Maarten Ipskamp

Centralizing the logistics of De Voedselbank

Bsc Thesis

UNIVERSITY OF TWENTE.

VOEDSELBANKEN

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Centralizing the Logistics of De Voedselbank

Creating a new distribution network for De Voedselbank

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Management Summary

The goal of this research is to solve a problem for the food banks in the region Twente-Salland. (De Voedselbanken). There are 11 food banks in the region Twente-Salland and there is one distribution center. Each food bank drives once or multiple times per week to the distribution center to pick up their products. The problem is that the transport costs of this current situation are too high.

The aim of the research is to lower the transport costs by creating a new distribution strategy. This strategy consists of a new scenario in which the food banks do not pick up their goods at the distribution center but the goods are delivered to them. Furthermore, the aim is to give an advice on how this scenario should look and which vehicles should be used in this new scenario. The last part of the aim is to create a tool which will help the food banks to create a strategy on a daily basis.

To solve the problem a few steps are needed. The first step was an analysis of the current situation of the food banks. This is done by a data-analysis of the database of the distribution center. This database is reorganized so that per day the weight and volume of the products from the distribution center to the food banks was known. This table is used later in the thesis in the experiments section.

The next step was a literature search on a Vehicle Routing Problem (VRP). A vehicle routing problem considers the situation in which there are a few customers requiring a certain demand and a few vehicles with a capacity limit that must visit all the customers. The goal of this problem is to find the shortest route for which all constraints are met. After assessing different approaches, the one fitting the best for the problem and the scenarios of the food bank was an exact approach in which a MILP is solved.

After this, the mathematical model of the VRP for the situation of the food banks was developed. The approach for this was to start with the basic model from the literature review and add other constraints such as a time constraint and a second capacity constraint. After this, a tool is created so the food banks can solve their VRP on a daily basis.

The next step were numerical experiments with the tool. In these experiments, 3 different scenarios were researched by calculating the yearly total costs of these scenarios and comparing it with the current costs. Per scenario, 4 demand levels were considered even as 4 different options for the vehicles. The first conclusion is that it is best to create a new scenario in which food banks that are located relatively close to each other are grouped and visited on the same day. The next conclusion is that if the demand does not increase with more than 10%, two trucks are profitable. The investment will be approximately €32.000, while the savings per year are €10.799, which is 47% of the current variable costs. This investment will be profitable in three years. If the demand increases it is best to buy a third truck. If the demand increases with 25%, the investments will be €48.000, while the savings will be €14.208 per year or 50% of the costs of the old strategy in this situation.

The contribution of this thesis to the practice is that it delivers a tool which helps the food banks solve the problem on a daily basis. This tool can also help food banks in other regions since it is easy to use and all parameters can be changed quickly. The contribution to the theory is that it can even help solving VRPs in other contexts besides the food banks.

The recommendations in this thesis are among other things that the food banks can lower their variable costs by approximately 50% if they decide to transform their distribution strategy to a scenario in which the products are delivered instead of picked up. In this scenario some food banks must be grouped. The

vehicles for this scenario are 2 trucks if the demand does not increase. The implication for the food banks will be that some food banks must change the days on which they receive their products. Another implication is the distribution center must improve their registration of the incoming and outgoing products.

Further research can be done by improving the tool such that time windows, multiple depots and dynamic time matrices are included. This will improve the tool for the situation of the food banks but it will also increase the number of situations in which the tool can be helpful.

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1 Introduction

In this chapter the thesis is introduced. The chapter starts with section 1.1 in which the background of the problem will be discussed. Section 1.2 and 1.3 describe the preliminary research and the related work. In section 1.4 the problem statement is discussed and in section 1.5 the aim of the research is given. Section 1.6 provides the research question and the chapter ends with section 1.7 in which the structure of the thesis will be described.

1.1 Background

The companies/organizations for which the assignment will be done are 'De Voedselbanken' in the region Twente-Salland. In the rest of the report, they will be called food banks. In the Netherlands, there are in total 172 food banks. (voedselbanken.nl, sd)The employees of the food banks all work voluntarily to ensure that the clients get free food. The clients are relatively poor people in the Netherlands who struggle to make the ends meet. There are 37.000 households (Feiten en Cijfers Voedselbanken Nederland 2020, 2020) that are helped per year. These households can often get one food parcel per week. This parcel consists of enough basic products so that the households can eat for a whole week. There is also a distinction between the sizes of the households. A household that consists of 4 persons receives more than a household that consists of one person.

Each food bank is a foundation and has a board. There is one umbrella organization: Voedselbankennederland. But each food bank and distribution center are a sole organization which means that they can have their own policy. In the region Twente-Salland, there are 11 food banks and there is one distribution center in Deventer. The food banks get 50% of their foods from Deventer by driving to the distribution center once or more times per week. The other half of the products comes from local suppliers.

1.2 Preliminary research

During the preliminary research, I did some interviews with the chairmen/coordinators of the food banks in the region. These interviews were guided interviews. A few questions were prepared, and these questions can be found in Appendix A. The goal of this interview was to get an overview of the current situation of the food banks qualitatively. These insights will be further explained in Chapter 2 in which the characteristics will be described. The other goal was to get an insight in the covid-situation at the food banks and discover how covid will impact the number of clients. This will also be explained in Chapter 2 and the results will also be used in Chapter 5 in which experiments will be done with these results.

1.3 Related work

Related work which was done earlier is a survey by students of the University of Tilburg. In this survey, all food banks in the Netherlands were asked about their current logistics system (Tilburg, 2021). The start of this survey consists of a few basic questions such as the number of households per food bank. After this, there are questions on the capacity of each food bank. The relevant part of this survey is however on the vehicles that each food bank has and the capacity of these vehicles in both weight and volume. There is also a question on the fuel costs of the food banks which will be relevant in this thesis. Both parts will be used in Chapter 2 in which the characteristics of the food banks will be described and the total relevant transport costs will be calculated. (Tilburg, 2021)

1.4 Problem Statement

The problem of the food banks is that their travel expenses are too high. This is mainly because of three subproblems as Figure 1.1 shows. The first subproblem is that the capacity at the different food banks is too low. The location of most food banks is relatively small, and these food banks have a problem when they receive an unexpected big batch of products.

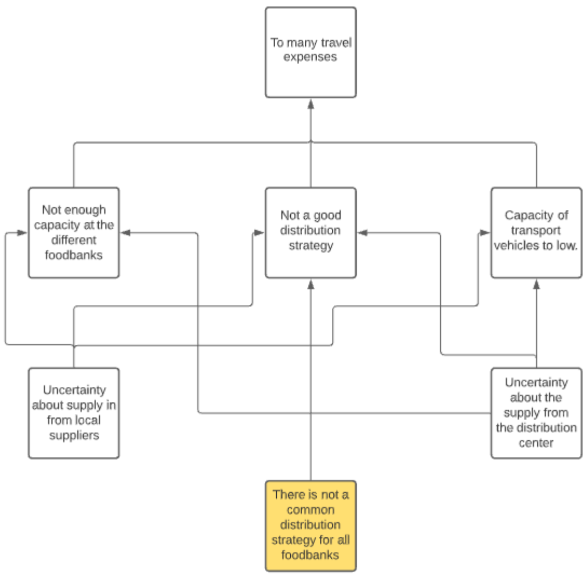

Figure 1.1. Problem Cluster

Another subproblem is that the capacity of the transport vehicles is too low. Every food bank in the region has its own transport vans and these vehicles are a bit too small. This means that these vehicles must transport in smaller batches, and this implicates that these vehicles must travel to Deventer more often which is not efficient.

The third subproblem is that the food banks lack a good distribution strategy. This is due to a few factors. The first two factors are that there is an uncertainty in the supply from either the local suppliers or the distribution center in Deventer. It might be the case that there is an enormous supply on Monday for example in Deventer and there is nothing on Tuesday. This is also the case for the local suppliers. The core problem is that each food bank has its own transporting strategy. There is not good communication, and each food bank has its own vehicles and drives on their own to Deventer. So, there is not a good common distribution strategy. This problem can also be seen as a Vehicle Routing Problem (VRP) in which the food banks are the customers and the distribution center is the depot. Further explanation of the VRP can be found in Chapter 3.

The norm of the action problem is that the costs should be lower than they are now, and the reality is that the costs are too high. The total relevant variable costs in the reality will be discussed in Chapter 2, and an expectation of the norm is that these costs should be approximately 50% lower than they are now. The norm of the core problem is that there should be a clear common distribution strategy, but the reality is that the food banks lack a good strategy. The problem owners are the food banks in the Region Twente-Salland.

1.5 Aim of the Research

The aim of the research is to create a new distribution strategy for the food banks. This strategy consists of advising on the vehicles the food banks need to buy as well as advising on how to carry out the new distribution. This advice can for example be to only include a few food banks in the common distribution or use more cooperation between the food banks by using one of the food banks as a sub-distribution center. The last part of the research aim is a tool to help the distribution center distribute on a daily basis. This tool will give the best routes for the vehicles to drive, considering the food banks which need to be visited per day and how many pallets need to be delivered.

1.6 Research questions

This research consists of the main research question and a few subquestions. The main question for this research is:

How can the vehicle routing problem related to the supply of the food banks in the regional network from Deventer be optimized?

To come to an answer to this question, a few subquestions will be needed. The first subquestions are:

1 What is the current situation of the food banks regarding transportation?
1.1 What is the current situation of the food banks regarding transportation qualitatively?
1.2 What are the quantitative characteristics of the food banks (location, vehicles, important days)?
1.3 How many products do the food banks pick up in the distribution center per day?
1.4 What are the variable costs of the current system per food bank?

These questions will be answered in chapter 2. The next subquestions are:

2 How can the Vehicle Routing Problem of the food banks be solved?
2.1 What are the characteristics of a Vehicle Routing Problem?
2.2 Which solving methods are available for this Vehicle Routing Problem?
2.3 Which solving method is the best for solving this Vehicle Routing Problem?

To solve these subquestions, literature research will be done. The first part of the literature search is on a Travelling Salesman Problem (TSP) which is the basis for a VRP. In this part, we will look at the characteristics and solving methods of this TSP. Hereafter, we will research the VRP.

The next subquestions are:

3 What is the solution to the VRP?
3.1 What is the mathematical model of this VRP?
3.2 How can the food banks solve the VRP on a daily basis?
3.3 How can the tool and the model be validated?

These questions will be answered in Chapter 4. The next subquestions are:

4 What is the best distribution strategy for the food banks?
4.1 Which scenarios can be used to improve the distribution and lower the costs?
4.2 Which vehicle(s) are best to use in these scenarios?
4.3 What are the costs of these new scenarios?

These questions will be solved in the experiments chapter. The last subquestions are:

5 What is the advice for the food banks?
5.1 What are the main conclusions of this research?
5.2 What are the recommendations of these conclusions?
5.3 What are the implications for the food banks?
5.4 What are the next steps for the food banks?

The research design for answering the above research questions is provided in Appendix A.

1.7 Structure of the thesis

After the introduction, Chapter 2 is the context analysis chapter. Chapter 2 consists of two parts, the first part are the descriptions of characteristics of the food banks and the second part will be an analysis of the database. In this part, I will research the database to come to a table with the products which need to go to the different food banks per day for the year 2020. We will then use this table to calculate the number of trips to the distribution center per food bank. This can then help to calculate the total fuel costs, which we will validate by the real fuel costs per food bank.

Chapter 3 is a literature study chapter. The first half of the chapter considers the Travelling Salesman Problem (TSP) with its characteristics and solving methods. In the other half of Chapter 3 the Vehicle Routing Problem will be discussed with its characteristics and solving methods.

Chapter 4 starts with the mathematical model of the VRP for the food banks. The next part of that chapter is an explanation and demonstration of the tool for the food banks and the last part is the validation of the tool.

Chapter 5 is the experiments chapter. In that chapter, the experiments are performed. 3 scenarios will be researched together with multiple demand increases and vehicle options. Chapter 6 is the last chapter and in that chapter, the recommendations and results of this thesis will be discussed.

2 Context analysis

2.1 Introduction

In this chapter, the context analysis, and the current situation of the food banks in the region Twente-Salland will be discussed qualitatively and quantitatively. Sections 2.2, 2.4 and 2.5 provide the characteristics of the food bank (i.e., the location and size, the important days, and the current trucks). In between, in Section 2.3 the qualitative characteristics of the food banks and their transport network are discussed. Section 2.6 provides a database analysis of a database with all order lines of the distribution center of 2020. In Section 2.7 the fuel costs per food bank are discussed. This completes the current situation and is the standard for comparing the new situations later in the thesis.

2.2 Location and size

Table 2.1. Sizes of each food bank

Food bank	Number of households
Enschede	325
Almelo	178
Midden-Twente	256
Oost-Twente	150
Losser	45
Rijssen	70
Hellendoorn	70
Raalte	170
Zutphen	250
Vaassen	75

There are 11 food banks and one distribution center in the region Twente-Salland. The distribution center is located in Deventer, but one of the 11 food banks is also located in Deventer, even at the same location. This means that this food bank does not need vehicles to travel to the distribution center. This implicates that this food bank is not important for this VRP. This means that there are 10 food banks in this VRP. These food banks are listed in table 4.1 with the number of households that the food bank provides food for. As can be seen in Table 4.1, there are big differences in the number of households between the different food banks. There are relatively big food banks such as Enschede, Almelo and Zutphen, there are a few medium-sized food banks and there are small food banks like Losser and Rijssen.

Figure 2.1 shows the locations of the food banks in the region Twente-Salland which will be included in the vehicle routing problem. The yellow pin shows the location of the distribution center while the blue pins show the locations of the food banks in the region. The figure shows that most of the food banks are relatively close to each other and the east of the distribution center, with the exception of the food banks in Vaassen and Zutphen.

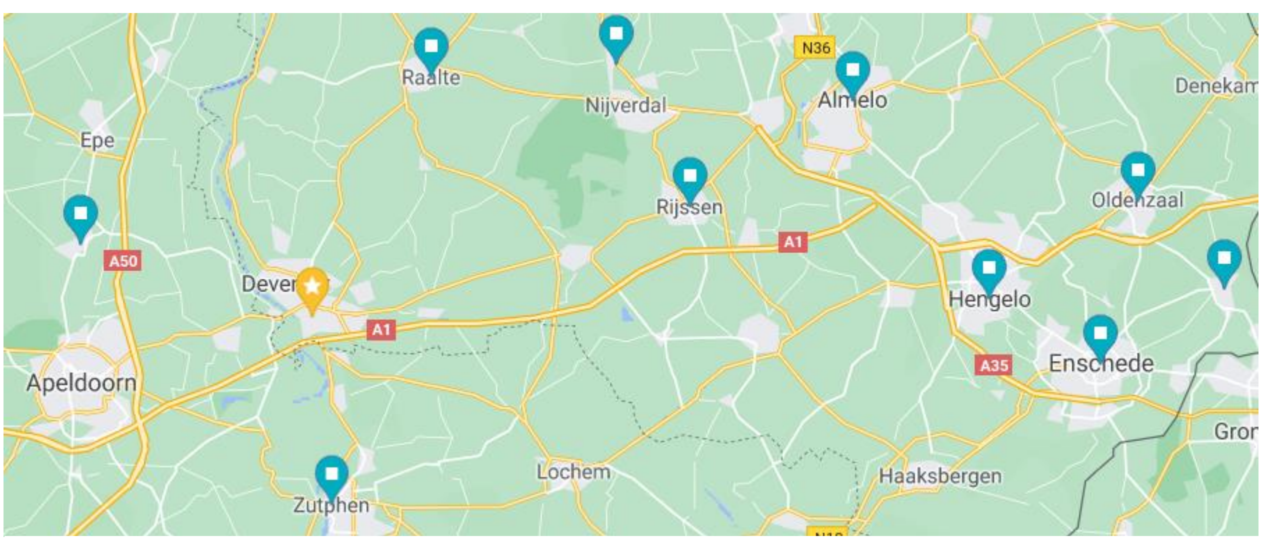

Figure 2.1. Location of the food banks

This yields the following distance- and timetable as can be seen in Table 2.2 and Table 2.3. For example, ithe distance from the food bank of Almelo to the food bank of Enschede is 27 kilometers and takes 22 minutes. These numbers are calculated by using Google Maps. These tables will be used later in this report when the tool will be created. Both tables have a triangular shape. This is because there is no distinction between the way out and the way back between the food banks. The drivers in the current system and the new system will drive the same route on both ways between the food banks. It might be the case that there is a small difference due to eventual roundabouts or highway entries and exits but these differences are neglectable. Congestions are also not included in this research since there are not much congestions in this region and it is not relevant for giving an advice on the new distribution strategy. However, this can be researched. This will be explained in Chapter 6.

Table 2.2. Distance matrix

Deventer	0										
Enschede	62	0									
Almelo	46	27	0								
Midden-Twente	48	9	17	0							
Oost-Twente	58	11	26	12	0						
Losser	65	11	39	18	8	0					
Rijssen	25	37	18	28	38	44	0				
Hellendoorn	31	39	18	28	38	44	10	0			
Raalte	20	52	31	40	50	57	22	12	0		
Zutphen	19	58	58	48	61	73	40	49	34	0	
Vaassen	20	87	77	80	84	90	60	62	38	33	0
Distance in km	Deventer	Enschede	Almelo	Midden-Twente	Oost-Twente	Losser	Rijssen	Hellendoorn	Raalte	Zutphen	Vaassen

Table 2.3. Time matrix

Deventer	0										
Enschede	44	0									
Almelo	35	22	0								
Midden-Twente	36	11	15	0							
Oost-Twente	44	14	21	12	0						
Losser	47	13	33	18	10	0					
Rijssen	30	28	18	22	28	33	0				
Hellendoorn	35	32	20	23	29	34	13	0			
Raalte	25	37	25	29	35	40	21	11	0		
Zutphen	18	59	42	50	50	58	34	40	37	0	
Vaassen	27	65	49	57	57	65	41	47	45	33	0
Time in minutes	Deventer	Enschede	Almelo	Midden-Twente	Oost-Twente	Losser	Rijssen	Hellendoorn	Raalte	Zutphen	Vaassen

2.3 Qualitative characteristics

In this section the qualitative characteristics of the food banks are explained. This will be done using the outcomes of the interviews which were discussed in section 1.2. It starts with an explanation of the transport network of the food banks. Then, Section 2.3.3 provides a discussion on the covid situation and the impact of covid on the demand of the clients of the food banks.

2.3.1 Local network

Each food bank has its own local network. This means that they have a standard route for one day or more days, depending on the size of the food bank. On this route are a group of stores or other producers who want to help the food bank with food. The food bank then uses their trucks for these routes to pick up the food. It might also be the case that there is an unexpected phone call of a food producer who has a lot of food for the food bank and that the food bank can pick it up. Sometimes a producer comes with such a big batch that it is too much for one food bank. If this happens the food banks work together, and all go to this producer to pick up a part of the batch. This kind of cooperation often happens at some food banks in the east, mainly Enschede, Oldenzaal, Losser and Almelo.

2.3.2 Trip to distribution center

Every food bank visits the distribution center once or twice a week. Often, they call beforehand to know how many products are available for them to pick up, so that they know how the number of trucks they need to bring. An important note is that this fluctuates a lot. A food bank cannot ask for a standard number of pallets each week since the supply fluctuates and depends on the number of products that the distribution center receives from their suppliers.
The distribution center has a way of dividing the products between the food banks depending on the number of households each food bank has each week. When this is known at the distribution center, they divide the products by percentage. For example, when Enschede has 25% of all the customers in the region, they will get 25% of the products.

2.3.3 Covid-19

According to the respondents, there is a national expectation that the total number of customers of the food banks in the Netherlands will increase by 50%. (Meer huishoudens naar voedselbank door coronacrisis, 2021) However, while no respondent is sure about the future and most do not know what is going to happen, the expectation that this increase will not happen in the region Twente-Salland mainly because there are not that many big cities in this region and the Covid crisis did not have that much influence on the wealth of the people in this region.
Most food banks have seen a decline in customers since the Covid crisis started. The best example of this is the food bank in Enschede. This food bank had 530 households as customers before the Covid crisis started. This has declined to 325 customers. The people of the food bank Enschede do expect that the number of households will increase back to 530 but not that much more. However later on in the experiments section the case in which the demand grows with 50% will be researched.

2.4 Important days

The next characteristics are the so-called ‘important days. These days are the days of issue and the day on which the food bank visits the distribution center. The day of issue is relevant because on this day the goods from the distribution center may not arrive too late, preferably before 11h or 11.30. The day of the trip to the distribution center is important as well since most food banks do not want to change this day so the products need to arrive on this day in the new situation. Table 2.4 shows the day of issue and the day of the trip to the distribution center per food bank.

Table 2.4. Important days per food bank

Food bank	**Day of Issue**	**Trip to Distribution center**
Enschede	Tuesday + Friday	Wednesday + Friday
Almelo	Friday	Tuesday + Wednesday + Thursday
Midden-Twente	Friday	Wednesday + Friday
Oost-Twente	Friday	Wednesday + Friday
Losser	Friday	Thursday
Rijssen	Mostly Friday	Wednesday + Thursday
Hellendoorn	Friday	Thursday
Raalte	Friday	Thursday
Zutphen	Friday	Wednesday + Thursday
Vaassen	Tuesday	Thursday

2.5 Current trucks

Table 2.5 shows the current vehicles of each food bank. These numbers are based on both the interviews as an earlier survey which was done by students of the University of Tilburg (Tilburg, 2021). Some food banks only have one vehicle while others have more. If a food bank has more vehicles the fields which shows the capacity of the vehicles in weight and volume do have more numbers in it.

Table 2.5. Vehicles per food bank

Food bank	**Number of vehicles**	**Weight limit in kg**	**Volume limit in pallets**
Enschede	3	All 1500	4, 4, 3
Almelo	3	1200, 1200, 1500	3, 3, 4
Midden-Twente	3	1256, 1360, 1054	3, 4, 5
Oost-Twente	1	3500	4
Losser	1	1500	3
Rijssen	2	3500, 500	4, 0/1
Hellendoorn	1	1500	3
Raalte	2	2800, 400	6, 3
Zutphen	2	1400, 1700	4/5, 6
Vaassen	2	2500, 500	7, 5

2.6 Database analysis

2.6.1 Introduction

In this section, data analysis is done to get an overview of the current system quantitively. There is a database available with all order lines of the last three years. These order lines consists of a documentnumber, articlenumber, articlename, articlegroup, date, weight, clientname (the food banks).

2.6.2 Weight and volume per day

When the data from the database grouped, we know the total weights of the products which need to go to a food bank on a certain day. Table 4.6 shows this for January 2020.

Table 2.6. Total weight in kg per day per food bank

	VB Almelo	VB Enschede	VB Hellendoorn	VB Losser	VB Midden Twente	VB Oost Twente	VB Raalte	VB Rijssen	VB Vaassen	VB Zutphen	Total
jan	**7398,61**	**17910,92**	**2446,75**	**1948,05**	**13318,87**	**5384,91**	**5225,40**	**3084,09**	**2421,16**	**8189,54**	**67328,30**
3-jan		1428,56			1076,88	419,18					2924,63
8-jan	2013,70	3027,67	461,39	359,10	2244,94	914,84	975,21	822,96	337,33	2128,38	13285,52
9-jan	379,04	1365,72	217,76	149,35	999,61	419,11	447,18	151,20	104,08	444,80	4677,84
10-jan		428,20			305,52	126,64					860,36
15-jan	1471,29	2837,77	377,44	307,49	2100,11	881,63	925,38	593,19	483,80	1682,92	11661,02
16-jan	150,00	441,28	144,03	91,17	356,42	103,92	273,52	61,74	87,24	299,16	2008,48
17-jan		1070,86			782,70	321,14					2174,70
22-jan	1492,37	2707,74	388,36	287,26	1976,96	792,50	881,07	612,87	485,98	1534,27	11159,39
23-jan			100,60	78,80			244,10		136,80		560,30
24-jan		422,42			302,99	126,07					851,48
29-jan	1892,20	3689,58	472,77	438,69	2816,91	1131,74	1227,14	842,12	699,53	2100,00	15310,68
30-jan			284,40	236,20			251,80		86,40		858,80
31-jan		491,13			355,83	148,15					995,10

As can be observed, the volume of each orderline was not given. The volume is important in this vehicle routing problem since there are only a certain number of pallets that fit in a vehicle and if we do not know the volume, we cannot create a good model for this vehicle routing problem. In order to obtain the volume, a report was used with a table in which we could calculate a ratio between the weight and the volume in pallets per articlegroup. (Voedselbanken.nl, 2021) This table can be found in Appendix B.

With this ratio, the volume of each orderline can be created. When we group this orderline we can create the same table as Table 2.6 but then with volume instead of weight. The next step is to incorporate the days from Table 2.4. For example, on the 8 of January 2020, every food bank visits the distribution center according to the database. This does not match with the reality, so the database was rearranged in such a way that the days are taken into consideration. In order to achieve this, for some food banks the number of pallets on a Wednesday are added to the Thursday and the number of pallets that travel on a Wednesday then become zero for example. This is the case for the food banks that only travel to the distribution center on Thursday. So, the new database can be seen in Table 2.7.

Table 2.7. Number of pallets per food bank per day (1)

	VB Almelo	VB Enschede	VB Hellendoorn	VB Losser	VB Midden Twente	VB Oost Twente	VB Raalte	VB Rijssen	VB Vaassen	VB Zutphen	Total
jan	**11**	**26**	**4**	**4**	**20**	**11**	**8**	**5**	**4**	**11**	**80**
3-jan	0	2	0	0	1	1	0	0	0	0	3
8-jan	3	6	0	0	5	2	0	2	0	0	15
9-jan	1	0	1	1	0	0	2	0	1	4	8
10-jan	0	1	0	0	1	1	0	0	0	0	1
15-jan	2	5	0	0	4	2	0	1	0	0	12
16-jan	1	0	1	1	0	0	2	0	1	3	7
17-jan	0	2	0	0	1	1	0	0	0	0	3
22-jan	2	4	0	0	3	1	0	1	0	0	9
23-jan	0	0	1	1	0	0	2	0	1	2	5
24-jan	0	1	0	0	1	1	0	0	0	0	1
29-jan	2	4	0	0	3	1	0	1	0	0	9
30-jan	0	0	1	1	0	0	2	0	1	2	6
31-jan	0	1	0	0	1	1	0	0	0	0	1

We now know the total number of pallets transported to the different food banks per year. To validate this, some food banks were asked how many pallets they pick up per week on average. This is the case for the food banks of Almelo, Enschede, Hellendoorn, Raalte and Rijssen. Based on this information and the number of clients of the other food banks, the number of pallets per year for all food banks could be estimated. We can compare this to the number of pallets in the model (Table 2.8). The first row shows the number of pallets per year per food bank according to the reality and the second row the number according to the database.

Table 2.8. Comparison of pallets per year in reality and in the database

	VB Almelo	VB Enschede	VB Hellendoorn	VB Losser	VB Midden Twente	VB Oost Twente	VB Raalte	VB Rijssen Holten	VB Vaassen	VB Zutphen
Pallets per year reality	416	520	156	104	468	364	364	156	156	468
Pallets per year database	179	327	71	61	211	129	126	70	70	171

When we compare both rows, we can see that there is a big difference between the database and reality. There are two reasons for this difference. The first difference is that there might be inconsistencies in the database and that the database is not complete at all. This is a plausible reason because most chairmen and coordinators stated in the interview that the registration is not good and after talking with the creator of the database, it was discovered that not all products are registered.

The other reason might be that in my calculations I calculated that almost all pallets are full, except for the pallets which are rounded up. This is not the case because the shape of some products is not suitable for using the complete pallet. So, when the ratio states that there are only 2 pallets needed, and the products cannot be piled up, there are more pallets needed. So, to come up with reasonable numbers, the volume of the products will be multiplied by a factor. Since the relative difference per food bank is different, the factor per food bank will also be different. The factor that will be used is the ratio between the two rows of Table 2.8. Table 2.9 shows the new data for the month of January with the number of pallets that are transported to each food bank per day.

Table 2.9. Number of pallets per food bank per day (2)

	VB Almelo	VB Enschede	VB Hellendoorn	VB Losser	VB Midden Twente	VB Oost Twente	VB Raalte	VB Rijssen	VB Vaassen	VB Zutphen	Total
jan	**21**	**37**	**8**	**6**	**38**	**21**	**19**	**9**	**8**	**26**	**193**
3-jan	0	3	0	0	3	2	0	0	0	0	**8**
8-jan	6	9	0	0	10	5	0	3	0	0	**33**
9-jan	1	0	2	2	0	0	6	0	2	9	**22**
10-jan	0	1	0	0	1	1	0	0	0	0	**3**
15-jan	5	8	0	0	8	4	0	2	0	0	**27**
16-jan	1	0	2	1	0	0	5	0	2	7	**18**
17-jan	0	2	0	0	2	1	0	0	0	0	**5**
22-jan	4	6	0	0	6	3	0	2	0	0	**21**
23-jan	0	0	2	1	0	0	4	0	2	5	**14**
24-jan	0	1	0	0	1	1	0	0	0	0	**3**
29-jan	4	6	0	0	6	3	0	2	0	0	**21**
30-jan	0	0	2	2	0	0	4	0	2	5	**15**
31-jan	0	1	0	0	1	1	0	0	0	0	**3**

2.6.3 Distance driven to the distribution center per year

The next step is calculating the number of trips to the distribution center per day. This can be done by using the number of pallets per food bank per day and the list of the vehicles per food bank. When combining this information, the number of vehicles needed per food bank per day can be discovered. After that we can sum it up for the whole year and calculate the number of trips to the distribution center per year. When we multiply this number by the distance between the food banks and the distribution center (and by 2 since the vehicle has to drive to the distribution center and back) we know the total distance driven by the food banks. These numbers are shown in Table 2.10.

Table 2.10. Trips and kilometers to the distribution center per year per food bank

	Trips per year	Kilometers per year
VB Almelo	117	10.764
VB Enschede	147	18.228
VB Hellendoorn	56	3.472
VB Losser	54	7.020
VB Midden Twente	120	11.520
VB Oost Twente	87	10.092
VB Raalte	70	2.800
VB Rijssen	54	2.700
VB Vaassen	53	4.240
VB Zutphen	109	4.142

We can compare these numbers with the numbers that the food banks filled in in their survey with the university of Tilburg. (Table 2.11) (Tilburg, 2021) The reason that there is no number at Oost-Twente is that they did not fill an answer in this survey.

Table 2.11. Kilometers per year driven to food bank reality

	Kilometers per year
VB Almelo	20.800
VB Enschede	31.200
VB Hellendoorn	4.160
VB Losser	5.200
VB Midden Twente	23.400
VB Oost Twente	
VB Raalte	2.340
VB Rijssen	3.120
VB Vaassen	3.120
VB Zutphen	4.680

It can be seen that there are big differences between the reality and the database, mainly for the relatively bigger food banks such as Almelo, Midden-Twente and Enschede. The reason for this might be that those food banks do not know how many products are available for them and they bring 2 buses when only 1 bus would be enough. Or it might be that there are more products that need to go to the distribution center than the other way around. In these cases, the driven kilometers would be higher than the database shows. For the smaller food banks who only have one vehicle, the database is relatively correct. Since it is known that the database is not completely correct and the model assumes that most trips are with vehicles that are loaded to the maximum capacity, it is acceptable that the number of trips and therefore driven kilometers are higher in the reality than in the model so for the total kilometers I will consider the numbers of the survey as the right ones.

2.7 Fuel costs

Fuel costs are the important costs in this problem since they are the only costs which should be reduced by using a new system. Every driver works voluntarily for the food bank and the food banks cannot sell their vehicles because they need the vehicles for their local network. This means that the only costs that we could decrease are the fuel costs. The only fuel costs we can decrease is the cost of the fuel we need to drive to the distribution center and not the fuel costs for the local network since the local network will be the same in the new situation. Table 2.12 shows the fuel costs for the trips to Deventer per year for the last three years. Midden-Twente in this case is Hengelo and Oost-Twente is Oldenzaal. The input for these costs is a combination of the interviews with the chairmen/coordinators, and the survey of the University of Tilburg. As can be seen, Rijssen does not have fuel costs at all. This is because the vehicles of the food bank in Rijssen are sponsored including the fuel. As a consequence, food bank Rijssen does not need to pay for their fuel.

Table 2.12. Fuel costs per food bank

	2018	2019	2020
Enschede	4.966	4.800	3.750
Almelo	4.500	4.500	4.500
Hellendoorn	618	699	650
Losser	750	750	750
Midden-Twente	4.500	4.500	4.500
Oost-Twente	2.500	2.500	2.500
Raalte	1.130	1.174	1.258
Rijssen	0	0	0
Vaassen	3.010	3.031	2.893
Zutphen	2.000	2.000	2.000

We could also use the database for an estimation of the fuel costs but since the driven kilometers by the food banks are not correct, we cannot calculate correct fuel costs. However, we can calculate a so-called price per kilometer, which we can later use for the experiments. To do this, we need to divide the total driven fuel costs for all food banks and divide it by the sum of all driven kilometers per year for all food banks. In this case, the food banks of Rijssen and Oost-Twente will not be considered since there lacks an overview either the driven distance of the fuel costs. When performing this calculation, the price per kilometer = €0,21

2.8 Conclusion

The research question for this chapter was: *What is the current situation of the food banks regarding transportation?* This question was divided in four subquestions:

1.1 What is the current situation of the food banks regarding transportation qualitatively?
1.2 What are the quantitative characteristics of the food banks (location, vehicles, important days)?
1.3 How many products do the food banks pick up in the distribution center per day?
1.4 What are the variable costs of the current system per food bank?

The answer to subquestion 1 is that each food bank picks up some of their products from a local network There is some cooperation between the food banks if there are too many products for one food bank in the local network. Food banks also pick up products from the distribution center in Deventer once or multiple times per week.

The answer to subquestion 2 is that they all have a certain day of issue and certain day(s) in which they visit the distribution center. They also own a number of trucks which they use to pick up their foods. This characteristics per food bank can be seen in Table 2.2, 2.3, 2.4 and 2.5.

The answer to subquestion 3 is the table we designed with the weight and volume of all products which are picked up in the distribution center. A part of this table can be found in Table 2.9

In the last section we discussed the answer of subquestion 4. The answer is Table 2.12 in the variable costs per food bank can be found. The total variable costs for 2020 is €22.800. These costs will be used later in Chapter 5 even as table with the weight and volume of all products picked up in the distribution center (Table 2.9)

3 Literature Research

3.1 Introduction

In this chapter, we look at the literature regarding a vehicle routing problem (VRP). The goal of this chapter is to choose the best solving method for the vehicle routing problem. In Section 3.2, the basic VRP is explained together with its mathematical model. In Section 3.3, the solving methods are discussed and in Section 3.4 the best solving method is chosen.

3.2 Vehicle Routing Problem

The first research on a VRP was done by Dantzig and Ramser (1959). They discuss a problem with multiple customers and vehicles with a capacity and the goal is to find the shortest route for which all customers are visited and the capacity of the vehicles is not exceeded. Then Braekers et al (2016) discuss an overview of different variants of the VRP. But the variant which suits the problem of the food banks is the Capacitated Vehicle Routing Problem (CVRP). (Kijun, 2020).

3.2.1 Classic formulation

The classic formulation for the VRP starts with the objective of minimizing the total distance of the routes. (1) (Kijun, 2020)

$$\sum_{i\in V}\sum_{j\in V}\sum_{k\in K} c_{i,j}\, x_{i,j,k}$$

Equation 1. Objective Function VRP

In this equation V is the set of customers which need to be visited and K is the set of available vehicles. $c_{i,j}$ is the costs/distance between customer i and customer j while $x_{i,j,k}$ is still a binary number which is 1 if vehicle k leaves customer i and goes directly to customer j, otherwise $x_{i,j,k} = 0$.

The first constraint of this problem is that each customer should be visited once. Equation 2 shows this constraint. (Kijun, 2020)

$$\sum_{k\in K}\sum_{\substack{i\in V\\ i\neq j}} x_{i,j,k} = 1 \qquad \forall j \in V - \{0\}$$

Equation 2. Constraint 1 VRP, Each customer should be visited once

The next constraint is that if vehicle k ‘enters’ customer i, then vehicle k must leave customer i as well (equation 3). (Kijun, 2020)

$$\sum_{\substack{i\in V\\ i\neq j}} x_{i,j,k} = \sum_{i\in V} x_{j,i,k} \qquad \forall j \in V,\ \forall k \in K$$

Equation 3. Constraint 2 VRP, if vehicle enters customers it must also leave customer

Another constraint is that each vehicle must start at the depot. (Equation 10) (Kijun, 2020)

$$\sum_{j\in V\{0\}} x_{o,j,k} = 1 \qquad \forall k \in K$$

Equation 4. Constraint 3 VRP, vehicle must start at depot

The depot in this case is customer 0. This equation combined with equation 3 implies that the vehicle will also end in the depot.

The next constraint is the capacity constraint. This constraint ensures that the demand of all customers per vehicle does not exceed the capacity of the vehicle. q_j is the demand of customer j while Q is the capacity of the vehicles. (Kijun, 2020)

$$\sum_{i \in V} \sum_{\substack{j \in V-\{0\} \\ i \neq j}} x_{i,j,k}\, q_j \leq Q \qquad \forall k \in K$$

Equation 5. Constraint 4 VRP, capacity constraint

The next two constraints ensure that $x_{i,j,k}$ is a binary variable. (Langevin, Soumis, & Desrosiers, 1990)

$$0 \leq x_{i,j,k} \leq 1 \qquad \forall i \in V, \forall j \in V, \forall k \in K$$

Equation 6. Constraint 5 VRP, binary constraint (1)

$$x_{i,j,k}\ integer \qquad \forall i \in V, \forall j \in V, \forall k \in K$$

Equation 7. Constraint 6 VRP, binary constraint (2)

The last constraint is the constraint of removing the subtours, u_i is introduced as a continuous variable. (Langevin, Soumis, & Desrosiers, 1990)

$$u_i - u_j + n x_{i,j,k} \leq n - 1 \quad \forall i,\ j \in n - \{1, i\}, \forall k \in K$$

Equation 8. Constraint 5 VRP, removing subtours

3.3 Solving methods

After defining the classic formulation and model, the solving method needs to be determined. There are four general methods for solving a VRP: An exact approach, heuristics, metaheuristics and matheuristics.

3.3.1 Exact approaches

Exact approaches always give optimal solutions. An example of an exact approach is Mixed Integer Linear Programming (MILP). MILP are problems with an objective function and a few constraints so that is perfectly suited for VRP. (Gurobi Optimization, sd) These problems are often solved by the Branch-and-Bound algorithm. This algorithm starts with finding all feasible solutions, then creating subsets of these solutions, then finding the lowest bound per subset. The subset with the lowest bound will be chosen and the lower bound will be the solution. (Little, Murty, Sweeney, & Karel, 1963)

However, exact approaches can take a long time, especially when the problem has a lot of customers. So in that case, heuristics are necessary. A heuristic is a solving method which produces a good-enough but not necessary optimal solution. There are two sorts of heuristics, namely construction heuristics and improvement heuristics. (Khan & Agrawal, 2016) Examples of heuristics are explained in the next sections.

3.3.2 Heuristics

There are multiple heuristics for solving a VRP. In this section, a few heuristics will be discussed. The first heuristics is The Sweep Algorithm. (Laporte, Gendreau, Potvin, & Semet, 1999) This algorithm consists of two phases. The first phase is solving the cluster problem. In this phase, each customer is connected to a vehicle. This phase can be seen in figure 5.3 It starts with creating a map of the distribution center and all the customers. The next step is to choose one customer and assign it to the first vehicle. In the figure, this is the customer who is directly right to the depot. The next step is to create a line and turn that line clockwise or anti-clockwise until the line touches the next customer. This step repeats until the demands of the chosen customers exceed the vehicle capacity. In the figure, this happens after three customers in total for the first vehicle. This means that the next customer in the rotation is assigned to vehicle 2. This process continues until all customers are assigned to a vehicle. (Laporte, Gendreau, Potvin, & Semet, 1999)

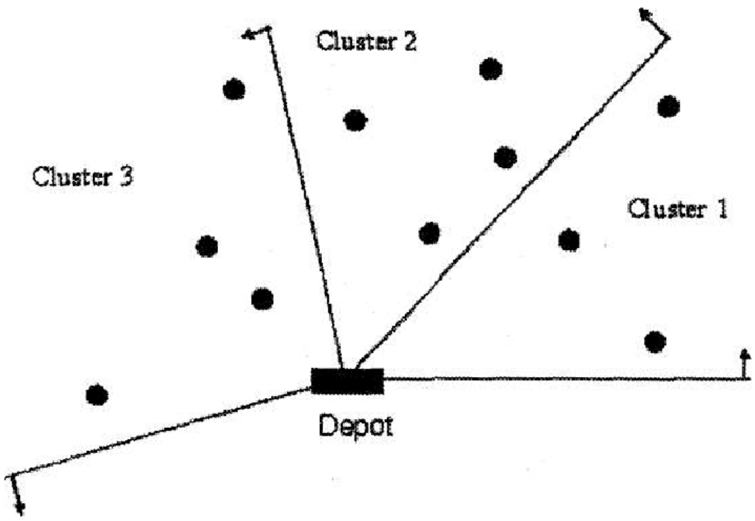

Figure 3.1. Sweep algorithm (Nurcahyo, Alias, Shamsuddin, & Sap, 2002)

The second phase is the routing phase. In this phase the routes for each cluster are optimized. For this optimization problem the nearest neighbor heuristic can be used.

The methodology of this heuristic starts with randomly choosing a starting point and then compute the distances from this starting point to all unvisited customers. The next step is to choose the customer with the lowest distance to visit next, and then again compute the distances from the new point to all unvisited customers. This goes on until all customers are visited. (Khan & Agrawal, 2016)

Another construction heuristic is the Clarke & Wright savings algorithm. This algorithm is explained the best by van der Wegen & van der Heijden (2017). The algorithm starts with creating a number N tours, each tour consists of one customer and goes from the depot to the customer and back to the depot. The distance of the start situation is twice the distance between all customers and the depot. The next step is to calculate the possible savings when two tours are merged. To calculate the savings s_{ij} of merging customer i and customer j the following equation needs to be used (15).

$$s_{ij} = d_{0i} + d_{j0} - d_{ij}$$

Equation 9. Clarke & Wright savings equation

In this equation d_{oi} is the distance between the depot and customer i, d_{j0} is the distance between the depot and customer j and d_{ij} is the distance between customer i and customer j. s_{ij} is the savings when merging the tours which visit customer i and customer j. This calculation needs to be done for all customers i and j. The next step is to choose the largest saving and checking the possibility of this saving. This saving is only possible if the two customers are not connected yet, are connected to the same depot and the demand of the customers together do not exceed the total capacity of the vehicle. If saving is possible, the tours can be merged. If the saving is not possible, the next highest saving will be checked for its possibility. If the tours are merged, the step can be repeated until there are no possible savings left. (van der Wegen & van der Heijden, 2017)

The most common improvement heuristic is the so-called 2-Opt heuristic. When a tour is constructed, this heuristic will look at the routes in this tour and swap two routes for two other feasible routes. For example, when the route A-B-C-D-A is constructed using the nearest neighbor heuristic, the 2-Opt heuristic will delete 2 routes (B-C and D-A) and replace them with 2 other routes (B-D and C-A). The new route then becomes A-B-D-C-A. When this route is shorter than the constructed route, this will be the new optimal route. This process continues until no further improvement is possible. This heuristic is also possible with changing more than 2 routes so this heuristic can also be called k-Opt where k routes are swapped. (Hahsler & Hornik, 2007)

3.3.3 Metaheuristics

Metaheuristics are problem-independent heuristics. So that means that these heuristics are suited for a lot of problems instead of only a VRP. Meta-heuristics often perform better than normal heuristics. (Yang, 2010)

An example of a metaheuristic is a Tabu-Search. This is stochastic search meta-heuristic which uses specific directions to improve the initial feasible solution. This heuristic will firstly look to the close neighbors of the initial solution in the hope to find a better solution. If this is not the case, there will be a move which will make the initial solution worse. This is to prevent that the researcher stops when there is a local optimum. The earlier and better solution will be memorized in a so-called Tabu list. (Qiu, Fu, Eglese, & Tang, 2018)

Another method is evolutionary programming. This heuristic starts with creating a population of feasible solutions. Then the individual solution which has the most costs will be deleted from the population and mutated by using operators such as swapping orders between the vehicles or swapping orders within each vehicle. Then the costs of this new solution will be evaluated and when the new solution scores better than one solution in the population, this new solution will be included in the population and the worse solution will be deleted and mutated again. In the end it will lead to a population with good solutions. (Kota & Jarmai, 2015)

3.3.4 Matheuristics

The last solving method is a matheuristic which makes use of mathematical programming in a heuristic context. Matheuristics often provide better solutions than meta-heuristics. (Archetti & Speranza, 2014). Matheuristics are also faster than meta-heuristics according to Kramer et al (2015). In this study a matheuristic is compared with a meta-heuristic on a problem with 100 customers. Both heuristics came to fairly good solution but the matheuristic was almost three times as fast as the meta-heuristic. This means that matheuristic are a good alternative for large problems.

3.4 Conclusion

The main research question in this chapter was: *How can the Vehicle Routing Problem of the food banks be solved?*

The chapter started with an introduction of the VRP and the mathematical model of the Capacitated Vehicle Routing Problem, which suits the problem of the food banks best. Then the four solving methods were discussed: Exact approach, heuristics, metaheuristics and matheuristics. The last step in this chapter is choosing the right solving method for this situation. The advantage of the exact approach is that the solution will be the optimal solution, however, the solving process might take a long time if the problem is too big. This will not be the case in the problem for the food banks since this problem only consists of 10 customers. That means that heuristics are not necessary to solve this problem. Also, since the goal is to solve a mathematical model, an exact approach is needed. This means that we will choose an exact approach for solving the VRP, namely the MILP.

4 Solution design and validation

4.1 Introduction

In this chapter the solution design and validation will be discussed. The chapter starts with the mathematical model of the VRP. In Section 4.2.1 the changes to the basic literature model are discussed, in section 4.2.2 the definition of the variables is given, and in section 4.2.3 & 4.2.4 the model is given and explained. In section 4.3 the tool is explained, the section starts with an explanation of the input form, section 4.3.2 provides a schematic explanation of the code and in section 4.3.3 the output of the tool is provided. In section 4.4 the validation of the tool is discussed, it starts briefly with an explanation of the external validation, then the correctness of the tool and the results are discussed, and the section ends with a discussion whether the tool actually solves the problem for the food banks.

4.2 Mathematical model of the VRP

In this section, the mathematical model of the VRP will be discussed. It starts with a definition of all the variables and then it will continue with the complete model with the objective function and the constraints. The model is based on the classical formulation of the VRP in the literature research but with a few updates to convert it to the model of the food banks.

4.2.1 Changes to the basic model

The model is relatively comparable to the model which was discussed in the previous chapter. However, there are three differences between both models. The first difference is that this model has 2 capacity constraints and the literature model only has 1. This model has both a capacity and a weight constraint since both constraints do matter in the situation of the food banks. Each vehicle has a weight limit and a volume limit so both limits are needed in this model.

Another constraint is that there are also products that need to go from the food banks to the distribution center. This is displayed in the model by introducing the parameters $w_{i,j}$ which is the weight of the products which need to transport from customer i to customer j. In the model the weight constraint will be the max of $w_{0,j}$ (the weight of the products from the depot to customer j) and $w_{j,0}$ (the weight of the products from customer j to the depot). So, there is no transport of products between the customers, only between customers and the depot. The same holds for the volume constraint with $l_{i,j.}$

The next difference is the added time-constraint. The time-constraint is needed in this model because on some days (mainly the days of issue) the food banks want to have their products relatively early. So, in this model each route will have a maximum duration T. The exception is that the last part of the route, from the last customer back to the depot, is not included in this constraint since that may take as long as it needs. For each customer that a vehicle visits, a time p is included for the unloading and loading of the vehicle.

The last change is the removal of the subtours. In this model the constraint from the literature is replaced with the subtour constraint from the python tutorials. (Lalla-Ruiz, Tutorial 2, Mathematical modelling in Python, 2021)

4.2.2 Definition of variables

$n = number\ of\ customers$

$V = set\ of\ customers$, V{0} = depot

$U = set\ of\ vehicles$

$d_{i,j} = distance\ between\ customer\ i\ and\ j$

$t_{i,j} = driving\ time\ between\ customer\ i\ and\ j$

$w_{i,j} = 'weight\ demand'\ from\ customer\ i\ to\ customer\ j$

$W_k = weightlimit\ of\ vehicle\ k$

$l_{i,j} = 'volume\ demand'\ of customer\ i\ to\ customer\ j$

$L_k = volumelimit\ of\ vehicle\ k$

$p = Time\ it\ takes\ to\ unload\ a\ vehicle\ at\ customer$

$T = maximum\ time\ vehicle\ underway\ except\ retour$

$x_{i,j,k} = binary\ variable, 1\ if\ vehicle\ k\ drives\ from\ customer\ i\ to\ customer\ j, otherwise\ 0$

$y_i = auxiliary\ variable\ to\ prevent\ subtours$

4.2.3 Model

$$Objective = Min \sum_{i \in V} \sum_{j \in V} \sum_{k \in U} d_{i,j}\, x_{i,j,k}$$

Equation 10. Mathematical model objective function

$$\sum_{\substack{i \in V \\ i \neq j}} \sum_{k \in U} x_{i,j,k} = 1 \qquad \forall j \in V - \{0\}\ if\ \max(w_{0,j}, w_{j,0)} > 0$$

Equation 11. Mathematical model constraint 1 (Each customer visited once)

$$\sum_{i \in V} x_{i,j,k} = \sum_{i \in V} x_{j,i,k} \qquad \forall j \in V,\ \forall k \in U$$

Equation 12. Mathematical model constrain 2 (Vehicle that enters customer must also leave customer)

$$\sum_{j \in V} x_{o,j,k} = 1 \qquad \forall k \in U$$

Equation 13. Mathematical model constraint 3 (Vehicle starts at depot)

$$\sum_{i \in V} \sum_{j \in V} x_{i,j,k} \max(w_{0,j},\ w_{j,0)} \leq W_k \qquad \forall k \in U$$

Equation 14. Mathematical model constraint 4 (Weight constraint)

$$\sum_{i \in V} \sum_{j \in V} x_{i,j,k} \max(l_{0,j,},\ l_{j,0)} \leq L_k \qquad \forall k \in U$$

Equation 15. Mathematical model constraint 5 (Volume constraint)

$$\sum_{i \in V} \sum_{j \in V - \{0\}} x_{i,j,k} t_{i,j} + x_{i,j,k} * p \leq T \qquad \forall k \in U$$

Equation 16. Mathematical model constraint 6 (Time constraint)

$0 \leq x_{i,j,k} \leq 1 \qquad \forall i \in V, \forall j \in V, \forall k \in K$

Equation 17. Mathematical model constraint 7 (Binary constraint (1))

$x_{i,j,k}\ integer \qquad \forall i \in V, \forall j \in V, \forall k \in K$

Equation 18. Mathematical model constraint 8 (Binary constraint (2))

$$y_i - (n+1) * x_{i,j,k} \geq y_j - n \qquad \forall i \in V - \{0\}\ \forall j \in V - \{0\}\ \forall k \in K$$

Equation 19. Mathematical model constraint 9 (Subtour elimination)

The objective function of the model (10) is to minimize the distance. Constraint (11) indicates that each food bank should be visited once, if there are products which need to be transported to that food bank or picked up at that food bank. Constraint (12) indicates that if vehicle k enters customer i, it should also leave customer i. Constraint (13) indicates that each vehicle starts at the depot. Constraint (14) and constraint (15) are the capacity constraints, constraint (14) indicates that the weight of the products transported to each food bank and the weight of the products picked up at the food bank should not exceed the weightlimit of vehicle k, and constraint (15) indicates the same but for the volume. Constraint (16) is the time constraint. It indicates that the total driving time plus unloading time of vehicle k minus the retour time back to the depot should not exceed the maximum time T. The reason that the retour is not included is that it may take as long as it needs. Constraint (17) and constraint (18) are the constraints to ensure that $x_{i,j,k}$ is a binary variable. Constraint (19) ensures that there are no subtours possible.

4.3 Explanation of the tool

In this section, the tool will be explained. It starts with an explanation of the input form. Then the code will be discussed using a scheme, and it ends with the output.

4.3.1 Input form

Table 4.1 shows the first part of the input form for the tool. It is made in excel. The input form starts with the input columns for the 'demand' of the food banks. In the second column, the total weight of the products from the distribution center to the food banks needs to be filled in. If there are not any products at all, a 0 needs to be filled in. The same holds for all input cells. In the third column the weight of the products from the food banks to the distribution center can be filled in. In Columns 4 and 5 the same can be done but for the volume in the number of pallets. Important is that if for example a cell in the second column is not 0, then the same cell in the fourth column should not be zero as well, since a batch has both a weight and a volume. This also holds the other way around and for columns C and E.

Table 4.1. Input form for the tool (1)

	Weight		Volume	
Foodbank	**DC-FB**	**FB-DC**	**DC-FB**	**FB-DC**
Rijssen	1400	400	3	1
Oost-Twente	1600	700	4	2
Hellendoorn	750	1300	2	3
Raalte	2700	2000	6	4
Vaassen	700	1200	2	3
Enschede	3900	5000	8	10
Almelo	3000	900	6	2
Losser	700	300	2	1
Midden Twente	3400	2500	9	5
Zutphen	2400	2900	5	6

Table 4.2 shows the second part of the input form. In second cell of the first column the number of vehicles can be filled in. After that, the weight limit of those vehicles can be filled in in the second column and the volume limit can be filled in in column 5. The time limit in minutes can be filled in in the second cell of column 4 and the unloading time in minutes can be filled in in the second cell of column 6.

Table 4.2. Input form for the tool (2)

Number of vehicles			**Unloading time in minutes**		**Maximum time in minutes**
3			10		120
Weight capacity vehicle 1	8000		**Volume capacity vehicle 1**	15	
Weight capacity vehicle 2	10000		**Volume capacity vehicle 2**	20	
Weight capacity vehicle 3	13000		**Volume capacity vehicle 3**	25	
Weight capacity vehicle 4	0		**Volume capacity vehicle 4**	0	
Weight capacity vehicle 5	0		**Volume capacity vehicle 5**	0	
Weight capacity vehicle 6	0		**Volume capacity vehicle 6**	0	
Weight capacity vehicle 7	0		**Volume capacity vehicle 7**	0	
Weight capacity vehicle 8	0		**Volume capacity vehicle 8**	0	

The last part of the input form is the distance matrix in kilometers (upper half) and the time matrix in minutes (lower half) as can be seen in Table 4.3. These numbers should not be changed except when a food bank moves its location. Then the distances and times need to be researched again and the matrices need to be updated.

Table 4.3. Input form for the tool (3)

Distance Matrix	Deventer	Rijssen	Oost-Twente	Hellendoorn	Raalte	Vaassen	Enschede	Almelo	Losser	Midden-Twente	Zutphen
Deventer	0	25	58	31	20	20	62	46	65	48	19
Rijssen	25	0	38	10	22	60	37	18	44	28	40
Oost-Twente	58	38	0	38	50	84	11	26	8	12	61
Hellendoorn	31	10	38	0	12	62	39	18	44	28	49
Raalte	20	22	50	12	0	38	52	31	57	40	34
Vaassen	20	60	84	62	38	0	87	77	90	80	33
Enschede	62	37	11	39	52	87	0	27	11	9	58
Almelo	46	18	26	18	31	77	27	0	39	17	58
Losser	65	44	8	44	57	90	11	39	0	18	73
Midden-Twente	48	28	12	28	40	80	9	17	18	0	48
Zutphen	19	40	61	49	34	33	58	58	73	48	0
Time Matrix	**Deventer**	**Rijssen**	**Oost-Twente**	**Hellendoorn**	**Raalte**	**Vaassen**	**Enschede**	**Almelo**	**Losser**	**Midden-Twente**	**Zutphen**
Deventer	0	30	44	35	25	27	44	35	47	36	18
Rijssen	30	0	28	13	21	41	28	18	33	22	34
Oost-Twente	44	28	0	29	35	57	14	21	10	12	50
Hellendoorn	35	13	29	0	11	47	32	20	34	23	40
Raalte	25	21	35	11	0	45	37	25	40	29	37
Vaassen	27	41	57	47	45	0	65	49	65	57	33
Enschede	44	28	14	32	37	65	0	22	13	11	59
Almelo	35	18	21	20	25	49	22	0	33	15	42
Losser	47	33	10	34	40	65	13	33	0	18	58
Midden-Twente	36	22	12	23	29	57	11	15	18	0	50
Zutphen	18	34	50	40	37	33	59	42	58	50	0

4.3.2 Tool

For the explanation of the tool a scheme was made. This scheme can be seen in Figure 4.1. It starts with importing the input form from excel. Then the characteristics of the situation are determined, such as the number and names of the customers and the number of vehicles. Then all parameters are filled in. These parameters are the distance- and time matrix, the volume and weight of the products per customer, the capacity limits per vehicle, the maximum time per trip and the (un)loading time.

Then the model is created. This is done by translating the mathematical model of section 4.2 into Python

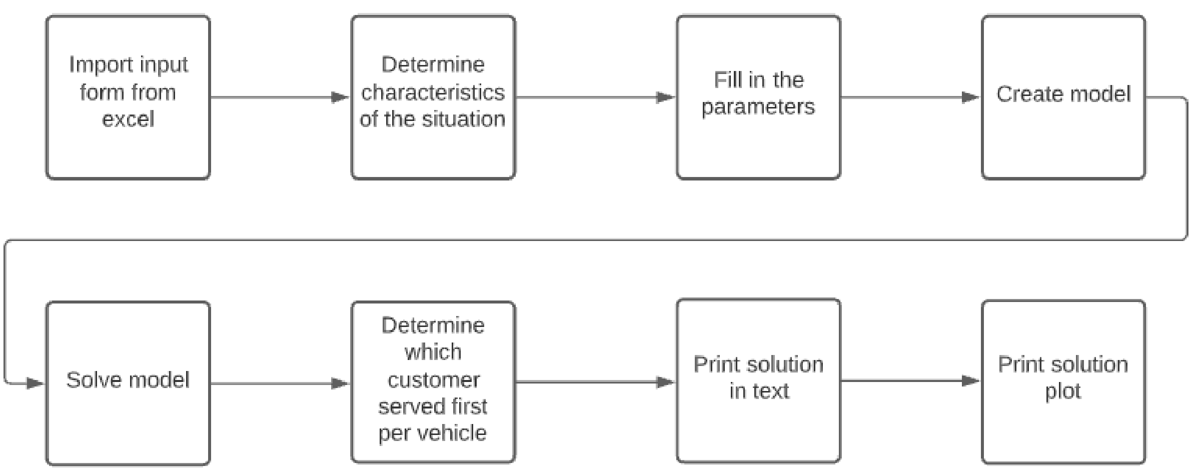

Figure 4.1. Schematic explanation of the tool

language. Then the model is solved by the computer. The next step is to determine which customer is visited first for each vehicle. For example if the solution for one vehicle is: Deventer-Raalte-Hellendoorn-Almelo-Rijssen-Deventer, it still needs to be decided if the vehicle visits Raalte first or Rijssen first. This is determined by looking at the time-matrix and see which of the two customers is closer to Deventer regarding the time. If Rijssen is closer than the solution is flipped and will be: Deventer-Rijssen-Almelo-Hellendoorn-Raalte-Deventer. The last two steps are printing the solutions in text and to plot the solution.

4.3.3 Output

When using the parameters from the input form and after running the model, the following text will be given (Figure 4.2.). It starts with the total distance which is the result of the objective function of the model which is 299 kilometers in this case. As a comparison, if all food banks are visited separately the distance would be 788 kilometers. This means that in the new situation the driven distance is only 38% of the old situation.

After this, it provides a list per vehicle of the food banks it needs to visit and in which order. In this example the first vehicle firstly visits Zutphen and then Vaassen. The second vehicle visits first Raalte, then Hellendoorn, Almelo and Rijssen. Vehicle 3 visits Midden-Twente, Enschede, Losser and Oost-Twente.

It also provides a graphical overview of the results. In this situation the graph will look like Figure 4.3. The colors represent the different vehicles. The order is not included in the graph but this can be seen in the textual output. If we look at the figure we can see that the outcome looks very plausible. The customers per vehicle are relatively close to each other. Vehicle 1 visits the South and the West, vehicle 2 visits the North and vehicle 3 visits the East. So this looks like a logical outcome of the tool.

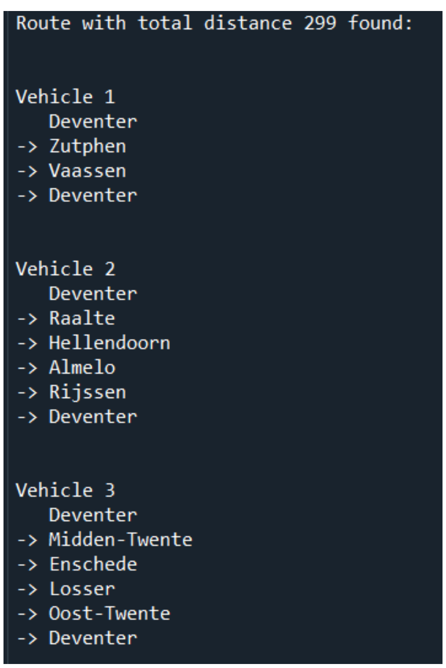

Figure 4.2. Textual output tool

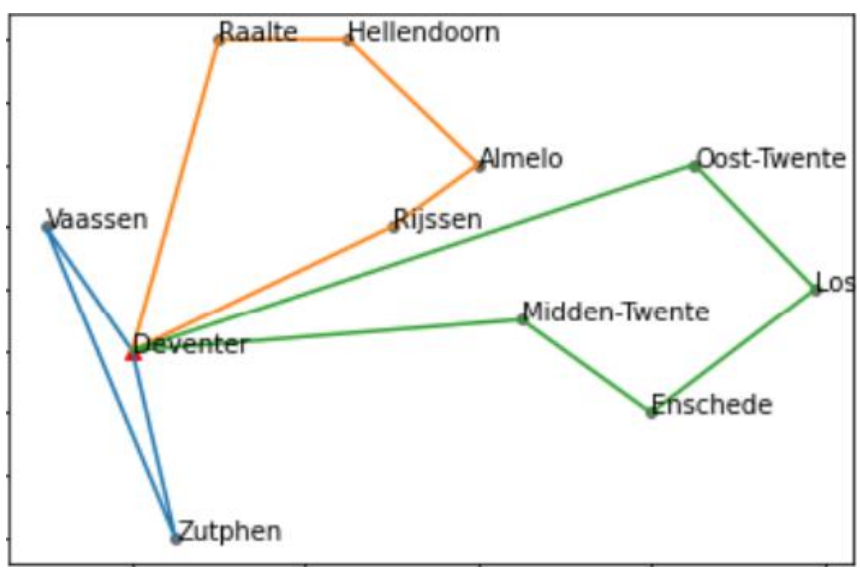

Figure 4.3. Graphical output tool

4.4 Validation of the tool

In this section, the validation of the tool will be discussed. Both the external validation and the internal validation will be discussed. After this, a validation with the coordinator of the distribution center will be discussed

A tool is external valid if it can be applied to other studies outside this specific study. In this case, the tool can be applied to other vehicle routing problems as well. Since almost all parameters can be filled in in an input form, the tool can be used for other VRPs pretty easily when the user has basic excel knowledge and knows how to run the program in Python (which basically is pushing one button).. Knowledge of the VRP can be handy but is not necessary, but the user needs to make sure that the problem that he is trying to solve is a VRP. The only things in the tool itself that need to be changed are the names of the customers and the coordinates of the customers. All other parameters can be changed in the input form. This means that the tool can be applied to other studies quite easily and this increases the external validity of the tool.

```
Route with total distance 299 found:
Vehicle 1
Distance of vehicle 1 = 72
Total weight of vehicle 1 = 4100
Total volume of vehicle 1 = 9
Total driving time minus retour of vehicle 1 = 71
   Deventer
-> Zutphen
-> Vaassen
-> Deventer


Vehicle 2
Distance of vehicle 2 = 93
Total weight of vehicle 2 = 8400
Total volume of vehicle 2 = 18
Total driving time minus retour of vehicle 2 = 114
   Deventer
-> Raalte
-> Hellendoorn
-> Almelo
-> Rijssen
-> Deventer


Vehicle 3
Distance of vehicle 3 = 134
Total weight of vehicle 3 = 10700
Total volume of vehicle 3 = 25
Total driving time minus retour of vehicle 3 = 110
   Deventer
-> Midden-Twente
-> Enschede
-> Losser
-> Oost-Twente
-> Deventer
```

Figure 4.4, validation output tool

For the tool to be internally valid, the tool has to provide the correct results. This means that the solution of the tool has to be the optimal solution and is feasible according to the constraints. To test this, we can test whether the model is right and the solution is valid. So, for each vehicle, the output was changed in a way that also the driven distance, the total weight of the vehicle, the total volume of the vehicle and the driving time + (un)loading time without retour was shown as an output. For the example of Section 4.3, the text output looks like figure 4.4.

We can compare these with the input form of Section 4.3.1 and see if these results are correct. For example, the distance of vehicle one should be equal to the distance from Deventer to Zutphen + Deventer to Zutphen to Vaassen + Vaassen to Deventer. This is correct because those distances added up are 72. For the other vehicles, this is also correct. For the total weight, we can see that for vehicle one this is 4100. From the input form, we can see that the weight capacity is 8500 so this results is valid. The result is also correct because the maximum weight of the products from Zutphen is 2900 and from Vaassen it is 1200. Also, for other vehicles and for the volume constraint these numbers are right and valid.

The last test is for the driving time. For vehicle one this is 71 according to the tool. This should be equal to the driving time from Deventer to Zutphen + Zutphen to Vaassen + 2 * unloading time (no Vaassen to Deventer because retour is excluded). This is correct because 18+33+2*10 = 71.

The last validation part was an interview with the coordinator of the distribution center. The coordinator is the person who will use this tool later to plan their trips on a daily basis, so he was the most relevant person for the validation. During the interview, the tool was explained and demonstrated. The coordinator was asked on 10 statements whether he agrees on a scale from 1 to 5 where 1 is “strongly disagree” and 5 is “strongly agree”. The questions and the results can be seen in Table 6.2.

Table 4.4, Validation Statements

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1.The input form is reliable			X		
2.The input form is easy to use					X
3. I will use this input form				X	
4. The tool is reliable			X		
5. The tool is easy to understand				X	
6. The tool provides correct results			X		
7. The tool provides useful results					X
8. The tool provides easy-to-read outcomes				X	
9. The tool helps solving the problem					X
10. I will use this tool				X	

As can be seen in the table, the tool + input form scored pretty well on most aspects. The reason that the tool and the input form scored a three on questions 1,4 and 6 is that the coordinator did simply not know whether these statements were correct However, when a few examples were shown he thought that the outcomes were logic and he said that he believed that the results were right and that the tool is reliable. Also, he did find the form easy to use and the tool relatively easy to understand. He did not understand the code, but he understood how to use the code and how to get an output. He also liked the output in text, the graph was a nice addition but not necessary. He totally agrees with the fact that the tool will help solving the problem of planning on a daily basis and he will probably use this tool when the food banks change to the new distribution. The reason that he filled in “Agree” instead of “Strongly agree” was that he firstly needs to know whether this new way of distributing will lead to lower costs. If this was the case and the new distribution will be actually carried out, he will use this tool to plan on a daily basis.

If we reflect on the validation, we can see that the tool work and gives the correct results and that the person who will use the tool is happy with it and wants to use it. To further develop the tool, the tool can be more dynamic by connecting it to for example Google Maps so that the drive times between the customers are more dynamic by for example taking congestions into account. Furthermore, an improvement point is that the programming code is visible for everyone. It would be nicer when this code was more hidden and that the tool only shows the output.

4.5 Conclusion

This chapter started with the mathematical model of the specific food bank VRP problem. In this section the changes to the basic model were explained, the definitions of the variables are given and the model itself was given and explained. After that, the tool was explained, with the input form and the output. This tool is also validated on the correctness of the results, on the external validation and whether the tool actually helps solving the problem which it does.

The research question for this chapter was: *What is the solution to the VRP?* The first subquestion was: *What is the mathematical model of this VRP?* This subquestion is answered in Section 4.2 in which the mathematical model of this VRP was given. The next subquestion is: *How can the food banks solve the VRP on a daily basis?* The answer to this subquestion is that the food banks can use the tool to solve the VRP on a daily basis. This tool comes with an input form in excel and an output in text and in graph. The last subquestion is: *How can the tool and the model be validated?* The answer to this is that the tool is validated in Section 4.4 and that the tool is both internally and externally valid and that the potential user of the tool is satisfied with the tool and wants to use it. So overall the research question is answered by a mathematical model, a tool and a validation.

5 Experiments

5.1 Introduction

In this chapter, experiments will be done with the tool and the database. The chapter starts with an explanation of the methodology for the experiments. In Section 7.3 experiments regarding the vehicles will be calculated and in Section 7.4 experiments regarding different scenarios will be calculated.

5.2 Changes to the model and to the tool

In this section, the changes to the model and to the tool will be explained. These changes are made to make the tool more suitable for the experiments. The data input for the experiments will be the dataset from the data analysis chapter. This dataset is a bit reformed so that for each day in the database the number of pallets that need to be transported to the different food banks is known, even as the weight of the products on those pallets.

The first change to the tool is the output. The output only consists of the distance in kilometers since that is the only relevant output of the tool for the experiments. The second change is that the time constraint will not be used during the experiments. The main reason for this is that the time constraint is most important on the days of issue, which is for almost all food banks on Friday. The days in the database are almost only Wednesday and Thursday and sometimes Friday. If the transport day is Friday there are often only products which need to go to Enschede, Midden-Twente and Oost-Twente and not that many products according to the database. These places are relatively close to each other, this means that the drive will not take too long, and the food banks will have their products relatively early. This means that it is not necessary to include the time constraint in the optimization model.

The next change is that the products who need to go from the food banks back to the distribution center are not considered, simply because they are not known in the database. However, the weight and volume constraint both are included in the optimization model.

Another change is that the input form is not used during the experiments, all parameters can be filled in in Spyder, such as the distances and the vehicle characteristics. The only parameters which are not in Spyder are the weightdemand and the volumedemand per day.

The next change is regarding the fact that the VRP needs to be solved many times in a row. This means that the whole code is going in one subfunction and this subfunction will be called once every day. In the database there are 115 days in total so the function will be called 115 times. This means that the output of the total experiment will be a list of 115 distances.. If we sum over these distances, we know the total driven distance per year and we can calculate the fuel costs using a price per kilometer. This price cannot be the price of section 2.6 which is €0,21 because trucks often use more fuel per kilometer than the current vehicles of the food banks. So, the price per kilometer of a truck is higher than the price per kilometer of a van. Trucks use 1 liter for approximately 3-3.5 kilometers. So, on average a truck uses 30 liters for 100 km. (Het gemiddeld verbruik van een vrachtauto, sd). Most trucks use diesel and the average price for diesel in the Netherlands is €1,463. (dieselprijzen europa, sd). This means that the price per kilometer will be 30*1,463/100 = €0,438. We can compare this with the fuel costs of the current situation so that we know whether the new situation can be profitable.

5.3 Scenarios and Methodology

In this section, the scenarios and methodology for the experiments will be explained. During the experiments, we will go over three main scenarios. The first scenario is the basic scenario. In this scenario the database will be used literally and no changes are made in the distribution strategy. Each food bank will receive the foods on the same day as in the current situation. The only difference is that they do not need to pick it up but the foods will be brought.

Table 5.1 shows which food bank receives their products on which day in scenario 1. In some weeks in the database Friday is included. If this is the case then Enschede, Midden Twente and Oost-Twente will receive a part of their products on Friday. If not, those products are added to their products on Wednesday.

Table 5.1. Distribution days in Scenario 1

	Wednesday	Thursday	Friday
Food banks	Rijssen, Oost-Twente, Enschede, Midden-Twente, Almelo	Hellendoorn, Raalte, Almelo, Losser, Zutphen, Vaassen	Enschede, Midden-Twente and Oost-Twente

In the second scenario, there are changes in which each food bank receives their products. Moreover Zutphen and Vaassen will be excluded from the VRP. They will continue picking up their goods as in the old situation. There are two reasons to exclude those food banks. The first reason is that those food banks are not close to other food banks in the region, so the vehicles need to drive a lot more to transport goods to those food banks. The other reason comes from the preliminary interviews in which the chairmen/coordinators of both food banks told that they do not want to cooperate in the new system necessarily and that they are satisfied with the old situation.

The other change in the second scenario is that the days in which each food bank receives their products are different. Table 5.2 shows which food bank will receive their products on which day in scenario 2. The changes compared with scenario 1 is that in scenario 2 Losser will be visited on Wednesday while Rijssen and Almelo will be visited on Thursday.

Table 5.2. Distribution days in Scenario 2

	Wednesday	Thursday	Friday
Food banks	Losser, Oost-Twente, Enschede, Midden-Twente	Hellendoorn, Raalte, Almelo, Rijssen	Enschede, Midden-Twente and Oost-Twente

In the third scenario the possibility of using sub-hubs is researched. For example, the food banks of Enschede and Losser work together, and all products of both food banks are delivered at the food bank Enschede. The food bank Losser then visits Enschede to pick up their products. For this scenario, the days of scenario 2 are used and there are four sub-hub connections. These connections can be seen in Table 5.3

Table 5.3. Cooperating food banks in the third Scenario. Enschede cooperates with Losser, Midden-Twente with Oost-Twente, Almelo with Rijssen and Raalte with Hellendoorn

Food bank where the products are delivered	Food bank which picks up the products
Enschede	Losser
Midden-Twente	Oost-Twente
Almelo	Rijssen
Raalte	Hellendoorn

These are the three scenarios which will be tested. Per scenario, the experiment will be done 4 times. The first time is the exact demand as given in the database, the second time is 10% more than the demand, the third time is 25% more than the current demand and the fourth time is 50% more than the current demand. This will be done because it is also important to see how the new situation will be if the demand increases in the future. According to section 2.3.3, the demand can increase up until 50% so when this happens the food banks should be ready for it.

Per experiment there are four options regarding the vehicles. The first option is to use one refrigerated truck since a refrigerated trucks can deliver all categories of products. To come up with the characteristics of this truck, a few trucks where researched. The results of this research can be found in Table 5.4. In this table 4 trucks are discussed so that the characteristic of an average truck can be determined. We assume that on average the truck has a weight limit of 10000 kg, a volume limit of 20 pallets and the price will be €16.000.

Table 5.4. Characteristics of 4 trucks

Vehicle number	Name	Weight limit in kg	Volume limit in Pallets	Price in euros	Reference
1	Mercedes-Benz AXOR 1926 Tautliner with Lift	10.400	18	€16.750	(Mercedes-Benz Axor 1926 Tautliner with lift, sd)
2	DAF CF 65 4x2 BOX	10.240	24	€15.850	(DAF CF 65 4x2 BOX, sd)
3	Renault Premium 340 DXI-6X2-10 PNEUS/TIRES+DHOLLANDIA	14.840	18	€16.900	(Renault Premium 340 DXI-6X2-10 PNEUS/TIRES+DHOLLANDIA, sd)
4	DAF LF 55.000 4X2 NL-Truck Ladebordwand Euro 5	10.030	22	€13.800	(DAF LF 55.000 4X2 NL-Truck Ladebordwand Euro 5, sd)

The second option is to use two of those trucks and the third option is to use three of those trucks. The last option is to use one semi-trailer. In this case both a truck and the trailer needs to be bought since the trailer consists of only the cargo space. Table 5.5 shows the characteristics of three semi-trailers. Based on these characteristics we can assume that the semitrailer will have a weight limit of 35.000 kg, a volume limit of 32 pallets and a price of €16.000 + €9.000 = €25.000.

Table 5.5. Characteristics of 3 Semi-Trailers

Vehicle number	Vehicle name	Weight limit in kg	Volume limit in Pallets	Price in euros	Reference
1	Schmitz Cargobull SCB*S3B, Kasten, LBW, Taillift : 2.500 Kg, Ladungsschicherung	39.000	35	€7.900	(Schmitz Cargobull SCB*S3B, Kasten, LBW, Taillift : 2.500 Kg, Ladungsschicherung, sd)
2	Schmitz Cargobull SKO 24 / CARRIER 1850 mt / DHOLLANDIA	42.000	35	€8.800	(Schmitz Cargobull SKO 24 / CARRIER 1850 mt / DHOLLANDIA, sd)
3	Mirofret 130 1 As Koel vries Oplegger	22.000	26	€9.400	(Mirofret 130 1 As Koel vries Ople, sd)

So there are three scenarios, per scenario there are four experiments and per experiment there are four options. Per option the total variable costs will be calculated and the number of times that there is no solution will be determined. So per experiment the outcome will look as in Table 5.6. The first column is the experiment which is: Scenario number.Experiment Number.Option. In the second column the number and type of vehicles is filled in. Column 3 shows the Experiment Time in seconds. Column 4 shows the total variable costs and Column 5 shows the number of days in which there is no solution. Per experiment 115 days are simulated so the number of days in which there is no solution will be between 0 and 115.

Table 5.6. Example of outcome per experiment

	Scenario 1, Current Demand			
Experiment Number	Vehicle	Experiment Time in seconds	Sum of the costs in euros	Number of days no solution
1.1.1	1 Truck			
1.1.2	2 Trucks			
1.1.3	3 Trucks			
1.1.4	1 Semi-Trailer			

So this is the methodology and the scenarios for the experiments section.

5.4 Scenario 1

In this section the experiments of Scenario 1 will be executed using the methodology of section 5.3. The first experiment is with the current demand. The outcomes of this experiment can be seen in Table 5.7. It can be seen that using 1 truck leads to 64 days in which there is no solution. This is 55,6% of all days, so that is not a feasible solution. The reason that the costs are so low is that for each day that there is no solution, there are also no costs, so this is not a realistic overview. Also 1 Semi-Trailer is not a good idea because of the 17 days in which there is no solution. Also using two trucks does not lead to a feasible solution since there are 7 days in which there are no solution The only feasible solution is to use 3 trucks.

The variable costs are then €10.268. The variable costs of the current situation are €22.800 so the savings will be €12.532 or 55,0% per year. The investment is 3 * €16.000 which is €48.000 so this will be profitable in approximately 4 years.

Table 5.7. Results Scenario 1 with current demand

	Scenario 1, Current Demand			
Experiment Number	Vehicle	Experiment Time in seconds	Sum of the costs in euros	Number of days no solution
1.1.1	1 Truck	7,90	€3.881,12	64
1.1.2	2 Trucks	57,81	€9.358,31	7
1.1.3	3 Trucks	108,83	€10.268,03	0
1.1.4	1 Semi-Trailer	16,51	€7.205,10	17

In Table 5.8 the results of the first scenario with a 10% increase in demand can be found. It can be seen that again the only feasible solution is to go for 3 trucks since that is the only option which has a solution for each day. The variable costs will then be €10.774 but the variable costs of the current situation will also increase with 10% , so the savings will be €25.080 - €10.774 = €14.306 or 57%. The investment is again €48.000 so if the demand increases with 10% it will still be profitable in 3,4 years

Table 5.8. Results Scenario 1 with 10% increase in demand

	Scenario 1, Demand + 10%			
Experiment Number	Vehicle	Experiment Time in seconds	Sum of the costs in euros	Number of days no solution
1.2.1	1 Truck	7,24	€3.316,54	71
1.2.2	2 Trucks	66,64	€9.139,75	12
1.2.3	3 Trucks	138,79	€10.774,36	0
1.2.4	1 Semi-Trailer	13,87	€6.520,07	25

Table 5.9 shows the results of the experiment with the first scenario and a 25% increase in demand. The only feasible solution is again to go for 3 trucks, however there are 3 days in which there is no solution possible. This is just acceptable as it is only 2,6% but we have to be cautious and plan well so that we can always handle the situation. The variable costs in this situation are €10.914 and the savings are €28.500 (current costs*1,25) - €10.914 = €17.586 or 61,7%. It will also still be profitable in approximately 2,7 years.

Table 5.9. Results Scenario 1 with 25% increase in demand

	Scenario 1, Demand + 25%			
Experiment Number	Vehicle	Experiment Time in seconds	Sum of the costs in euros	Number of days no solution
1.3.1	1 Truck	5,72	€2.158,47	85
1.3.2	2 Trucks	76,04	€8.864,68	18
1.3.3	3 Trucks	145,94	€10.913,65	3
1.3.4	1 Semi-Trailer	13,89	€5.676,04	36

In Table 5.10, the results for the last experiment of Scenario 1 are shown, namely the experiment with an increase of 50% in demand. It can be seen that even 3 trucks will lead to 11 days in which there is no solution. This is 9,6% so 3 trucks is not a feasible solution. To further research this scenario an experiment with 4 trucks was done. This experiment took 230,25 seconds and also had 7 days in which there was no possible solution. So we can say that if the demand increases with more than 50%, an efficient strategy is not possible in this scenario.

Table 5.10. Results Scenario 1 with 50% increase in demand

	Scenario 1, Demand + 50%			
Experiment Number	Vehicle	Experiment Time in seconds	Sum of the costs in euros	Number of days no solution
1.4.1	1 Truck	3,97	€1.253,56	96
1.4.2	2 Trucks	50,01	€7.465,71	34
1.4.3	3 Trucks	129,50	€10.464,26	11
1.4.4	1 Semi-Trailer	9,24	€4.300,28	57

To conclude this first scenario, we can say that in this scenario the only option is to buy three trucks. These trucks can manage the planning up and until a 25% increase in demand. The investments will be €48.000 but the savings will be €12.532 per year in the current situation, €14.306 if the demand increases with 10% and €17.586 if the demand increases with 25%. However in the last case, we must be cautious because there are three days in which there is no solution possible. It still means that this scenario can be profitable in 4 years with the current demand or even less if the demand increases.

5.5 Scenario 2

In this section the experiments of scenario 2 will be executed. In this scenario the distribution days for some food banks are changed and Zutphen and Vaassen are not included in the distribution strategy as can be seen in Section 5.3. This means that the variable costs of Zutphen and Vaassen should be added to the variable costs of the new situation.

In Table 5.11 the results for the first experiment in this scenario (experiment with the current demand) can be seen. It can be seen that both using 2 trucks and using 3 trucks are feasible solutions since they provide a solution for everyday. The variable costs for both outcomes are the same. This is logical because when two trucks are enough to deliver everything, it is never necessary or more efficient to use three trucks. This means that the best solution is to use two trucks. The variable costs are €7.162 + €2.839 (costs of Vaassen) + €2.000 (costs of Zutphen) = €12.001. This is a saving of €10.779 or 47,3%. This is lower than in Scenario 1 but in this scenario only 2 trucks need to be bought. So the investment is only €32.000 and this scenario will be profitable in only 3 years instead of 4.

Table 5.11. Results Scenario 2 with current demand

	Scenario 2, Current Demand			
Experiment Number	Vehicle	Experiment Time in seconds	Sum of the costs in euros	Number of days no solution
2.1.1	1 Truck	7,18	€3.954,70	35
2.1.2	2 Trucks	41,40	€7.162,18	0
2.1.3	3 Trucks	45,68	€7.162,18	0
2.1.4	1 Semi-Trailer	10,89	€5.411,49	7

In Table 5.12 the outcomes of the experiment in Scenario 2 with a 10% increase in demand can be found. It can be seen that it is a bit debatable is using two trucks is still feasible since there are 4 days in which a solution is not possible. If we still decide to use 2 trucks the variable costs will be €7.145,97 + 1,1* variable costs of Zutphen and Vaassen = €12.468. This is a saving of €25.080 - €12.468 = €12.612 or 50,2%. The investments are €32.000 so it will be profitable in 2,5 years. If we use three boxtrucks the savings will be €11.997 or 47% using the same calculations. It will be profitable in 4 years. So the option of 2 trucks is more efficient in this experiment but there will be situations in which there is no solution so it might be better to buy three trucks if we expect an increase of 10%.

Table 5.12. Results Scenario 2 with 10% increase in demand

	Scenario 2, Demand + 10%			
Experiment Number	Vehicle	Experiment Time in seconds	Sum of the costs in euros	Number of days no solution
2.2.1	1 Truck	6,42	€3.340,19	47
2.2.2	2 Trucks	47,21	€7.145,97	4
2.2.3	3 Trucks	101,07	€7.759,61	0
2.2.4	1 Semi-Trailer	9,27	€5.253,37	10

Table 5.13 shows the result of a 25% increase in the second scenario. It can be seen that the only feasible solution is to go for three trucks. However even this will lead to a situation in which there is no solution possible. The variable costs in this situation are €8.243 + 1,25* variable costs of Zutphen and Vaassen = €14.292. The savings will be €28.500-€14.292 = €14.208 or 49,9%. The investments are €48.000 so this will be profitable in 3,4 years.

Table 5.13. Results Scenario 2 with 25% increase in demand

	Scenario 2, Demand + 25%			
Experiment Number	Vehicle	Experiment Time in seconds	Sum of the costs in euros	Number of days no solution
2.3.1	1 Truck	5,75	€2.531,64	62
2.3.2	2 Trucks	51,74	€7.241,89	9
2.3.3	3 Trucks	148,48	€8.243,16	2
2.3.4	1 Semi-Trailer	8,73	€4.937,14	16

Table 5.14 shows the results of the experiment in Scenario 2 with 50% increase in demand. It can be seen that there are no feasible solutions in this experiment because even 3 trucks would lead to a relevant number of no solutions.

Table 5.14. Results Scenario 2 with 50% increase in demand

	Scenario 2, Demand + 50%			
Experiment Number	Vehicle	Experiment Time in seconds	Sum of the costs in euros	Number of days no solution
2.4.1	1 Truck	4,08	€1.531,25	84
2.4.2	2 Trucks	45,56	€7.187,14	16
2.4.3	3 Trucks	145,08	€8.742,48	5
2.4.4	1 Semi-Trailer	7,02	€4.175,02	30

So to conclude this section, if demand stays the same as the current demand, it is best to buy two boxtrucks. This will lead to a saving of €10.799 but the investments are only €32.000 so it will be profitable in 3 years. If the demand increases with 10% it can be efficient to buy two trucks. In that case the savings will be €12.612 and it will be profitable in 2,5 per year but there are situations in which there is no possible solution. So if more safety is the preferred option it is best to go for 3 trucks. In that case the savings will be €11.997, it will be profitable in 4 years but there is more security. If the demand increases with 25%, the only option is to go for three trucks. The savings will be €14.208 and it will be profitable in 3,4 years.

5.6 Scenario 3

In this scenario the option of a sub-hub will be discussed. This means that the variable costs of Enschede, Almelo, Midden-Twente and Raalte will be calculated in the tool. The variable costs for Zutphen and Vaassen are the same as in Scenario 2 since those distribution strategies will not change. To calculate the variable costs for Losser for example, the variable costs of Table 2.12 should be divided by the distance from Losser to Deventer and multiplied by the distance from Losser to Enschede. If we do that for Rijssen, Oost-Twente and Hellendoorn as well we can calculate the total variable costs of those food banks in the new situation. The results of this calculation can be found in Table 5.15. The total variable costs of these food banks are €896.

Table 5.15. Variable costs in Scenario 3 for Losser, Oost-Twente, Rijssen and Hellendoorn

Food bank	Variable costs
Losser	€127
Oost-Twente	€517
Rijssen	€0
Hellendoorn	€252
Total	€896

In Table 5.16 the results of the experiment in Scenario 3 with the current demand can be found. It can be seen that the only feasible solutions are to buy two trucks or three trucks. Since both have the same variable costs, it is best to go for two trucks. The variable costs will be €6.636 + €896 + €4.839 = €12.371. The savings will be €10.429 or 46%. It will be profitable in 3 years since the investment will be €32.000

Table 5.16. Results Scenario 3 with current demand

	Scenario 3, Current demand			
Experiment Number	Vehicle	Experiment Time in seconds	Sum of the costs in euros	Number of days no solution
3.1.1	1 Truck	7,77	€3.731,76	35
3.1.2	2 Trucks	41,53	€6.636,14	0
3.1.3	3 Trucks	61,14	€6.636,14	0
3.1.4	1 Semi-Trailer	10,22	€5.056,27	7

In Table 5.17 the results of the experiment in Scenario 3 with 10% increase in demand. It can be seen that there is no feasible solution. Even three trucks lead to 5 days without a solution. An explanation for this is for this scenario to work, it is necessary that all the products of for example Enschede and Losser fit in the same truck. If this is not the case, there is no solution. In other scenarios there might be ways to split Enschede and Losser over two vehicles and come up with a feasible solution, this is not the case in this scenario.

Now we know that an increase of 10% does not lead to a feasible solution, we can also say that an increase of 25% or even 50% will not lead to feasible solutions so it is not necessary to do those experiments.

Table 5.17. Results Scenario 3 with 10% increase in demand

	Scenario 3, Demand + 10%			
Experiment Number	Vehicle	Experiment Time in seconds	Sum of the costs in euros	Number of days no solution
3.2.1	1 Truck	6,46	€3.163,24	47
3.2.2	2 Trucks	43,42	€6.601,97	5
3.2.3	3 Trucks	61,63	€6.601,97	5
3.2.4	1 Semi-Trailer	9,71	€4.911,29	10

So to conclude this scenario, we know that this scenario only provides feasible results of the current demand does not increase. In this case the savings are €10.429 and it will be profitable in 3 years. If the demand increases, this scenario will not work.

5.7 Conclusion

In this chapter we experimented with the tool and the database. The first section of the chapter was an explanation of the changes in the tool to make it suitable for the experiments. In the next section the scenarios were discussed even as the methodology for the experiments. Then the experiments were done in three scenarios, with 4 experiments per scenario and 4 options regarding the vehicles.

The research question for this chapter was: *What is the best distribution strategy for the food banks?*

It also had three subquestions. The first subquestion is: *Which scenarios can be used to improve the distribution and lower the costs?*

To come up with an answer for this subquestion, the outcomes of the experiments for the three scenarios must be compared. These outcomes are compared in Table 5.18 and Table 5.19. Table 5.18 shows the savings per scenario for each demand. Table 5.19 shows the investments per scenario for each demand. If we compare the three scenarios we can immediately see that Scenario 3 is not the right scenario since it cannot even manage a 10% demand increase. Furthermore, when looking at the current demand we can see that Scenario 2 is better than Scenario 1 since the investments are €16.000 lower. The savings are not lower but this difference is only €1.733. This means that it would take more than 9 years for Scenario 1 to be more profitable than Scenario 2. If the demand increases with 10% Scenario 2 will still be more profitable if it is decided to buy 2 trucks. If the demand increases with 25% Scenario 1 is more profitable but the expectation is that this would not happen. (Section 2.3.3). So the best Scenario is Scenario 2. In this Scenario the food banks close to each other are grouped on the same day and Vaassen and Zutphen will be excluded from the new distribution.

Table 5.18. Variable costs savings per Scenario and Demand

Savings in variable costs	Current Demand	Demand + 10%	Demand + 25%	Demand + 50%
Scenario 1	€12.532	€14.306	€17.586	-
Scenario 2	€10.799	€12.612/€11.997	€14.208	-
Scenario 3	€10.429	-	-	-

Table 5.19. Investments per Scenario and Demand

Investments	Current Demand	Demand + 10%	Demand + 25%	Demand + 50%
Scenario 1	€48.000	€48.000	€48.000	-
Scenario 2	€32.000	€32.000/€48.000	€48.000	-
Scenario 3	€32.000	-	-	-

The next subquestion was: *Which vehicle(s) are best to use in these scenarios?* The answer to this subquestion is that when the demand does not increase to much, it is best to buy two trucks. The investments will be €32.000. The savings will be €10.799 per year (and it will be profitable in 3 years) if the demand does not increase and €12.612 if the demand increases with 10%. However, if this is the case, we must be cautious because there might be days in which two trucks is not enough. And if the demand increases with more than 10%, two trucks are not enough

If we take the more conservative approach, we need to buy 3 trucks. The advantage is that 3 trucks can manage an increase of 25% of the demand. However the investments will be €48.000. The savings will again be €10.799 if the demand does not increase. This means that this investment is profitable in 4,5 years.

So to conclude this subquestion, both options have advantages and disadvantages, two trucks is more profitable but three trucks provides more safety. So my advice is to start with buying two trucks, and if the demand increases a third truck can be bought

The last subquestion is: W*hat are the costs of these new scenarios?* The answer to this subquestion is either €32.000 or €48.000 depending on the number of trucks that are bought.

To give an answer to the main research question for this chapter is that the best strategy for the transport is to create a scenario in which relatively close food banks are visited on the same day. Then it is best to buy two trucks as a start and buy a third truck if the demand increases.

6 Conclusion

6.1 Introduction

In this section, the conclusion of this thesis is discussed. It starts with a section which gives a summary of the main results and findings. Section 6.3 then provides an insight in the contribution of this study to the practice and to the theory. Then in Section 6.4, the limitations of the study are discussed, in Section 6.5 the recommendations to the food banks are given and in Section 6.6 the implications of this thesis on the food banks are discussed. This chapter ends with a discussion on future research regarding this problem and other relatable problems.

6.2 Summary of the main results/findings

The aim of the research was to come up with a new transport strategy for the food banks in the region Twente-Salland. To do that, a few steps were needed.

This thesis started with a chapter with a data-analysis on the database with all order lines of the food banks. This database is reformed in such a way that per day the volume and the weight of the products per food bank are known. This database is used later in Chapter 5.

The next chapter was the literature chapter. The main question of this chapter was how to solve the Vehicle Routing Problem (VRP) of the food banks. Four options were discussed namely: Exact Approaches, Heuristics, Metaheuristics and Matheuristics. It was decided that the best solution approach was the Exact Approach, since it was the only option which always provides the optimal solution and since a mathematical must be solved later the method has to be an exact approach. The disadvantage of an Exact Approach is that it takes to long but this is not the case in this research since the VRP is relatively small. In Chapter 6 the solution model was discussed. It started with the mathematical model of the VRP, then the tool was explained and demonstrated and also the validation of the tool was discussed.

Chapter 7 provided the numerical experiments of this thesis. Here we analyzed 3 different scenarios. Per scenario we conducted 4 four experiments and per experiment we had 4 options regarding the vehicles. We calculated the variable costs of all outcomes and the number of days in which there was no solution. Based on those numbers we decided to go for scenario 2 in which the food banks of Vaassen and Zutphen are not incorporated in the new distribution system and the food banks are grouped per day. The food banks of Enschede, Midden-Twente, Oost-Twente and Losser will be visited on Wednesday and the food banks of Hellendoorn, Raalte, Rijssen and Almelo will be visited on Thursday.

The next step was to come up with an advice on the vehicles. The advice is that both 2 trucks or 3 trucks can be a good option. 2 trucks means that the investment will be €32.000. If the current demand stays the same the savings will then be €10.799 which is 47% of the total variable costs of the current situation. This also means that this investment is profitable in 3 years. If the demand increases with 10%, the savings will be €12.612 which is 50% of the current variable costs (taking the 10% increase into account). However if the demand increases with more than 10%, having only two trucks can lead to situations in which there is no possible solution for the VRP. In that case it is better to have 3 trucks. If the demand does not increase the savings are still €10.799 but the investments are €48.000. So the investment is only profitable after 4,5 years. If the demand increases with 10%, the savings are €11.997 and the investment is profitable in 4 years. If the demand increases with 25%, the savings are €14.208

and the investment is profitable in 3,4 years. So the advice is to start with two trucks and if the demand increases, a third truck can be bought

The main research question of this thesis was: *How can the Vehicle Routing Problem related to the supply of the food banks in the regional network from Deventer be optimized?*

The answer to this question consists of two parts. The first part is the tool which is created during the thesis to help the food banks to solve their VRP on a daily basis. The second part is the advice on the distribution strategy. My advice is to create a scenario in which closely located food banks are connected and visited on the same day by the same truck. Furthermore my advice is to buy two trucks if the expectation is that the demand will not increase that much or that increases can be handled well. If the demand increases, a third truck can be bought.

6.3 Contribution and significance of the study

The contribution of this thesis to the practice is that the transport costs of the food banks will be lowered drastically. The variable costs in the new distribution strategy will decrease with 47%. The second contribution to the practice is that the distribution center can use the tool which was created during this thesis for planning the distribution on a daily basis. This means that the study was significant in helping the food banks to lower their costs and have a more efficient distribution strategy.

The contribution to the theory is closing a gap between the basic Vehicle Routing Problem model with a capacity constraint and the model which was needed to model the distribution system of the food banks. This was solved by adding constraints to the basic model such as the time constraint and the changed capacity constraint which also considers the products which needed to be picked-up.

Another contribution of the study to the theory is that the tool can be used for many other cases. Since the input for the tool is an excel form, the parameters can be changed very easily. This means that this tool can also be used by food banks in other regions for example. The only thing they have to do is updating the distance matrix and then they can fill in the parameters and use the tool for their region. The tool can also be used for a national network between distribution centers. A condition for this is that this VRP should have one depot. The tool cannot solve problems with more depots yet. This can be an option for further research. The same holds for time windows within a VRP. Also, the tool can be used for other VRP with two capacity constraints and a time constraint.

6.4 Limitations

The first limitation of this thesis is that the database was not fully correct and complete. The first problem with the database was that the volume of the products was not given. Estimations of the volume were necessary and could be done using the table in Appendix B. But these are only estimations and could lead to big differences between the database and the reality. The second limitation was that the database was not complete. In Chapter 2, we discussed that the first calculation of the number of pallets was too low. Then we increased these numbers based on the interviews with the chairman/coordinators of the different food banks and the number of pallets they said that are picked up at the distribution center per week. These estimations could also lead to differences between the database and the reality.

The next limitation is that in the model and experiments section, the constraints whether a food bank can only receive products on a Wednesday for example are not used. This could mean that the scenarios that were chosen cannot be valid scenarios in the real situation.

6.5 Recommendations

The first recommendation for the food banks and for the distribution center is that they should make sure that their database is complete and also have a volume indicator per product. By doing this, it would be way easier to do the planning on a daily basis, because the distribution center then knows how many products need to go to different food banks and the weight and volume of those products, so that they can plan their strategy for the day by using the tool for example.

The next recommendation considers the vehicles which need to be bought for the new situation. The recommendation is to buy two boxtrucks for the distribution center to distribute the foods to the food bank. When buying these secondhand they will cost approximately €32.000 with variable costs of €7200 if scenario 2 is used and the total savings for the food banks will be € 18.000 per year. That means that the investment will be profitable in three years. These vehicles can also be used for the distribution center to pick up some products somewhere else, another distribution center or a food producer.

The third recommendation considers the distribution system. If the new distribution system will take place it is recommended to change the distribution days of a few food banks to make sure that the food banks which are located close to each other are grouped. So, for example, it is recommended to distribute Raalte, Hellendoorn, Rijssen and Almelo on the same day, even as Enschede, Midden-Twente, Oost-Twente and Losser since that would lower the drive distance massively. It is also recommended to not include Zutphen and Vaassen in the new distribution system because they are not located close to other food banks so it would not be profitable to include those food banks in the new system.

6.6 Implications

The recommendations of Section 6.4 on the new distribution network have a few implications. The first implication is that the people in the distribution center need to work with the tool to plan the transport on a daily basis. This means that they should learn how the tool works. Since everything can be filled in in an input form in excel, this should not be too difficult, however it might take time for the volunteers to getting used to this new planning system.

The second implication is that there are more drivers needed at the distribution center. Since each trip now starts at he distribution center instead of at the food bank, the drivers need to start at the distribution center as well. This means that the distribution center needs more volunteers as drivers while the food banks need less driver.

The third implication is a significant implication. The research implicates that some food banks must change the days in which they are provided with the products from the distribution center. It is important for food banks which are located relatively close to each other, to be visited on the same day. In the scenario experiment we calculated the example of Almelo, Losser and Rijssen changing the distribution days but also other situations can possible. It is adviced to group food banks such as Enschede, Midden-Twente, Oost-Twente and Losser. Another group that can be made is Raalte, Hellendoorn, Almelo and Rijssen.

The fourth implication is also important. This distribution strategy can only work if all incoming and outgoing products are registered well. This means that both the weight and volume needs to be registered so the situation per day is known and a plan can be made.

The fifth and last implication is that the vehicles of the food banks are only necessary for the local network and not for driving to the distribution center. This means that those vehicles can be used less or maybe even be sold. If this is the case, the new distribution strategy would be even more profitable.

6.7 Future research

For future research, the study could be repeated if the database is updated and complete with the volumes,

Another option is to include time windows in the model. Time windows are constraints that for example say that the food bank of Enschede may only be distributed on a Wednesday or between 10 and 12 in the morning. This research would improve the distribution model and can also improve the tool for daily planning. It would also improve the tool in such a way that it can be used for other situations outside the food bank.

The tool can also be developed further by making it more dynamic and connecting it to a website such as Google Maps. The advantage of this is that the tool can then account for congestions and create a better plan based on those congestions.

There are also other regions in the Netherlands for whom a new distribution network might be profitable. So, an idea for future research is to research in those regions for a better network. And also, for the network between the distribution centers nationally can be researched whether a new distribution network is better to better divide the products over the distribution center or to distribute more efficient. For this problem, further research could also usefully explore how to include multiple depots in the tool so that the vehicles can stay at multiple distribution center for one night.

Besides those VRP problems, there are also other problems that can be researched. A problem that will occur in the new situation is how to load the trucks in such a way that the products can be unloaded easily at the food banks and the new products can be loaded easily as well. It might be the case that when a route for the vehicle is Deventer-Enschede-Hengelo-Deventer, products need to be picked up in Enschede, when packaging these products, it is important that the products for Hengelo can be unloaded easily without the returned products standing in the way.

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Appendix A

In this Appendix, a list of interview questions can be found. As said, the interviews were guided interviews, which means that there are only a few questions prepared and most of the interview questions were made during the interview and were mainly follow- up questions or other questions due to the explanations of the respondents.

Questions:

1. How many households come to your food bank?
2. How many volunteers do work at your food bank?
3. What is your day of issue?
4. Do you expect more customers in the coming months due to Covid-19?
5. How many vehicles do you have and what are the weight limit and volume limit of these vehicles?
6. Do you have a local network where you pick-up the food and how does that work?
7. On which day do you go to the distribution center to pick up the food there?
8. Do you work together with other food banks?

Appendix B

In this appendix, the research design table is given and explained. For the research design, I created a research design table for subquestion 1,2,4 because those questions are knowledge questions and suited for a research design table. The research design for subquestion 3 will be explained in the methodology chapter. But table B.1 shows the research design for subquestions 1,2,4.

Table B.0.1, Research design Table

Knowledge problem	Research Type	Research Population	Research subjects	Research strategy	Data gathering method	Data analysis method
Subquestion 1	Descriptive study & exploratory study	The food banks in the region Twente-Salland	Chairmen/coordinators of the food banks, database of the distribution center	Direct contact with population, no influence of the variables, cross-sectional	Guided interviews, analyzing raw database from distribution center	Qualitative and quantitative
Subquestion	Exploratory	The food	Literature	No direct	Literature	Qualitativ

2	study	banks in the region Twente-Salland		contact, no influence of the variables, cross-sectional	study	e
Subquestion 4	Descriptive study	The food banks in the region Twente-Salland	The tool and the database from the distribution center	No direct contact, no influence of the variables, longitudinal	Using the tool and the database	Quantitative

For the first subquestion, the research type is descriptive and exploratory. The exploratory part of the research is in the preliminary interviews where the respondents are asked about their current distribution strategy. The descriptive study on the other hand is the analysis of the data.

For the second subquestion the study is exploratory since I want to know how I need to solve the VRP, which is a 'how-question' and therefore an exploratory study. Subquestion 3 is then a descriptive study because I want to know the costs of the solution, this is a descriptive study.

The research population for the whole research are the food banks in the region Twente-Salland and the distribution center. However, the research subjects for the knowledge questions are different. For Subquestion 1, the research subjects are the database of the distribution center and the interviewees, which are the chairmen/coordinator of the food banks. Since the second subquestions is a literature study, there is not really a research subject. So, the research subject for those questions is literature. For the fourth subquestion I will use the tool I made, combined with the database so that will be the research subject.

The data gathering method of Subquestion 1 are the guided preliminary interviews for the qualitative part of the subquestion and the analysis of the raw database from the distribution center for the quantitative part. This means that the data-analysis method is both qualitative and quantitative. The data gathering method for the second subquestion is a literature study and the data analysis method will be qualitative. For the fourth subquestion, the data gathering method will be using the tool and the database to calculate the costs of each scenario. The data-analysis method will then be quantitative.

For Subquestion 3 I will take a few steps. The first step is to use the knowledge from Subquestion 2 to create a mathematical model of the new situation at the food banks. The next step is to program a code in Spyder to solve the mathematical model and create an input form in excel to create a tool. Spyder is an application in which Python can be used to solve problems such as a VRP. At the start of the thesis, I did not know how to use Python, so I first needed to learn Python. I did this by using tutorials of Eduardo Lalla. (Lalla-Ruiz, Tutorial 1, Introduction to Python, 2021) (Lalla-Ruiz, Tutorial 2, Mathematical modelling in Python, 2021) (Lalla-Ruiz, Tutorial 3, Heuristics with Python, 2020). I also used Gurobi which is an application to speed up the process of solving the model.

With this knowledge, the tool can be created, and the next step is to validate the tool. To do this, the coordinator of the distribution center will be asked to give his opinion on the tool and whether he will use this tool in the new situation.

For Subquestion 5 the research design is to use the answers of subquestion 4 to come up with a conclusion and provide implications, recommendations and advice on further research based on those conclusions.

Appendix C

Table C.1 shows the number of pallets transported in 2020 per article category. This table can be used to calculate the ratio between the weight of the products and the number of pallets for different product categories. The left column of the table indicates the category, the middle column indicates the weight in kilos. (aantal CE means weight in kilo), and the right column indicates the number of pallets. By dividing the middle column by the right column, we can make an estimation of the weight per pallet per product category. (Voedselbanken.nl, 2021)

Table C.0.1. Volume and Weight per product group

Productgroep	aantal CE	aantal pallets
Kruidenierswaren	9.684.157	8.264
AH koelvers	3.226.347	3.305
XPO assortiment		0
Zuivel	2.571.564	4.489
Drank	1.848.871	1.691
Snacks	4.131.822	3.792
Maaltijden	135.561	87
Broodbeleg	13.788	18
AGF (min of meer vers)	2.282.793	3.255
Babyvoeding	90.801	58
Graanproducten	703.365	719
Conserven	436.419	333
Maaltijden diepvries	379.974	461
Non-food	1.187.013	1.308
Snacks diepvries	614.793	620
Supplementen	2.004	1
Vis en vlees	57.748	46
Pasta & rijst	0	0
Vis en vlees diepvries	199.968	213
Zuivel diepvries	5.000	3