer i on day t. Another part of the integer program involves a constraint concerning the total volume that can be delivered on a single day. Here the articles provides a model for multiple vehicles, but in the case of this study only one vehicle per day can be driven. Therefore, this part can be easily simplified by using the vehicle capacity as the daily total volume. Other variables which are included in the IRP are: u_i for the consumption rate of customer i, C_i for the maximum capacity at customer i, , I_i for the inventory level at customer i and Q for the capacity of the vehicle. For the integration of the routes an additional set of variables is defined. To begin, variable r represents a possible route, with T_r being the duration of the route (as a fraction of a day). Next to that, the c_r is the cost of executing route r, this involves fuel, the costs of the driver and other vehicle related costs. Finally, the variable x_r^t is a binary variable which tells if on day t, route r is driven. All of this combined makes it possible to create an objective function, namely minimize the total costs, by summing all the costs of the routes that have been driven. This objective function can be modelled as:

$$min \sum_t \sum_r c_r x_r^t \qquad (1)$$

Campbell et al. (1997) reflect on this model and have found two drawbacks. The first is the huge number of possible routes and the second is about the length of the planning horizon. In order to obtain a manageable solution set, the set of delivery routes should be small, however the set should contain logical routes. Next to that, to tackle the planning horizon issue the times in the last period can be aggregated. In order to get a small but good set of routes, clusters are formed. A cluster is a group of customers which can be supplied by one truck in one route. This cluster is not only based on the location, but also on the demand of the customers. The article provides a three-step approach to identify a good set of clusters. First, a large set of possible clusters should be generated. After that a cost estimation of each cluster should be made. And finally, a problem should be solved to evaluate the clusters. In the article they use a heuristic which focusses on the usage of the customers. This way, it becomes clear which customers cannot be in the same cluster. However, all types of heuristics can be applied. With the solution of how much should go where and when, and the additional set of routes, a solution for the IRP is established. (Campbell et al., 1997)

Pantelis Z. Lappas et al. (2017), also created a two-phase algorithm to solve an IRP. Although they both have two steps concerning inventory and logistics, they are not exactly the same. Lappas et al. (2017) chose to calculate the delivery frequencies in the first step, rather than the lower and upper bound of the inventory. This calculation is made based on a (s,S)-policy, where on a certain level s, the inventory will be refilled to level S. With the s- and S-level known and the expected demand, it becomes possible to establish the delivery frequencies. In the second step of the two-phase algorithm, the routes are created based on those delivery frequencies, by an algorithm called: Variable Neighborhood Search Algorithm. With these two steps combined it is possible to make a planning with optimized routes with respect to the inventory levels of the customers. (Pantelis Z. Lappas et al., 2017)

3.1.4. Conclusion

To conclude, the literature study about the IRP provides enough information to solve the IRP of this study. From the introduction part, more knowledge is gained about the sources of the problem and the different variants. Since the description of the IRP has a lot of similarities with the problem of this study, it can be concluded that this study is dealing with an IRP as well. To be able to get a better understanding of the way an IRP is model, the article of L. Bertazzi and M. Speranza (2012) was consulted. This article explained how to look at an IRP, by showing simple examples. After gaining the information on how a simple IRP is approach, the only thing left was to look for an approach suitable for the problem of this study. This has been found in an article provided by Campbell et al. (1997). Moreover, the article makes use of a two-phase algorithm. The first step is concerned about the amount and frequencies of the deliveries. The second step involves creating the best routing clusters. These two steps combined result in planning which indicates, when each route is driven and, how much is delivered at each customer. Another article, written by Pantelis Z. Lappas et al. (2017), also provided a two-phase algorithm. This approach differs mainly in the inventory part, Lappas et al. first calculate the delivery frequencies, which will form a foundation for the routing plan. However, both articles both uses two steps, one for calculating the inventory levels and one for the routing. In the next chapter these approaches and steps will be used in order to reach an optimal solution for the IRP of the company.

3.2. The vehicle routing problem

3.2.1. The introduction

The second part of the two-phase algorithm involves creating optimal routes, in other words, it is a VRP. In order to be able to create the best possible routes for the situation, some more insights should be gained about the VRP. The basic restrictions of the Capacitated VRP are all the routes start and end at the depot, each consumer is visited at least once and the total demand of any route should not exceed capacity Q of the respective vehicle involved. Because this is considered an NP-hard problem, calculating the optimal solution is too time-consuming. An alternative to the exact methods is the heuristic methods. The objective of the heuristic methods is to find an approximate solution, which has an acceptable solution according to some criteria and does not exceed a certain computation time (Tavares et al., 2009).

From the literature different heuristics will be talked over, which will be used and tested for the second phase of the two-phase algorithm of the IRP.

3.2.2. Different heuristics

The VRP distinguishes between three different types of heuristics: constructive heuristics, improvement heuristics, and metaheuristics. The constructive heuristic constructs the first feasible solution for the problem. The improvement heuristics looks for better alternatives of this constructive solution. And finally, the metaheuristics, they have been improved some much over the years that they only need a starting point, feasible or not, in order to get a sub-optimal solution. The next part will focus on the different approaches used for constructive and improvement heuristics, which are planned on being used in the solution approach.

Constructive heuristics

Constructive heuristics are usually employed to provide a starting solution to an improvement heuristic (Laporte et al., 2014). They serve as a foundation for the improvement heuristics. While constructive heuristics try build a feasible solution with the costs in mind, they do not contain an improvement phase. This makes them useful for creating initial routes, but the solutions are far from optimal. Furthermore, because of the great improvement of the metaheuristics, constructive heuristics are not that relevant anymore. However, because they are fairly simple, they can be implemented easily as well. This makes it interesting to used them in a tool for creating a planning. One of the most well-known constructive heuristics is the one from Clarke & Wright (1964). This principle creates all single routes from the depot to the individual customers. After that, those routes will be merged and if the costs of the merged route are lower than the individual routes, this will be the new route. This process continues until there are not more feasible solutions. Another heuristic is the route first–cluster second heuristic from Beasley (1983). This heuristic is based on two simple steps, first you create one large route and then you cluster it in groups, as the name already suggested. The goal of the first step is to create an optimal route which goes through all the points (i.e., the well-known traveling salesman problem). When the giant route is established, the goal is the divide the routes into a set of feasible routes. This approach is great to use for multiple reasons. First, it makes sure the closest cities will be on the same route, since they are already close to the giant route. Secondly, it is suitable for a large set of customers. And finally, it can be computed relatively fast, also the large set of customers. However, it must be stated that it is only a constructive heuristic, meaning that, in order to get close to an optimal solution, improvement heuristics are necessary. Finally, there is another common and intuitive heuristic called the Nearest Neighbour Heuristic (NNH). This heuristic takes a random location and looks for the nearest point which has not been visited yet. Partly due to the randomness of selecting the point, the heuristic normally results in solutions of around 20 to 35% worse than the optimal solution (Hoos & Stützle, 2005).

Improvement heuristics

As stated before, the improvement heuristics need an initial solution, created by a constructive heuristic. The overall idea of every improvement heuristic is to adapt the initial feasible solution in many ways and evaluate whether or not this adaption is an improvement. In practice, inter-route improvement moves are essential to achieve good results. These include classical operators such as removing customers from their current route and reinserting them elsewhere (called relocate) or removing n edges from different routes and reconnecting them differently (called n-opt), swapping consecutive customers between different routes (called swap) (Laporte et al., 2014). All of these heuristics can be applied individually and in combination with the others. An example of a relocating heuristic is the cheapest insertion. This method takes a location and tries to place it elsewhere within or out of its route. When this new situation is more optimal than the original, it will replace the original situation. Next to the relocate heuristic, the 2-opt heuristic knows two different variants, the inter-route and the intra-route heuristic. The 2-opt approach takes two non-consecutive edges (route between two points) removes them and connects them in a different way. As all other improvement heuristics, if the new situation is better, it replaces the current situation. The difference between the inter- and intra-route is the location in which they swap the edges, inter swaps edges within a route and intra swaps edges between different routes (Tavares et al., 2009). Lastly, the swap operation can have multiple forms, it is possible to swap one location in one route with one location in another route. However, it is also possible to swap two items with only one item. Moreover, it must be said that a swap is not always possible capacity wise, and solutions which exceed the capacity can never be a valid solution.

3.2.3. Conclusion

To conclude, heuristics are the key to get a sub-optimal solution within a short amount of time. According to the research of Tavares et al. (2009) the heuristics resulted in a sufficient decrease in average distance compared to the constructive heuristic, with only a minor increase in computation time. This is not the same for every case, however it shows the potential of using heuristics. A combination of a quick and efficient constructive heuristic with one or more good improvement heuristic will result in a sub-optimal result within an acceptable time frame. The goal for this assignment is to analyse the different heuristic and find the most suitable approach for the company. These heuristics will be used in a planning tool, which makes it relevant to also look at the computation times besides the distances and costs.

4. The model

In this chapter it is explained how the model for this situated is constructed using the information gathered by the literature study. A description of the model is given, together with the model assumptions and the mathematical model. Next to that, it is explained how this model is implemented in a planning tool constructed in Excel/VBA.

4.1. Model description

The model used for this thesis is inspired by the two-phase approaches from Campbell et al. (1997) and Pantelis Z. Lappas et al. (2017). It also consists of two steps. The first step is to determine the delivery frequency of each location (storage box of the service engineer). The second step is to solve a VRP for all locations with the same delivery frequency. The model tries to minimize the total distance driven, while visiting and supplying all the storage boxes of the service engineers.
In order to do this, the first step is to determine the delivery frequencies by means of a fairly easy calculation. This calculation is conducted on each of the six SKUs, where the highest delivery frequency of a location will be the delivery frequency of that location. The expected demand of product from a service engineer for a four-week period is divided by the storage capacity of that product. The location will get the correct delivery frequency, based on whether the outcome is higher or lower than a set value. Furthermore, the storage capacity can be seen as the order-up-to level for that product for one specific service engineer. Next to that, safety stock should not be considered, since the space the service engineers have in their own vans is considered safety stock.
Secondly, when all the delivery frequencies are determined, two VRPs can be solved. One for all the locations with a delivery frequency of once every two weeks. And one for the locations with the frequency of once every four weeks. The reason for solving two VRPs rather than one VRP with both delivery frequencies, is that separating the delivery frequencies gives a clear overview for the planner. It provides also more structure for the employees at the central depot who need to fill the truck with supplies. The impact of this approach will be analysed in section 5.4. The goal is to minimize the total distance travelled in a four-week period for both VRPs. Moreover, there are constraints which should be taken into account. The first constraint has to do with the maximum amount of time the truck driver is allowed to work according to the Dutch law. Not exceeding this maximum can be achieved by limiting the total distance to a certain number. The other constraint is about the truck capacity. In section 2.4.2 it is explained how the truck capacity can be quantified. Moreover, it is estimated that eight truck areas should be enough to store the six SKU. These constraints make sure that routes are created which are possible to use in practise.

4.2. Model assumptions/simplifications

In order to solve this model, some assumptions/simplifications are required. The first simplification involves the second part of the model. Since a VRP is a NP-hard problem (Lenstra & Kan, 1981), it needs heuristics to solve the VRP. Which is why different heuristics will be used and evaluated to come up with a sufficient solution for this model. Another simplification is to separate the delivery frequencies, meaning that every route only includes one type of delivery frequency. This is recommended by the company, because it will provide more clarity and structure for the employees. Next to that, it is assumed that the daily usage/ total demand is deterministic, while in practise this is stochastic. The service engineers plan their own work, which makes it difficult to accurately estimate the daily usage. Therefore, the model is assumed deterministic and because the values are estimated, an extra percentage of supplies needs to be added. This lowers the chance of not being able to fully supply a service engineer. Another assumption is that no shortage can occur at the central depot, in practise this has never been an issue, since enough inventory is kept at the central depot. The final assumption is that the distances for the routes will be estimated instead of exact distances. Because using the exact distances is not possible without the use of an Application Programming Interface

(API), an estimate is made based on the coordinates of the locations. For a more detailed explanation conduct Appendix A: Planning tool.

4.3. Solution methods

Since a clear model is constructed, it becomes possible to solve this model. In this section it is explained which steps have been taken to determine the expected daily usage of the service engineers, which routing heuristics will help to find a near-optimal solution and how that resulted in a planning tool.

4.3.1. Solving the first step

The first step of the solving the model is to calculate the delivery frequencies. In order to calculate the delivery frequencies of the products, the daily usage and order-up-to level (which can be the maximum capacity of the storage box) must be known. First, the daily usage can be derived by gathering data. The demand of the last three years per product per service engineer is derived from the data. Based on this information a daily usage can be estimated. Since the model is assumed deterministic the estimated values need to be increased by a percentage to compensate for the stochastic behaviour of the daily usage. In section 5.2 an analysis is conducted on the amount of supplies with respect to the expected shortages and total distance. In order to decide if this percentage is accurate, the values will be evaluated by the company to check if the values are in line with the expectations.
Secondly the order-up-to level must be stated. A possibility would be to use the maximum storage capacity as order-up-to level. However, the problem with that is that the maximum capacity of the storage box is not the same for every service engineer. Therefore, the maximum capacity for a single product is also not the same for all service engineers. All the boxes are different in size and have a different layout. That is why the first step was to double the original order-up-to levels set by the service engineer for a two-week period and check if these values were possible. This was done by consulting the employee at the central depot. Since the service engineers decide on their order-up-to levels for a two-week period, it would be possible to double their order-up-to levels and that would half the delivery frequency. So, for instance, if a service engineer has an order-up-to level of 10 for a two week period, he would also have enough if the order-up-to level is 20 for a four week period. This can only be done if the storage capacity allows it.
With the daily usage and order-up-to level per product known, the delivery frequencies per product can be estimated. If the expected demand of a four-week period is higher than the storage capacity, the delivery frequency will be once every two weeks. Because this would mean that on average more products are used in a four-week period than can be stored. If a product's expected demand is lower than the storage capacity, a delivery frequency of once every four weeks should suffice. It also should be taken into account that the expected demand is increased by a percentage to lower the chance of shortages in the truck. Next, the delivery frequency of a location is the highest delivery frequency of a product for that location. Meaning that even if five of the six products need to be supplied once every four weeks, if one products needs to be supplied once every two weeks, all the products for that location will be supplied once every two weeks. The delivery frequencies of each location conclude the first part of the model. For the current situation, 85% of the locations needs supplied once every four weeks. With this information two VRPs can be solved, one for each delivery frequency.

4.3.2. Solving the second step

In order to solve the second step of the model, two VRPs need to be solved. Both VRPs are mainly the same, the only difference is that each VRP has different locations. One VRP for all the locations with a delivery frequency of once every two weeks and one VRP for the locations with a delivery frequency of once every four weeks. The VRP is a standard VRP where the truck capacity and the maximum number of kilometres are constraints. The goal of the VRP is to minimizes the total driven kilometres in a four-week period, while visiting all the locations. This should be achieved by not exceeding the maximum amount of 480 kilometres driven in a route. If the average speed of the truck would be 80 km/h, the total driving time of the maximum route would be 6 hours. This is significantly below the allowed time, but the distances are estimated by the tool, so a margin is necessary. It should also be taken into account that the driver also needs time to (un)load the supplies at the location. Next to that, the truck capacity of 8 areas should not be exceeded. And it can also be assumed that the storage capacity will not be exceeded, since the calculation of the delivery frequency makes sure it will not be exceeded. In order to solve this VRP, heuristics will be used.

4.3.3. Routing heuristics

Different heuristics from the literature will be tested and evaluated. From the literature multiple constructive and improvement heuristics were found to solve the VRP. For the constructive heuristics the 'route first, cluster second' heuristic was selected. It is a simple constructive heuristic and according to Beasley, J. (1983) "the basic method (route first, cluster second heuristic) has promise as a foundation for an effective procedure for practical vehicle routing problems.". This makes it a great choice for the constructive heuristic. As stated in section 3.2.2. the improvement heuristics often makes the difference, which is another reason why there is no need to experiment with more constructive heuristics. Next to the constructive heuristics, improvement heuristics will also be used in to solve the VRP. The different improvement heuristics from the literature will be tested with different settings. These improvement heuristics are: 2-opt, cheapest insertion and the swap heuristic. The 2-opt heuristic takes two non-consecutive edges and reconnects them differently, this heuristic will be implemented within the constructive heuristic. Meaning that the constructive heuristic creates one route through all locations, then uses 2-opt to optimize this route, and then clusters them into multiple routes. After the Hamiltonian circuit is established and improved by the 2-opt heuristic, the clustering starts at the closest location to the central depot. Then the next location on the route (Hamiltonian circuit) will be added to the cluster (clockwise) if it does not exceed the total route limit or truck capacity. Next to the 2-opt, after the routes have been clustered, the cheapest insertion heuristic takes one location and inserts it somewhere else, within or out of its original route. Cheapest insertion checks all locations and tries to insert them in all possible places, if the inserting a location into a new place it will be the new situation. When an insertion is successful the entire process of inserting locations will start at the first location again. Lastly, the swap operation that will be used, swaps one location with another location from another route. The swap operation also tries to swap all combination of locations and checks whether or not it is an improvement. When there is an improvement, the process starts over beginning at the first locations. These three improvement heuristics (where the 2-opt heuristic is only used in the constructive part) together with the constructive heuristic will create the near-optimal solution for the vehicle routing part of my IRP. An evaluation of the heuristics can be found in section 5.1.

4.3.4. The planning tool

The model (the delivery frequency calculations and heuristics) is implemented in Excel/VBA. Not only for calculating the model once, but rather to make a future proof planning tool. Excel/VBA offers the ability to create user friendly interfaces which can be used as input for the planning tool. Next to that, Excel is also used frequently in companies, making it easy to use and export the output. The goal of the planning tool is that it can be used by the company for future analyses and planning. The planning tool offers multiple features. The first feature makes it possible to add, remove and edit locations. Secondly, the tool offers the possibility to increase or decrease the total demand by a set percentage. This can be helpful in the future when it is concluded that the estimations of the demand are inaccurate. And the final key feature is the option to change the amount of truck areas which can be used for the six products. In Appendix A: planning tool, it is explained how the planning tool is created and which features are implemented. It must be noticed that although it is called a planning tool, the tool only provides the routes, since the company prefers to plan the routes themselves.

4.4. Model validation

To be able to make sure that the model is accurate, the company is asked to evaluate different assumptions and input of the model. These evaluations are concerning the route distance and truck capacity constraints, estimated demand, chosen order-up-to levels and the calculated delivery frequency. Lastly there will also be an evaluation on the planning tool itself, this will not be included in the thesis, but will be performed to help adapt the tool to the company's preference.

First, the company looked in more depth into the route length restriction. They used an estimate of 70 kilometres an hour to estimate the time driven on a route. Moreover, a fixed amount of time was added for all locations that are visited on a route. The time it takes to complete an entire route cannot be longer than nine hours, with the exception of two routes which are allowed to be ten hours. The current set of routes satisfy the requirements. Next to that is the truck capacity, the employee at the central point estimated the 8 areas of truck capacity. However, there are some uncertainties with regards to this number. The changes can have an unexpected influence on the waste and other items which are stored in the remaining 4 truck areas. The question remains whether 4 truck areas is enough to store the waste, small items and other stuff. If eventually it seems that this is not the case, the solution with a capacity of 7 truck areas for the six products should be chosen. Another variable that is validated, is the delivery frequency. This is created from the expected demand and the storage capacity. The storage capacity has been evaluated by the employee at the central point, he has enough experience to tell whether a location has the right maximum capacity. For the expected demand, the company use data from the previous six months to validate this demand. The data used in the tool is considered valid if the expected demand is within 30% of the average? demand from the previous six months. The 30% margin is given by the company, this margin should make sure that the not too many or too few supplies are in the truck. The numbers which did not fulfil this requirement were discussed in a short meeting and adapted. Finally, the delivery frequencies were evaluated. The company agreed with the calculation of the frequencies, however there are some locations which for special reasons needs to be supplied once every two weeks. These locations were given the right frequencies. Moreover, an option was added in the planning tool which enables the user to give a location a delivery frequency of once every two weeks, rather than letting the tool calculate the best frequency.

5. Numerical experiments

With the planning tool it becomes possible to perform different experiments. Many different experiments can be ran by the planning tool with ease, making it an useful tool to analyse different variables. This will especially be helpful regarding the recommendations for the company. In order to gain insight in the variables it is important that different tests will be ran, where only one variable changes at the time. This means that the standard situation has a truck capacity of eight areas, the locations are the same as the current locations, delivery frequency are divided in once per two and four weeks and the routes will only include locations with the same delivery frequency. In the next part the variables ‘truck capacity’ and ‘number of locations’ will be tested. Also, the influence of the constraints concerning the delivery frequencies will be evaluated. To compare the results, we will look at the total driven kilometres in the four week period. However, before those tests will be run, the routing heuristics needs to be evaluated. In order to check the influence of every heuristic and make sure the best possible results are obtained, an analysis on the heuristics will be conducted.

5.1. Routing heuristic evaluation

In order to measure the individual and collective influence on the improvement heuristics, an evaluation is done with different sets of improvement heuristics. The locations and data used in this test are the actual locations and data from the company. All the combinations of heuristics were tested with a truck capacity of seven, eight and nine areas. This, because heuristics can give different outcomes based on the constructive heuristic. By changing the truck capacity different routes will be formed, by evaluating the three different situations we gain a more accurate representation of the heuristics. Moreover, changing the truck capacity can happen, since it is difficult for the company to estimate exactly how many areas in the truck can be used for the six ‘largest’ products. The order in which the heuristics are executed are as followed: first the constructive heuristic is called. This is the route first group second heuristic. Together with this constructive heuristic the first improvement heuristic is called, namely the 2-opt heuristic. This makes the Hamiltonian circuit (one long route through all the locations) as short as possible. After that improvement the groups are made based on their order on the big route and are split by the capacity/maximum route length. Thus, in order to get an initial solution of the routes, a Hamiltonian circuit is created, this is improved by a 2-opt and then the routes are clustered. When the routes are formed the single swap heuristic and the cheapest insertion are called, respectively. This order is kept in all the experiments, but in different experiment different heuristics are left out. Below in table 1 the results of the experiment are shown. Moreover, the values are produced by the planning tool made in excel, this tool makes use of estimated distances based on coordinates, for more information conduct section 8.2. The tool calculated the current total distance driven in a four-week period at 5073 kilometres. The real (not estimated by the tool) distance is 5141, this is a deviation of 1,3%.

Table 1, Overview of the results of the improvement heuristics experiments in driven kilometres per four weeks

Improvement heuristics \ Truck capacity	7	8	9
2-opt, CI, single swap	3613	3267	3251
CI, single swap	3503	3360	3174
2-opt, CI	3902	3297	3251
2-opt, single swap	4141	3931	3805
CI	3572	3360	3285
Single swap	3946	3846	3818
2-opt	4373	3961	3835
Only constructive heuristic without 2-opt	4055	3968	4010

Note: CI stands for cheapest insertion. 2-opt is applied at the constructive heuristic.

The first major point that stands out in table 1, is that the best combination of heuristic (highlighted in yellow) is not always to use all the improvement heuristics. With a capacity of 7 areas a decrease of 110 kilometres is obtained by not using the 2-opt. With a capacity of 8 areas, 93 kilometres are between using all the improvement heuristics and all but 2-opt. Capacity of 9 areas, saves almost 100 kilometres if the situation with all the heuristics is compared to all but 2-opt. This case makes it difficult to determine whether or not to include the 2-opt heuristic. One simple solution is that one run is done with 2-opt and one without and the best is chosen. This will influence the computation time, but as explained later in the paragraph, this will not matter that much. It is also good to notice that if one would only look at the Hamiltonian circuit, the 2-opt improvement heuristic does cut some kilometres from the total distance. Without the 2-opt heuristic the total distance of the Hamiltonian circuit is 1206. If one tries to improve it by using the 2-opt heuristics a total distance of 1135 kilometres is reached. This distance is almost a 6% decrease but can still provide a less optimal initial solution for the other improvement heuristics. Another point which stood out is the influence of the single swap heuristic. If one looks at capacity of 9 areas, it does not matter for the total distance if single swap is applied or not for the case with all the heuristics and all but single swap. This shows that the single swap heuristics does not add any value in this situation. However, in the experiments with capacity 7 and 8 areas, there is always some decrease in total distance when the single swap is involved, where the biggest decrease is almost 300 kilometres between all heuristics and all but single swap with a capacity of 7 areas. Because the single swap never negatively influenced the total distance in these experiments, it is useful to include it in the planning tool. Besides the influences of the 2-opt and single swap, it is interesting to see that some situations from capacity 8 areas are better than capacity of 9 areas. This is due to the nature of heuristics, since heuristics try to find a good solution from a large set of solutions, it can happen that different situations can have different outcomes than expected. Next to that, in order to measure the contribution of the improved routing on the total improvement, the planning tool needs to be used with all the locations having a delivery frequency of once every two weeks. These frequencies need to be the same as the original situation, thus once every two weeks. When the frequencies were changed and the code ran, a total distance of 4426 km was acquired, which is an improvement of 12,8% achieved solely by more efficient routing. The last comment is about the computation times, these are not provided in the table. Since the computation times are not significantly high, there is no reason to base choice of heuristics on them. The computation time of the run of the planning tool with all the heuristics is 3,05 seconds. The computation time of the tool without any heuristics is only 3,04 seconds. (The experiment was run by a Intel i7 running Windows 10 with an 3,5-GHz processor and 16 GB of memory)

To conclude the heuristic evaluation, the constructive heuristic route-first cluster-second, with and without the 2-opt heuristic, together with the cheapest insertion and the single swap heuristic is the most optimal combination. If the standard situation of 8 areas is compared to the current supply planning, a decrease of 35,6% is achieved, where 12,8% is due solely by the improved routing. From 5073 estimated kilometres to 3267 estimated kilometres. This can be explained by more efficient routing and a better estimation of supplies needed by the service engineer. Because the supplies needed are better estimated, it becomes possible to supply certain locations less frequent. This results in a lower total distance of a four-week period. Below in figure 12 the difference between the new and old routes are shown.

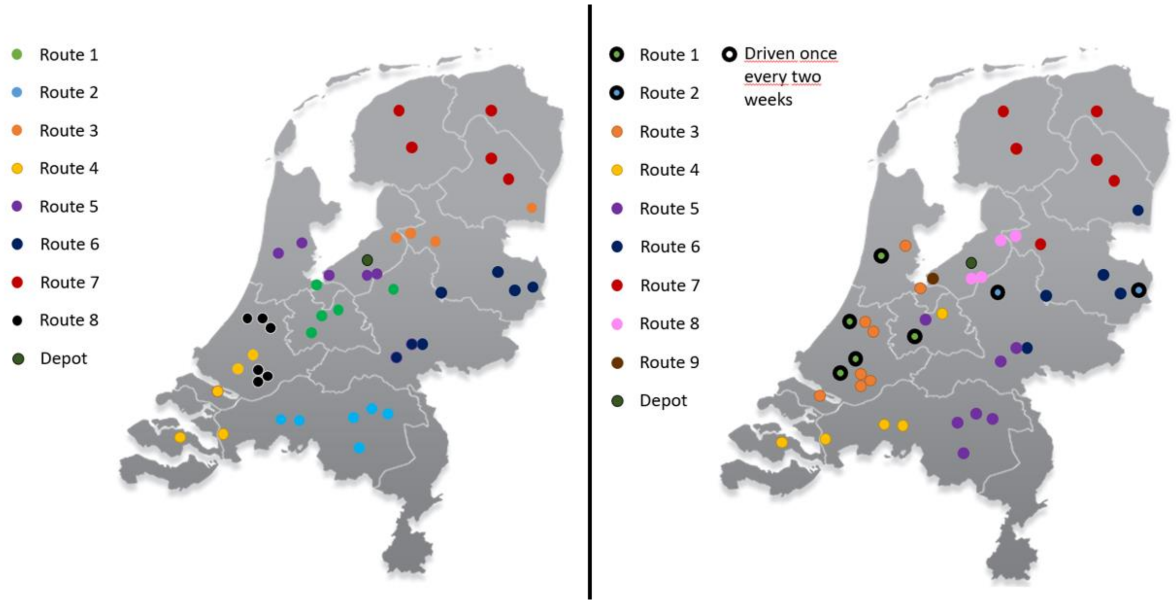

Figure 11, old (left) and new (right) routes

5.2. Shortages evaluation

Next to the routing, an evaluation on the expected shortages will be conducted. This will be approached as follows. First, data will be used of each type of supply used by the service engineers. This will be grouped per month over a period of the last three years. Each month will be compared with the amount of supplies the tool calculated. The shortage percentage is the percentage that the tool did not estimate enough supplies. By changing the supplies brought, an analysis can be performed on the relation between the supplies and the expected shortages. Furthermore, the total distance is calculate, to be able to gain more insights in the impact of bringing more or less supplies.

Table 2, evaluation shortages and total distance based on demand.

Extra supplies	Estimated shortages	Total distance
-20%	20,8%	3046 km
-10%	18,0%	3109 km
-5%	17,1%	3179 km
0%	16,8%	3250 km
5%	16,5%	3250 km
10%	15,6%	3267 km
20%	14,3%	3564 km
50%	9,1%	3988 km

Note: Extra demand is the extra percentage of demand brought based on the average demand (given by the data).

From table 2 it can be concluded that 16,8% of the supplies cannot be completely supplied, when using the supplies based on the average demand. Moreover, when 50% extra supplies are brought the expected shortages will be below the 10%. However, although 7,7% less shortages occur, the total distance driven is increased by 22,7%. Below in figure 12 the results are plotted in a scatter plot and a trendline is used to show the relation between the supplies and shortage. From this trendline it can be concluded that bringing 30% extra supplies, will result in 5% less shortages. Finally, the best option depends on the importance of the shortages and how easy shortages can be solved. This is for the company to decide. However, for the future calculations 10% extra supplies will be used. Because this option has the lowest shortage with a total distance close to the original.

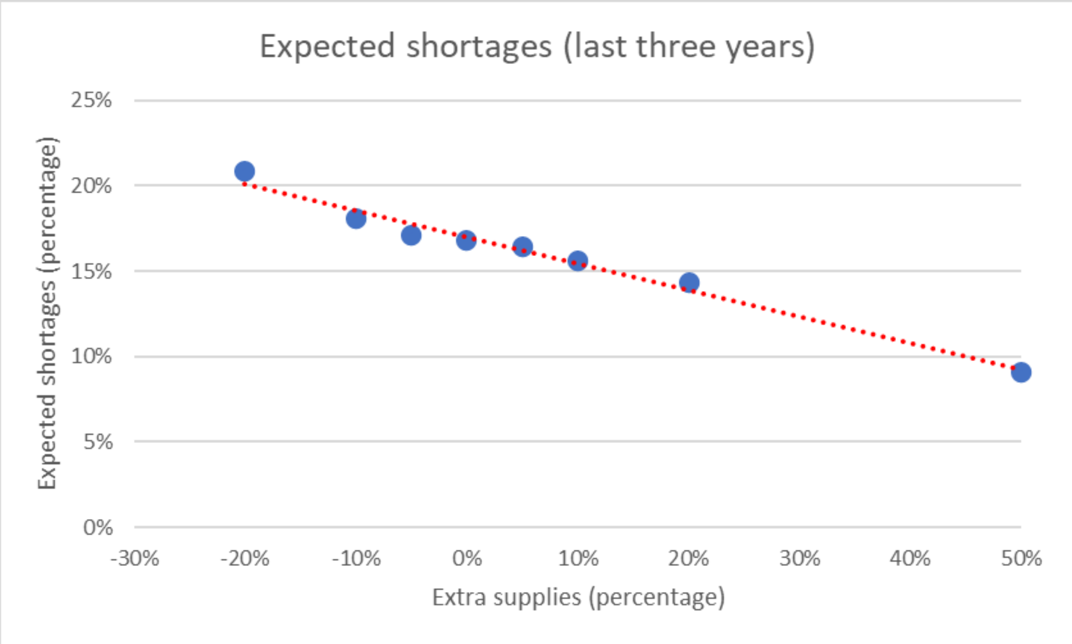

Figure 12, Expected shortage based on the amount of supplies

5.3. Truck capacity

Since the optimal heuristics and quantities are known, other tests can be performed. In order to test the truck capacity, we change the truck capacity by one and let the other variables be the same. For this case we can partly reuse the results from the heuristic tests. They are as follows:

Table 3, Evaluation truck capacity

Truck capacity	7	8	9	10
Total kilometres in a four-week period	3560	3267	3251	3109

The results of the new planning compared to the current situation are as follows. For capacity of 7 areas this is 29,8% decrease in total driven kilometres to the current situation of 5073 kilometres. For 8 areas, this is 35,6%. For 9 areas, 35,9%. And a capacity of 10 areas results in a 38,7% decrease. Although it must be noticed that a capacity of 10 areas is highly unlikely under these circumstances. When taking a closer look at the exact percentages, it can be seen that from capacity 7 areas to capacity 8 areas there is a decrease in kilometres of 8,2%. From capacity 8 to 9 areas this is only 0,4%. In order to see if this trend continues, a truck capacity of 10 areas is also examined. The decrease from capacity 9 to 10 areas is 4,6%. Thus, logically, when the truck capacity increase, the total kilometres driven in four weeks decreases. However, the percentages of the decrease varies a lot. While capacity 8 and 9 areas are close, 9 and 10 areas on the other hand are far apart. This can be explained by the fact that heuristics do not give an optimal, but rather a sub-optimal solution. Some variations of variables will be closer to the optimal solution than others. The theoretical lower bound for the total distance is two times the Hamiltonian circuit, which is 2270 kilometres. This would be the case if the truck capacity would be infinite without maximum route restrictions and all the locations would be supplied once every two weeks. This means that even with a capacity of 10 areas, there is still almost a thousand kilometres to be gained by having no capacity and maximum routing distance restrictions.

5.4. Delivery frequencies

Finally, experiments will be conducted regarding the delivery frequencies. In the current solution, it is arranged that a location either has a delivery frequency of once per two or four weeks. Also, a route consists of locations with the same delivery frequency. In order to get an insight on the effect of this approach, different scenarios will be tested. The first scenario that will be tested, tests if it would be beneficial if the delivery frequency can also be once every three weeks besides the other two delivery frequencies. This means that the length of the route will be multiplied by 4/3 in order to get the distance driven in a four-week period. The second scenario will test the influence of the constraint that every location in a route has the same delivery frequency. This scenario works as follows. First a planning is created for the first two weeks, this involves all the locations. Then the planning for the other two weeks is created, this only involves the locations which need to be supplied once every two weeks. The results of both scenarios can be found below in table 3.

Table 4, Evaluation delivery frequencies

	Standard situation	Delivery frequencies of once per 2, 3 and 4 weeks	Routes can contain locations with different delivery frequencies
Total kilometres in a four-week period	3267	4064	3336

First of all, the total length when adding a third delivery frequency is increased by 24,4%, which indicates that the two delivery frequencies are better than the option with three. This extra delivery frequency reduces the flexibility of the routing, since three VRPs are solved instead of two. Although the delivery frequencies might be more accurate, the model becomes less flexible which results in a higher total distance driven in a four-week period.
The second test shows only a minor increase in total distance, an increase of 2,1%. This is not a significant difference and because heuristics were used to find a solution it could be also the case that his approach is more beneficial in some situations. However, since the difference is not significant there is no reason to change the current planning approach to this new one.

6. Conclusion and recommendations

6.1. Conclusion

The first conclusion is that the company can theoretically obtain a decrease of 35,6% driven kilometres by use the planning from the planning tool. By estimating the demand, delivery frequencies could be calculated more efficiently, which resulted in less frequent supply moments for certain locations. Only 15% of the locations needs to be supplied once every two weeks, in the current situation this is 100%. Also, the number of supplies that will be delivered will be arrange by the company, rather than by the service engineers. This results in more efficient storing of the products, which makes it possible to supply certain locations less frequent. Another reason for the 35,6% decrease, is the routes, which are provided by heuristics. The routes are created by evaluating many alternative solutions, rather than just looking at geographical position and route length. If only the routes were changed, thus without changing the delivery frequencies, an improvement of 12,8% will be achieved. These two reasons reduced the total estimated distance of 5073 kilometres to 3267 kilometres.

The second conclusions explains where most is gained regarding the delivery frequencies and order quantities. As stated in the first conclusion, 15% of the locations is supplied once every two weeks rather than 100%. This was only possible at locations where the expected demand was low enough or the storage capacity large enough. In other words, the expected demand in a four-week period should be lower than the storage capacity of a location, for all the products. As the numbers show, it is possible to supply less frequently for a significant number of locations. Also, the order quantities are estimated by means of historical data. However, it is difficult to estimate the impact and accuracy of the new order quantities, since the exact delivery quantities per location were never mapped the company. Although the expectations are that the percentage of items in the truck that will actually be delivered, is higher in the new situation. This is expected, because the current situation stores a general number of items in the truck, which is mainly the same for each route. The new situation, provided by the planning tool, has estimated the demand for each location in the route, which will be more accurate. However, since the supplies are different for each route, more time will be needed for supplying the truck. Nevertheless, the employee at the central point stated, that it would not be a significant increase in time and workload since there are a fixed amount of different routes which he can prepare in advance.

The next conclusion is about how the routes are created. The best results were obtained by using all the improvement heuristics or all except the improvement heuristics used at the constructive part. Different scenarios resulted in different results. In one scenario the result did benefit from the improvement heuristic at the constructive heuristic. However, in another scenario the improvement heuristics only made it worse. Because of that, the best approach is to test both and use the best one. The other two improvement heuristics never contributed to a worse result, that is why those two will always be used to solve the VRP. These heuristics find the shortest total distance by trying different possibilities which satisfy the constraints. This is unlike the current routes, which is based on the geographical position of the locations and the goal to divide the routes equally in length.

The final conclusion regards the truck capacity. In section 5.2. it is concluded that the going from 7 areas of truck capacity to 8 areas (8,2%) is a more significant difference in total distance driven than going from 8 to 9 truck areas (0,8%). Moreover, from 9 to 10 areas a decrease of 11,6% kilometres driven can be obtained. This divergent can be explained by the nature of heuristics, since it does not provide an exact solution, difference scenarios have different impact. Nevertheless, the results made it possible to gain more insights in the effect of the possible change of truck capacity.

6.2. Recommendations

Grounded by the literature, experiments and other research, a set of recommendation will be advised to the company. These recommendations contribute to making this theoretical plan work well in practise and to prepare the company for potential problems.

The first recommendation is to try to use eight areas of truck capacity for the planning. As shown in section 5.2, going from eight to nine areas is not a significant improvement. However, from seven to eight areas, this is the case. Thus, going to seven will result in a significant increase in total distance. Although, it must be noticed that a capacity of seven areas still results in an improvement of 29,8%, which is above the target of 25%.

The second recommendation is to keep track of the first deliveries with the new planning. If the company is able to track the number of items that is delivered to every location, it could help to improve the quality of the estimation of the expected demand provided by the planning tool. Moreover, the demand is actually stochastic, but the tool estimates demand to make use of the deterministic model. If certain locations have too many or too few products to deliver, it can be changed in the tool per location. It is also recommended to look at the shortages analysis performed in section 5.3, here the expected shortages are shown with respect to the amount of supplies. Moreover, it can also happen that the truck has still too many products which are not supplied at a location, or that certain products can be supplied due to shortages in the truck. If one of these two happens a lot, it is possible to add or subtract a certain percentage on the total demand in the planning tool. This option makes it easy to adjust the demand if necessary.

Next to estimating the right number of high-demand products in the simulation, it is also highly recommended to take the other products into account. Especially for the routes that will be driven once every four weeks. Normally all the routes were driven once every two weeks, but most routes now will be driven once every four weeks. From this it can be concluded that the other products also need to be doubled. Thus, for the “once every four weeks” routes it is important to take into account that the other products also need to be supplied in larger quantities. Together with the increase in waste of used products. If all of this results in truck capacity issues, the tool provides an option to lower the amount of truck areas used for the six products. This can be used to tackle this potential problem.

Furthermore, the routes provided by the planning tool will offer a good potential solution, but since it is created with the heuristics it can still be that a better solution is possible. Thus, a recommendation is to make use of the possibility to adapt certain routes. It is not recommended to change entire sections of multiple routes, since then it can be possible that the outcome will be worse. However, the people at the company have a lot of experience already with supplying, so it is likely that they will see an optimization compared to the result of the planning tool. The routes will be provided by the planning tool, however when each route will be driven is up to the company, which gives the company the possibility to plan the routes in a beneficial way. If in this process an opportunity arises to optimize a route by changing it, the company is free to do so. By not planning everything to the exact date, the company will have the freedom and opportunity to adapt it to their preferences.

One more recommendation to optimize the accuracy of the deliveries, is that the service engineers have knowledge of the exact number of supplies, for the six products. If they know exactly when the supplier comes and how much he brings, they will be able to message the day before if they need more or even less supplies than expected. For example, if the service engineer knows he or she will get ten products x, but he or she only needs five, that will provide extra space in the truck. The supplies will be prepared ahead of the delivering date, thus the employee at the central depot only needs to add or remove some supplies in the area where the supplies are for that date. This approach will prevent possible shortages and help improve the percentage of products in the truck that will actually be delivered. However, this does not mean that the routes will change last minute, only the quantities of items that will be brought in the truck.

Continuing on the previous recommendation, it must be noted that this recommendation is an option for later use and requires additional research. If the service engineers would communicate in advance how much they exactly need for the next month, it would be possible to create the routes with even more accuracy than the current planning tool. However, this requires a lot of good communication between the company and service engineers. Next to that, it requires the ability from the service engineers to estimate the demand and plan ahead. Most service engineers which were contacted during this study, pointed out that this was possible, but would cost some additional work. Not only for the service engineer this would cost more work, also for the employee at the central point. He would need to run the planning tool more often and filling in the data of all the service engineers every time. Also, he cannot plan ahead, because every planning will include different quantities and routes. This flexibility results in more work for the employee at the central depot to prepare. To conclude, this might be a better option, however it would require some more work for the parties involved. This means that in order for this to be implemented well, sufficient research needs to be conducted.

One final recommendation is to have good communication with the service engineers and explain the importance of their cooperation. If they know they will be supplied and they expect a shortage or the still have too much, it would be a ton of help if they would communicate this to the central point. Also, they have a van in which a lot of supplies can fit. If they know they will be supplied the next day, it would be better if they would load the van as full as possible. This van can function as a sort of safety stock, if they fill the van before their storage box will is supplied, they will have the maximum number of supplies, which will help the efficiency of the process. However, in order for this to work smoothly it is crucial that the communication between the supplier, service engineers and central depot is clear.

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8. Appendix A: Planning tool

8.1. Creation of the planning tool

In order to put the model to good use, it is crucial to have an efficient and clear planning tool. The tool must be intuitive for the employee at the central point (operator), give a quick and clear overview of the planning, be future proof and be able to include all the data and heuristics without compromises. Microsoft Excel/VBA will be used to build this planning tool, since a lot of people already use it (including the operator) and it offers clear output of the data (in an Excel sheet). In VBA (programmable part of Excel) it is easy to implement the heuristics and Excel functions as an input and output. It is important that the tool has one overview where the input can be filled in and one overview for the output. This makes it easy and thus prevents errors. The input should include the daily usage of the customers and the order-up-to levels, since both are needed in order to determine the delivery frequencies. Moreover, the input should contain options to add, delete and change locations, this makes it future proof. All of this means that the company can use the planning tool in the future, in case the situation changes. Another reason why the tool should be quick and future proof is that the tool might be used more frequent in the future. Currently, the information is based on historical data and experience, however to get a more accurate planning it can be the case that the company wants to use the exact demand from the service engineers. It is a possibility to ask the service engineers in advance to send the expected demand for the next month, since they can estimate pretty accurate what the demand will be for the next month. However, since this requires more communication and effort from the company and the service engineers this is not applicable right now. Nevertheless, it can be possible in the future if the company decides to adapt to this new system and if they do they can still use this tool. Regarding the output of the tool, it is important that the planning is given over a four-week period. A repetitive cycle of four weeks makes it easy for the company to plan and the service engineers to know when the supplies will arrive. This fixed cycle will help to increase productivity since the employees at the central point need less time preparing the supplies for the truck. The service engineers also know that they will be supplied at a fixed interval, this gives them structure, which will contribute to less supplying mistakes, since they know in advance when they will be supplied. Lastly, the final output should consist of the following information: A route number, the locations of the route, the estimated distances and number of products that will be supplied (per product).

The tool will provide some additional options to gain more insights in the effects that certain variables have on the planning. One of the options will be to change the capacity of the truck, which is used for the six products, in section 2.5.2. the capacity of the truck is discussed. Currently it is estimated that eight areas can be used for the six products, however this might change. Even if it does not change, they are at least able to simulate what would happen if they would want some more space for other uses, which means less truck capacity for the six products. It should be kept in mind though that every area is good for storing around twenty products. The other options have to do with the supply quantities. There will be an option which provides the opportunity to set an extra order quantity above or below the estimated quantities. If the company would like to have more reassurance that the supplier can deliver enough supplies to everyone, they can choose to bring a percent of items above or below the estimate quantities. The final option is a general option not implemented in the tool, which is the option to adapt the routes themselves. Since the planning tools makes use of heuristics and not the best solution, it might be that other solution are more desirable. The company is free to use the tool as a guidance rather than a strict solution. The company has a lot of experience in driving these routes, so they can decide if they want to drive a route in the order as it is showed by the tool, or in reverse order. This might have benefits concerning the waste collection at the storage boxes. Another aspect they can control is the week in which the route is driven. The tool provides the routes and the number of times the route needs to be driven in the four week period. The company needs to decide when to drove the routes, they can take factors into account a model is not always able to translate. With the experience they gained over the years, they are more suitable for this task. Lastly, the company is also able to adapt certain locations, if there is one route which only has only location and the company sees an option the heuristic did not, then they are free to adapt it. The goal is to provide the company with a sub-optimal solution, since this is obtained by heuristics it can/will be the case that there are still improvements available. If this is the case, the company can adapt it as much if they want, however by changing too many aspects of the route it might be that there will be a decrease in performance rather than an increase.

8.2. Explanation of the planning tool

In the previous section it is mentioned how the planning tool was created. In this section it is explained how the planning tool works on a more detailed level. The tool consists of four Excel worksheets, four user forms and a code to run the tool. First the four worksheets will be explained. The first worksheet is the settings sheet. It consists solely of a piece of text and one button. The text is a general description of the tool and the button opens the user form where the planning tool can be initiated. The second worksheet shows the data. Every row of data represents a location. Each row consists of location number, location city, latitude & longitude of the location, deliver frequency, total products, monthly usages of each product, order-up-to level of each product and extra space for additional comments. The third worksheet displays the distances between the locations, which are based on the latitude and longitude, for more information see below. Lastly, there is the output worksheet. After running the code this is the worksheet which will be displayed. This will give all the information needed to create a planning. This includes all the routes with the amount of supplies needed. Next to the worksheets there are the user forms. The user forms are Excel's implementation of a Graphical User Interface (GUI), these provide a clear overview of actions which can be executed. These user forms are fully customizable and programmable. A big advantage of user forms is that they can validate input, this makes it more suitable for input than changing cells in Excel. This advantage is used in three of the four user forms. These three user forms are made for: adding, deleting and editing locations. The user form for adding locations consist of different boxes, which need to be filled with the data of the location, this is the list from earlier in this section. Next is the user form of editing locations, rather filling in all the boxes, one only needs to select the location which needs to be edited and the data will be loaded in the boxes. From there the data can be edited and saved to the data worksheet. The other user form is the deleting user form, the user form provides a list with the current location and from that list one can choose which needs to be deleted. All the boxes in the user forms are checked for error before writing the data to the worksheets. This includes, checking if a box is empty, if the value of a box is not numerical, if the latitude or longitude is separate by a dot rather than a comma, etc. If a value is incorrect, the user will receive feedback in the form of a pop-up message, this message will tell what error did occur. Since the operator of the planning tool is only able to edit the data through the user forms mistakes are not possible, regarding the input. This makes it user friendly and future proof if someone else ever needs to use the tool. The last user form is where the planning tool will be initiated. This user form consists of two settings: the capacity of the truck and the extra percentage supplies. The user form also has three more buttons to open the add, delete and edit user form, respectively. When the settings are chosen and the locations and data is up to date, the planning tool can be ran. This will all be done by one large piece of code, the high-level pseudo code of this code will be discussed below.

The first step is to get all the locations from the data sheet and calculate the distances between them. This is done by the following formula, the basis of this formula is acquired from (*Latitude and Longitude in Excel: Calculate Distance, Convert Degrees, and Geocode Addresses – BatchGeo Blog*, n.d.):

$$Acos((Sin(latF * \frac{\pi}{180}) * Sin(latS * \frac{\pi}{180}) + Cos(latF * \frac{\pi}{180}) * Cos(latS * \frac{\pi}{180}) * Cos(lonS * \frac{\pi}{180} - lonF * \frac{\pi}{180}))) * 8180. \qquad (2)$$

Where latF and lonF are the latitude and longitude of the First location, and the latS and lonS the latitude and longitude of the Second location. The first part of the formula calculates the linear distance between the two point (taking the shape of the earth into account). The second part, the number 8180, is the factor which makes up for the non-linearity of the roads. This value is found by testing different factor and comparing the results of the estimation with the real distance, the factor which resulted in the lowest standard deviation is chosen as the factor. After the distances are known it becomes possible to start creating the routes with the constructive heuristic. A more detailed explanation of the algorithm of the constructive heuristics can be found below under the header "route-first cluster-second". The clustering of the routes will be done by dividing the locations into groups of locations which have the same delivery frequency. So first all the routes with delivery frequency once per two weeks will be grouped, then once per four weeks. After this distinction is made, the routes are created based on the capacity. When the routes are established and thus an initial solution is created, it becomes possible to use the improvement heuristics. The improvement heuristics which will be used are the single swap and cheapest insertion. More details about the algorithms can be found below under the header "single swap and cheapest insertion". These improvement heuristics will help to obtain more optimal routes. The 2-opt improvement heuristic can also find better solution from time to time, but since this is not always the case two models have been ran. One with the 2-opt heuristic and one without. Both will be evaluated and the best one will be chosen, based on total distance. The last thing to do, after the sub-optimal routes are established, is to write the routes in a clear overview to the output worksheet.

Route-first cluster-second

This constructive heuristic solves the problem called "Travelling Salesman Problem" (TSP). A TSP is defined as a set of locations which all need to be visited once. This heuristic technically gives one solution to this TSP, because to the first route (Hamiltonian circuit) is a solution of a TSP. In order to solve this TSP, it is important to establish a set of variables. Where S = a sub set of location which is not yet travelled, dist(i,j) = the distance between location i and j, and C(S,i) = the total distance of the route without the locations of subset S. In the end it is the goal to find the minimum value of C(S,i) where S=$\{i, 0\}$, with 0 being the depot. From this information the following functions can be created.

$$C(S, i) = dist(0, i) \qquad S = 2 \tag{3}$$

$$C(S, i) = \min\{ C(S - \{i\}, j) + dist(i, j)\} \quad j \subset S \ \wedge \ j \neq i \wedge j \neq 0 \ \wedge S > 2 \tag{4}$$

In order to solve the first part from equation (9): $C(S - \{i\}, j)$, recursion is needed. When starting at S=2 it becomes possible to solve the equation for S=3, until the best route is found with all locations included. (*Travelling Salesman Problem | Set 1 (Naive and Dynamic Programming) - GeeksforGeeks*, 2018)

2-opt heuristic

In the first part of the route-first cluster-second heuristic, a Hamiltonian circuit is created. With the 2-opt heuristic it becomes possible to optimize this route. In theory the 2-opt heuristic removes two edges and tries to reconnect them in another way. If this is successful and thus results in a shorter total distance, then the new route becomes the initial solution. After that the process of swapping will restart until no more optimizations can be found. Moreover, the algorithm, which is implemented in this tool, takes two points and reverses the route in between those points. This will have the same results as reconnecting the lines after removing two edges. In this implementation the 2-opt heuristic does optimize the Hamiltonian circuit, however this does not necessarily mean that the final routes will benefit from it.

Single swap and cheapest insertion

The two improvement heuristics have very much in common. In short, both heuristics take a location and put it somewhere else, evaluate if the new situation is better than the original and replace it if it is. After each replacement the first loop starts over, until no other replacements are made. Single swap, swaps one location with another. Cheapest insertion however, only replaces one location. The two main differences are: Cheapest insertion replaces only one location where single swap replaces two. The second difference is that cheapest insertion can replace a location within its route, where single swap only replaces locations from different routes. The pseudo code of a simplified version of the single swap can be found below in figure 13.

```
line1:
for i = 1 to last_location -1
    for j = i + 1 to last_location
        if i!=j and are_in_same_route = False
            calculate original_route1, original_route2, new_route1, new_route2
            if (new_route1 + new_route2) < (original_route1 + original_route2)
                k = location(i)
                location(i) = location(j)
                location(j)= k
                goto line1
            end
        end
    end
end
```

Figure 13, Pseudo code simplified single swap