# Bachelor Thesis

## Choosing between centralized and decentralized logistics for food banks in the region Twente-Salland.


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S2100142

University of Twente


July 2021


Industrial Engineering and Management

Faculty of Behavioural and Management Sciences

# Bachelor thesis Industrial Engineering and Management

## Choosing between centralized and decentralized logistics for food banks in the region Twente-Salland

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# Preface

Dear reader,

You are about to read my bachelor thesis “Choosing between centralized and decentralized logistics for food banks in the region Twente-Salland”. This research has been conducted at Voedselbanken Nederland as a final assignment for my bachelor Industrial Engineering and Management at the University of Twente. This thesis aims at investigating the possibility of improving through collaborating on logistics for food banks in the region Twente-Salland.

Hereby, I would like to thank all the people who supported me in the past few months. I want to thank Sebastian Piest, my first supervisor from the UT, for all his time and effort to supervise this research. I adored the discussions we had during our meetings and I am grateful for all the constructive feedback given on all development. He also helped me find direction in the academic part of the thesis. I also want to thank Eduardo Lalla, my second supervisor from the UT, for his guidance on the technical part of this thesis as well as the feedback he provided from the second perspective which enabled me to improve my thesis.

Without a doubt, I would like to thank Henny Ganseman, my supervisor from the organization, for providing the opportunity to perform this research. His enthusiasm for this project kept me motivated throughout the research. His connections within the organization ensured that I got in contact with the right people. I want to thanks all the people within the food banks organization for providing the help and answers needed to continue this research. Finally, I would like to thanks my family and friends for their support during the execution of this research.

I hope that you enjoy reading my thesis!

Kind regards,

Wessel Rienstra

Enschede, July 2021

# Management summary

A food bank is a charitable, autonomous organization that supports low-income families in its vicinity by distributing food packages free of charge. These packages are assembled with mostly donated products from companies and organizations. The region Twente-Salland counts eleven food banks and one regional distribution centre (RDC). The RDC functions as a warehouse where donated food is stored and divided into orders for the food banks. Depending on its size, a food bank transport orders from the RDC up to three times per week using its transport resources (i.e., small trucks that transport three to six pallets).

Due to the economic consequences of the Covid-19 virus, food banks expected an increase in demand as more families would become eligible for support. To be prepared for this increase, food banks wanted to improve their logistics through collaboration**.** In particular, they proposed a collective transport network for products from the RDC that would supply all food banks in the region and that would be able to handle an increase in product volume of 50%. This network would fall under the responsibility of the RDC and would be performed with a large truck that is currently not at the disposal of the food banks. Food banks lack the capabilities to investigate if a collective transport network would actually operate more efficiently than the current transport network. To solve this problem, a quantitative analysis of the performance of the current transport network and the performance of a future collective transport network is performed in this thesis. Thereby aiming to answer the following research question:

*What are the needs to promote transport collaboration via a collective transport network among food banks in the region Twente-Salland?*

a context analysis was executed to understand the situation of the food banks within the studied region. By performing on-site visits to the RDC and conversations with relevant stakeholders, the characteristics of the RDC, the food banks and the transport between them were investigated. This analysis showed, besides many other transport aspects, that each food bank uses their trucks, besides transporting the orders from the RDC, also to transport products from local donors. The development of a collective transport network would therefore not make these trucks completely redundant. This research did not investigate if,  and how many, trucks could be reduced per food bank to lower the fixed costs as a result of the development of a collective network. Therefore, this research directed its attention toward the variable costs made with transport. These costs only include fuel costs for the food banks.

A reference model was constructed to analyse the performance of transport to the RDC in the current situation. In Excel, data on the orders from the RDC in 2020, truck capacities of food banks, transport costs and distances between food banks and RDC were stored. This data was combined to provide information on the transport costs made by food banks in the year 2020. The model calculated variable and fixed transport costs to be 26102 and 70309 respectively in the current situation. Furthermore, the model provided information on the timing, weight and volume of all orders which is used as input in the solution model. Finally, to investigate an increase in demand, three scenarios were modelled where demand was increased 10%, 25% and 50%. The variable transport costs were 27733, 30060 and 34341 euro respectively.

The collective transport network was identified as a capacitated vehicle routing problem (CVRP). Via Google OR-Tools, an optimization model was constructed to test four collective transport scenarios. These scenarios considered two types of trucks and the inclusion of all food banks in the collective transport network versus the inclusion of only the five food banks that had the highest variable transport costs in the reference model. Their variable costs equalled 20449 euros currently and 21891, 23833 and 27502 euros for the 10%, 25% and 50% demand increases. The model was used to calculate, for each collective scenario, the transport costs that would be made if all orders of the year 2020 would be transported via the collective transport scenario. It thereby used the order data from the



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reference model as input. The scenario that considers a single-unit truck supplying the top five food banks was identified as the leading collective transport scenario. Given the normal demand and the three demand increases, this transport strategy saved 12333, 12372, 13440, and 15843 euros on fuel costs per year compared to the current situation.

Furthermore, costs levels of this single-unit truck including different components were calculated and compared with the fuel costs of the current situation:

- Including all variable costs (fuel, tire, maintenance and depreciation), the truck saved 5825 euros to supply the top five food banks.
- Comparing the fixed and variable costs of the single-unit truck with the fuel costs of the current situation, 7562 euros extra were made by the collective network.
- Finally, adding personnel costs to the fixed and variable costs, the collective network would costs 28820 euros per year more than the current fuel costs.

This research concludes that 56% savings on fuel costs can be achieved via collaboration on transport. Furthermore, 28% of costs were reduced if all variable costs of the single-unit truck were compared with the current fuel costs. The efficiency of the collective transport network is depended on whether food banks are able to reduce fixed costs due to the collective transport network. Finally, including personnel costs results in the collective transport network making more than double the current fuel costs. This research recognizes that due to the scope, the quantitative approach taken to analyse the current logistics was not all-inclusive. The operational activities and implications that play a vital role in the success of a collective transport network were not considered. Therefore, if food banks were to operate a collective transport network, the following is recommended to be further investigated by the food banks:

- Acquire a truck and recalculate the depreciation costs to provide a more accurate costs estimation. Find a driver, preferably a volunteer, with a C truck driver license who can drive the truck either for free or for a reduced salary.
- Develop the solution model used in this research into a user-friendly tool that could be used by the RDC to construct the optimal routes given a certain order demand of the food banks.
- Investigate the availability and flexibility of volunteers at the food banks. If they are able to cover a complete day, the current model can be used to construct routes as it does not take time windows of arrival per food bank into account. However, if food banks require the truck to arrive within a certain time interval, due to the limited availability of volunteers. The problem transforms to a Vehicle Routing Problem with Time Windows (VRPTW) which should be included in the tool used by the RDC.
- Increase information sharing between the food banks in the collective transport network. Aspect like the driven routes on a day, expected time of arrival and possible delay should be communicated to all the food banks in an efficient manner.
- Decide how the costs savings are divided between the participating food banks to ensure that each food bank perceived participating in the collective network as beneficial.
- Critically evaluate if the number of trucks currently used could be reduced as a result of the collective transport network to reduce total costs.

Finally, based on the performed research, the following general recommendations are made to the food banks:

- Improve transport data registration to increase the reliability of future research.
- Increase collaboration between smaller food banks by combining multiple orders of different food banks to be transported by one truck.
- Investigate other ways to make use of the single-unit truck. Currently, the collective transport network would only be operated on two to three days per week. This leaves at least two days on which the large truck is free to use.
- Finally, the number of orders that can be transported by a single truck depends on the weight and volume capacity of that truck. The solution model identified that the volume of orders is

the limiting capacity for the larger trucks. Since all orders are stacked on euro pallets, the advice is to improve pallet stacking. This would reduce the number of pallets needed to prepare an order for a food bank. Consequently, more orders could be transport by one truck which reduced the number of trips and thereby the total transport costs.

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# Abbreviations

**CE** Centrale Eenheid (Central Unit)

**CVRP** Capacitated Vehicle Routing Problem

**ERP** Enterprise Resource Planning

**RDC** Regional Distribution Centre

**TSP** Traveling Salesman Problem

**VB** Voedselbank (Food bank)

**VRP** Vehicle Routing Problem

**VRPTW** Vehicle Routing Problem with Time Windows

# 1. Introduction

This chapter introduces this research conducted at food banks in the region Twente-Salland. §1.1 introduces the background of the assignment together with the different parties involved in the organization. §1.2 identifies the core problem that this research aims to solve. The steps taken within this process are derived from the book "Solving Managerial Problems Systematically" (Heerkens &Van Winden, 2012). §1.3 states the goal of this research. §1.4 formulates the main research question and sub-questions. Lastly, §1.5 outlines the research design which includes the problem-solving approach as well as an overview of the content of the remaining chapters of this thesis.

## 1.1 Background of assignment

Today, in the Netherlands, around one million people of which 251 thousand children, live below the poverty line. This means that they struggle to achieve basic living standards such as a healthy and varied diet. Conversely, between 23 and 32% of food is wasted every year in the Netherlands ("Samen tegen voedselverspilling", 2020). This percentage means that over 2 billion kilograms of perfectly edible and nutritious food, goes to waste yearly. In this abysmal scenario, food banks have the dual mission of collecting good quality food that otherwise would have been discharged on one side, and redistributing it to people who have difficulties in purchasing enough food, on the other. Currently, there are 171 food banks active in the Netherlands which in 2019 alone, were able to redistribute 74 thousand euros worthy of food, helping over 160,500 people (Voedselbanken Nederland, 2020).

To explain how food banks operate, it is necessary to identify and introduce the three actors that work together in the food bank network, namely the food banks, the regional distribution centre (RDC) and the organization 'Voedselbanken Nederland', all of them operated by volunteers.

**Food banks**[1]

A food bank is a charitable, autonomous, non-profit organization that supports low-income families in its vicinity, distributing, free of charge, food packages consisting of approximately three meals per week. The food packages are assembled almost only with products donated by other companies and organizations, especially supermarkets. Food banks as well as the RDC`s and 'Voedselbanken Nederland' operate solely with the work of volunteers. The main mission of a food bank is to collect enough good quality and a diverse range of products to consistently provide enough food packages to their subscribed households each week. To fulfil its mission, a food bank performs the following activities: first, the food needs to be collected; food banks almost completely rely on food donations. Two main channels through which a food bank receives food supplies are identified: one is local and another one is regional/national. First of all, a food bank has to implement and maintain its relationships with local supermarkets, food companies and other organizations, creating its so-called 'local network'. This local network donates products to an individual food bank, so these donations happen on a **local level**. The second main source of food supplies is the RDC which is responsible for the distribution of food donated on a **regional** and **national level** and which functions are analysed more in depth later in this section. A food bank is responsible for the transport of food from both the local networks and the RDC. Therefore, each food bank uses its own transport resources. Being an autonomous organization, each food bank is free to organise independently its own logistics. On an operative level, this means that most food banks own or lease one or several smaller transport trucks, depending on the size of the organisation and consequently on the amount of food that needs to be collected and/or distributed. The capacity of these trucks ranges between three to six pallets.

Secondly, the donated products need to be stored. Consequently, each food bank has its own facility and warehouse. The general aim of Voedselbanken Nederland is to guarantee one food bank in each

[1] Food banks originated in America in the 1970s and were introduced to Europe via France in 1984 . The European Federation of Food Banks (FEBA) has 266 food banks in 22 countries in Europe.

municipality. The location of this facility determines to which particular food bank a household can subscribe.

The stored food is eventually arranged into food packages. The main goal is to provide packages with at least 25 diverse and healthy products that should complement the weekly needs of a household. However, it occurs that some food banks are better able than others to source food; for this reason, the amount of food provided can vary significantly between the various food banks. The packages can generally be picked up by the households at hand-out points. Some food banks have a single warehouse but operate multiple hand-out points while others use their facility also as their only hand-out point. Each food bank is free to decide on which day(s) households can pick up the packages.

**Voedselbanken Nederland**
Even though all the food banks are autonomous organizations, they are all affiliated with 'Voedselbanken Nederland', 'Food Banks Netherlands', the national umbrella organization for 171 food banks and 10 distribution centres whose core mission is to support local food banks in their core tasks. This umbrella organisation does not perform any operational task with regards to the supply of food packages, but it is mainly concerned with the acquisition of new food donors on a national level and with the sourcing of sponsors. It also provides financial aid in the form of a yearly donation to the individual food banks in the Netherlands.

**Regional distribution centres**
The national food donors donate big quantities of food to 'Voedselbanken Nederland'. Instead of transporting these donations directly to all the 171 food banks, they are transported to the ten RDC`s. They store these donations and distribute them between the food banks located in the various regions. While a food bank is responsible for the transport of food from its local network, the national donors transport their donations to the RDC. Besides storing food from national donors, an RDC is responsible for the acquisition and collection of food from bigger donors within their region. This is referred to as 'food collected at regional level'.

In only a decade, 'Voedselbanken Nederland' has grown substantially, going from 121 affiliated food banks in 2010 to 171 in 2020. This remarkable growth has had an immediate positive repercussion on the number of people helped by the food banks in the same decade, growing from 50 to 95 thousand. However, one million people still live below the poverty line and 'Voedselbanken Nederland' is actively trying to reach these people (Voedselbanken Nederland, 2020). Given this situation, Voedselbanken Nederland normally expects a yearly increase of 10% - 15% in demand. Due to the Covid-19 virus and its economic consequences they expect this increase to become 50% in the first half of 2021. As a result, the last general assembly of members meeting of Voedselbanken Nederland in September 2020 concluded that all food banks should take action due to this expectation. They were asked to make plans for a possible upscaling of their capacity to be prepared for this increase in future demand.

Following this meeting, the region Twente-Salland proposed a new solution for the organization of food transport from their RDC:

- The distribution of food from the RDC in Deventer is organized by the RDC itself instead of the individual food bank facilities. This organization of transport should fit the needs of the individual food bank.
- The RDC has their means of transport to execute this distribution. If needed, the capacity of this network should be able to handle an increase in product volume of 50% compared to the volume of products in 2020. Voedselbanken Nederland accounts for the investments needed and (part of the) exploitation of this new transport network

Based on this desired situation, the food banks asked the following questions:

- What is the need to execute the above-described distribution?
- Which investments are needed to execute the above-mentioned situation?
- What would be the costs of executing this transport network?

- What are the savings per food bank in the region?

These questions formed the basis of this research. Based on the above-mentioned points, conversations were held with people within the food bank organization to understand why they were focusing on the logistics and what would have been the resulting benefits expected.

As a result of the general meeting, food banks in the region Twente-Salland concluded that financial resources were a determining element on which focus is placed in the future as they were directly connected to the number of households they were able to supply. Being an autonomous organization, each food bank is responsible to cover its yearly expenses. They do not sell or produce anything to cover their expenses and they are therefore completely relying on funded money. 'Voedselbanken Nederland' allocates funds to each food bank every year, but this does only cover a small part of the total expenses. For the remaining bigger part, food banks rely on donations from private companies, organizations, charity foundations and churches. This makes it difficult for food banks to cover their yearly expenses, consequently keeping these expenses at a minimum is of absolute importance for every food bank. Foodbank Almelo was taken as an example of good practice in the handling of its yearly expenses which in 2019 amounted to 72 thousand euros of which 20107 thousand euros were allocated to transport costs alone which was consequently the biggest expense to be covered for that year.

For a food bank, it is beneficial to keep expenses at a minimum. Transport represents a substantial part of the general running costs for food banks and the process of transporting food from the RDC, from which food banks in the region Twente-Salland receive at least 50% of their total amount of food, is identified as an inefficient process. Next to this, if demand increases, the total amount of volume that needs to be transported will increase. This increases the need for an efficient working transport network. So the necessity of performing an analysis on the current transport network of food banks, and in particular the food transported from the RDC, while taking an increase in demand into account is useful for food banks in the region Twente-Salland.

Based on the points mentioned by the food banks and the conversations held with people within the organization, the management problem is formulated as:

*Food banks in the region Twente-Salland are not sure if, given an increase in expected demand, transport of food from the distribution centre should be centralized by operating a collective transport network.*

For the remainder of this research, when the text refers to food banks or an RCD, it refers to the food banks in the region Twente-Salland and the RDC in Deventer unless else is specified.

## 1.2 Problem identification

The management problem has been identified and the relevance to look into transport has been explained. The next step is to design a problem cluster around the management problem. A problem cluster is a model in which connections are made in a cluster of causes and effects. By identifying the causes for this problem, the eventual core problem can be identified. Besides this, a problem cluster places the problem in context and provides an overview of all the different aspects that are related to this problem (Heerkens &Van Winden, 2012). Figure 1 shows the problem cluster which is explained by outlining the four main causes.

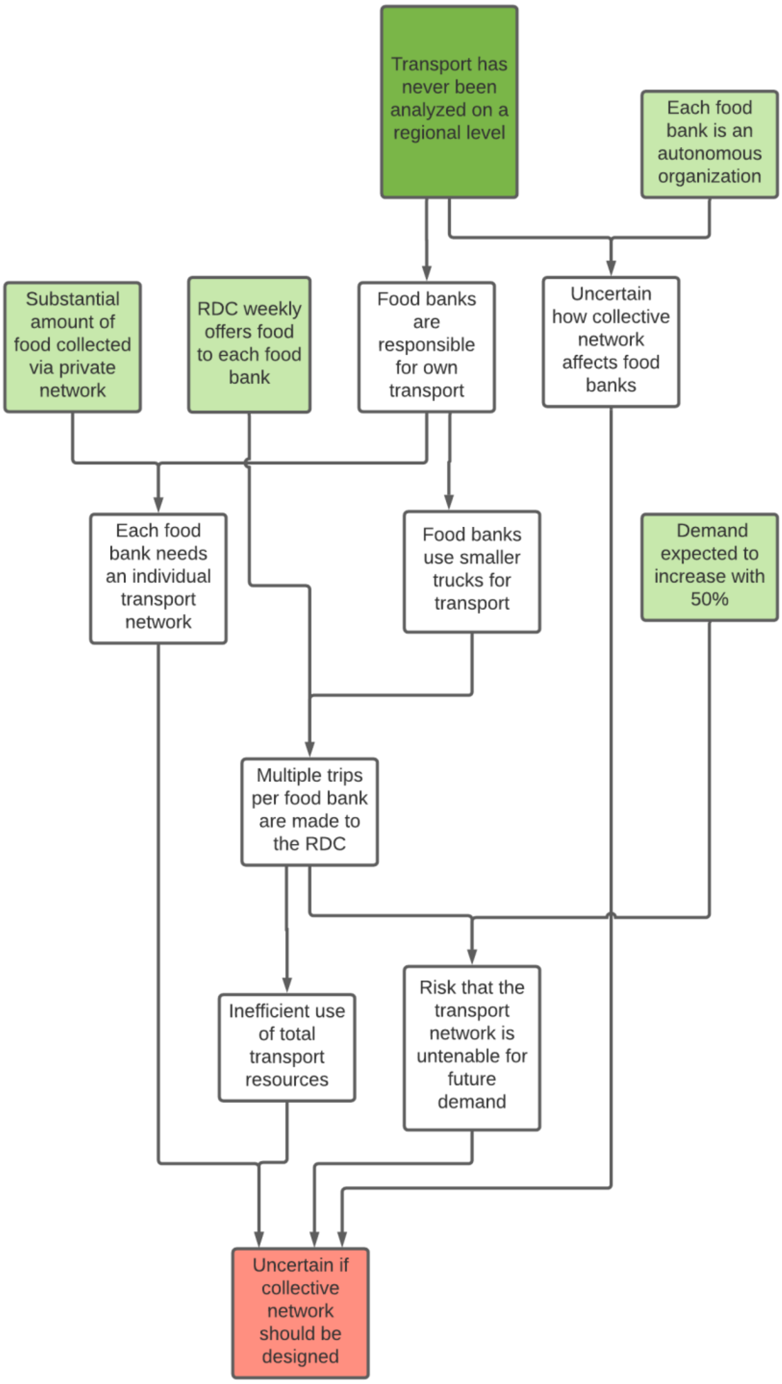


*Figure 1: Overview of the problem cluster for food banks in the region Twente-Salland*

**Combination of two causes**

The RCD has agreed to fixed days with the food banks on which they can pick up food. For smaller food banks, one day per week is sufficient while larger food banks agreed on two days per week. In itself, the number of kilometres driven and the number of trucks used to transport all products seems unnecessary big. On top of that, §1.1 explained that food banks use trucks with capacities between three to six pallets and 1000 to 1500 kilograms for transporting their food. Often, the orders from the RDC exceed these capacities resulting in multiple trucks needed to transport a single order. Therefore, the trucks used seem not efficient for transporting the products from the RDC. Altogether, this process seems inefficient which results in high fixed costs due to the number of trucks that are used for transport, and high fuel costs due to the many total kilometres driven from and to the RDC by the food banks. A collective network operated by the RDC could probably perform this transport more efficiently.

However, as already mentioned in §1.1, food banks use their own trucks to pick up food from their local network. These donations do not occur on regular days and their size and weight are variable every time. A local network is most of the time organised by a logistic coordinator of a specific food bank and the contacts among this network is maintained via personal relationships. All these reasons make it hard to design a collective transport network for food coming from the local network. It is also not the goal of food banks to organize this collectively. This results in the need for food banks to keep their trucks.

In conclusion, the way transport is currently organized, where each food bank is responsible for the transport of its own products, seems inefficient. In fact, if on one side the use of their own trucks is adequate for the collection of food on a local level, on the other side, the use of the same trucks is not sufficient to support the collection of food from an RDC. These two elements combined create the background to consider and evaluate the creation of a collective transport network.

**Uncertain how collective network affects food banks**

Each food bank functions as an autonomous organization with the responsibility to provide enough food to its subscribed households. Being a self-governing organization, food banks will only support the idea of a collective transport network if they completely understand how it would affect their organization and operational activities. If this is not clear, they are unsure how certain decisions will be made and are therefore not willing to cooperate in such a network. These decisions are related to costs and scheduling.

A food bank is responsible for covering its yearly expenses. Due to their societal position, food banks receive discounted or free services from companies in their network. This helps to bring their costs to a minimum. The amount of expenses that a food bank makes is in general directly proportional to the number of households it provides help to. In §1.1, a breakdown of the yearly expenses of food bank Almelo was given. However, the allocation of costs for Almelo is not necessarily representative of the other food banks in the region. This poses some problems about operating a collective transport network. First of all, there is a big difference in the proportion of costs that each food bank allocates to transport. Some foodbanks operate their logistics with vans that have been leased to them at a discounted price, while others do not receive the same beneficial discounts. In general, this results in significantly lower transport costs for some of the food banks. As a consequence, the food banks with low transportation costs are less interested in participating in an eventual logistics network than others which have to allocate a substantial amount of their total expenses to the transport only.

Secondly, assumed that it can be proven that a collective transport network from the RCD would be more cost-efficient than the current one, the reduction in costs eventually achieved by operating this new collective network would result in what could be called ‘the saving of the collaboration’. These ‘savings’ would derive from a reduction of kilometres driven by each food bank every year with a consequent reduction of fuel costs and from a reduction in the number of trucks needed for the logistic, with the reduction of leasing and insurance costs. Nevertheless, these apparently indisputable benefits would lead to two main questions among the food banks on an operative level. First, which food bank should reduce the number of its trucks to increase the saving achieved via a collective network? Second, how would the savings be redistributed amongst the food banks so that each of them received a fair share? Both questions cause uncertainty to the food banks with regards to the eventuality of using a collective transport network from the RDC.

As an autonomous organization, each food bank is free to schedules operational activities based on its own needs and wishes. They are in control of all food being transported which enables them to tailor their schedule to their own specific needs. Operating under a collective transport network would reduce their operational freedom which might pose a problem to the food banks. For example, a smaller food bank might have days where there are no volunteers available to process collected food. On these days, that particular food bank can decide to not transport any food. A collective transport network would mean that food banks have to adjust their schedules to each other which limiting their freedom.

**The risk that transport costs will increase**
If the expectation of a future demand increase of 50% would prove to be true, food banks will have to supply more households with food packages. Consequently, a higher volume of food would be needed to satisfy this demand increase. How this extra volume of food would be collected, both at the regional/national and local level is not clear yet, but most likely, at least part of it would be transported via the RDC. Operating an inefficient transport network in a scenario of demand increase would result in even higher transport costs which perhaps could be prevented if the transport network would be proactively optimized.

**Core problem**
The problem cluster identifies one main cause of the uncertainty that food banks have in regards to the planning of a collective transport network. Transport has never been considered on a regional level. The number of people supported by food banks grew by 90% over the past decade as 50 more food banks opened in the Netherlands, but the way its logistics has been organised hasn't changed accordingly, remaining substantially the same throughout this growth, leaving each food bank in charge for the transport of their products. However, this approach hasn't taken into consideration the fact that each food bank gets assigned to an RDC in its region and thereby becomes part of a network with other food banks on a regional level. This regional network has never been taken into account when analysing and organizing transport for the individual food banks. This results in the uncertainty that food banks have with regards to how such a collective network would affect their organization and whether it would actually work well and be more beneficial in terms of costs-benefits. This situation of uncertainty and unanswered questions has led to missed opportunities for the food banks in the region Twente-Salland to improve their efficiency with regards to logistics. Therefore, the core problem is formulated as follows:

*Food banks in the region Twente-Salland have never analysed their transport network on a regional level.*

**Norm and reality**
In the current situation, transport is organized from the autonomous perspective of food banks which results in the responsibility for each food bank to use its own resources to transport orders from the RDC. This approach has never been evaluated and none of the individual food banks has a complete quantitative overview to make argued recommendations on whether this approach is actually cost-efficient. Besides this, it is unsure how this transport network would perform when the expected increase of 50% becomes reality. Therefore, the norm is to analyse the costs made with the current transport network and compare them with collective transport network scenarios while taking the expected increase in demand into account.

## 1.3 Research goal

The objectives of this research are to provide insights to food banks into their current logistics as well as advice on whether it would more beneficial for the food banks to operate a collective transport network. This analysis should also consider the effects of the expected increase in demand on the transport of products from the RDC. The desired level of detail of the analysis needed to provide this advice should be stated as well. Given the scope stated in §1.5 and the fact that this is the first time that transport is analysed, this research aims at providing general directions for future research and requirements that should be met to perform a collective transport network. Therefore, the aim is not to provide a step-by-step guide to directly operate this collective network.

## 1.4 Research questions

To solve the identified core problem and thereby analyzing the organization of transport for orders from the RDC to the food banks on a regional level, the main research question is formulated as follows:

*What are the needs to promote transport collaboration via a collective transport network among food banks in the region Twente-Salland?*

The main research question is split up into three sub-questions. These sub-questions cover the different aspects of the main research questions. To answer each sub-questions, several sub-sub questions are formulated to ensure that each aspect of the question is covered.

**Sub-question 1:** How is transport in the region Twente-Salland organized and performing in the current situation?

- What are the characteristics of food banks?
- What are the characteristics of the RDC?
- What are the characteristics of the transport network?
- Which quantitative data is available?
- What costs are made in the current transport network?
- How can the found results be formulated into a reference model?

**Sub-question 2:** What is the impact of the expected increase in demand for the food banks on the transportation of products?

- Why do food banks expect an increase of 50% in demand?
- How will the extra needed amount of food be collected?
- How can the results be implemented into the reference model?

**Sub-question 3:** How could the collective transport network from the RDC be organized to meet the expected increase in demand?

- Which VRP methods exist and how can they be applied to this situation?
- What literature is available on collaboration on transport?
- How can this VRP be modelled to analyze different scenarios?
- How can a found solution be implemented into the food banks?

Based on the answers to these three sub-questions, a final answer to the main research can be formulated and conclusions and recommendations about the current transport network and possible improvements via a collective transport network can be given

## 1.5 Research design

This part introduces the research design chosen to answer the formulated questions. The chosen problem-solving approach is introduced and different research methods are explained. The reliability and validity of this research are discussed and finally, the scope and limitations are formulated.

**Problem-solving approach**
The main research question aims at both analyzing the current transport network of food banks and proposing an alternative for a collective transport network to optimize the way that products from the RDC are transported. Logistic consultants use step-by-step approaches for improving transport networks. The concrete formulation of the steps might differ per consultant but their general outline remains the same. The Supply Chain consulting group[2], Bruce Dzinski, partner at Zenza Consulting[3] and Argusi all provide step-by-step approaches. The approach of Argusi (Figure 2) was chosen for this research. However, it lacks two important steps that should be present in this thesis: the contextual analysis and the theoretical framework. They should be performed before step three. Furthermore, the content of step one has already been provided in the previous part and step two is explained at the end of this chapter. All the other steps are explained next.

[2] https://www.sccgltd.com/archive/logistics-network-planning-2/
[3] https://www.linkedin.com/pulse/7-steps-successful-network-optimization-modeling-bruce-dzinski/


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*Figure 2: Step-by-step approach to improve a transport network (Argusi, n.d.)*

**Context analysis and theoretical framework**
The context analysis summarizes all the preliminary work that was performed to understand the environment in which this problem exists. This includes an understanding of how the transport network is organized, the different actors that operate in this network and the relevant aspects that should be taken into account when designing a collective transport network. The theoretical framework summarizes the theory regarding vehicle routing problems and collaboration on logistics. Those theories form the basis for how this research investigates the core problem.

**Data gathering**
Based on the information from the context analysis and theoretical framework, the quantitative data needed to analyse the performance of the current transport network can be identified. According to the supply chain consulting group: “Finding and cleansing all this relevant data is often the longest and most demanding part of the optimization process”. The methods used to gather data are discussed in the research methods section**.** Once data is collected and cleansed, it is useful for this research. The deliverable of this step is an overview of cleansed data that is ready to use for the reference model.

**Reference model**
Based on the gathered data and the analysis of the current transport network, a reference model is developed. Within this model, KPIs of the transport network are identified and based on input data, these KPIs are calculated for the current transport network. This provides a clear overview of how the transport network has been performing during the past year. Qualitative data is gathered to analyse the effects of the expected increase in demand on the transport network. These results are processed into the reference model to test how the current transport network would perform under these circumstances. Finally, the model should be validated by stakeholders to make sure that its findings are accurate and realistic. The output of this step is thus an accurate reference model of the current situation which will serve as a baseline against which possible improvement could be measured.

**Analyze**
The next step is to analyze and model different collective transport scenarios. These collective scenarios can be viewed as a “distribution of goods between depots and final users” where the depot is the RDC, and the final users are the different food banks. “These problems are generally known as Vehicle Routing Problems (VRPs) or Vehicle Scheduling Problems” (Toth, 2002). The VRP methods will be used to develop a solution model and analyse the performance of the different scenarios. The deliverable of this step is to model one or multiple collective scenarios for a new collective transport network using the solution model. The costs output of this model should be comparable to the output of the cost of the reference model to make an accurate comparison.

**Results delivery**
This is the final step of the problem-solving approach. In this step, the results of the solution model are presented and discussed. Possible limitations are identified and the investments needed for implementation of these scenarios are explained. Finally, a recommendation on the best scenario is presented to the food banks.

Figure 3 shows a complete overview of the problem-solving approach and the chapter that contain the different steps taking within this research.

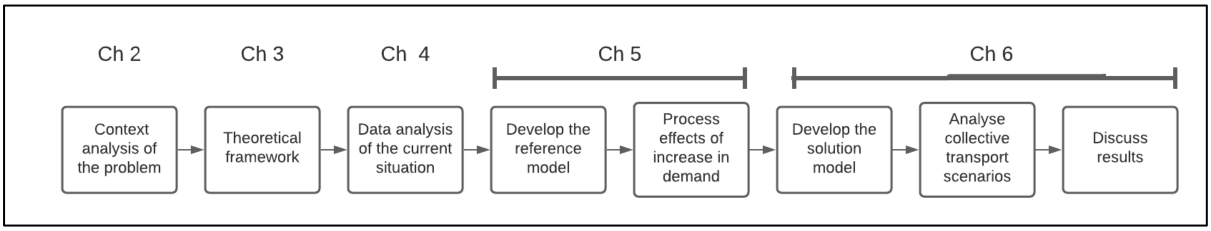


*Figure 3: Step-by-step overview of performed research*

**Research methods**
Research methods are specific procedures for collecting and analysing data. This research used a mixed-methods approach that integrates both qualitative and quantitative research.

*Data collection*

Qualitative data was collected during the preliminary study via on-site observations at the RDC and multiple conversations with directors and logistic coordinators of food banks within the region Twente-Salland. This provided information for the context analysis. Furthermore, qualitative data was gathered in semi-formal interviews with the director of the RDC and the food acquirer of Voedselbanken Nederland to understand the effects of the expected increase in demand on the transport network from the RDC. The secondary quantitative data in this thesis is drawn from three main sources. The ERP system used by the RDC provides historical data on the orders that were transported from the RDC by the food banks. The Zero Hunger Lab of Tilburg University conducted research for Voedselbanken Nederland. They conducted a survey amongst food banks in the region Twente-Salland on the different transport resources that are used. They allowed these results to be used within this research. Finally, public records on the finance of food banks were collected as well as personal documents of the general assembly of members meeting.

*Data analysis*

The data were processed and analysed using Excel which allowed the different types of data to be stored in separate sheets. Excel was also used to provide the charts and tables in the results section. Furthermore, Python was used in the solution analysis to model different collective transport scenarios. Qualitative data were not coded or categorized to increase understanding. Instead, its main function was to increase the understanding of processes that influence the transport network of the food banks.

**Reliability and validity**
"Validity is defined as the extent to which a concept is accurately measured in a quantitative study. Reliability relates to the consistency of a measure" (Heale, 2015). Both are important for the quality of research and issues within this research related to both of them should be taken into account.

Validity knows two major forms: External and internal validity. "The external validity of research findings is the data's ability to be generalized across persons, settings, and times" (Cooper, 2003). This research is specifically focused on the situation for the food banks in the region Twente-Salland and uses data for this specific situation. Therefore, the findings of this research will apply mostly to these food banks at this moment. It will be hard to make generalizations to other organizations due to the specific character of this organization. However, the approach taken within this research could be used by other food banks in the country to analyze and improve their transport network.

"Internal validity refers to the ability of a research instrument to measure what it is purported to measure" (Cooper, 2003). The reference model and solution model will both use input data to provide output. However, it is likely that due to the limited amount of time and unavailability of all required data that assumptions need to be made to ensure that these models function. These assumptions threaten the internal validity as they might result in wrong conclusions based on the outcomes of the model. Therefore, this research tries to minimize the number of assumptions needed and provides arguments for assumptions that are made.

"A measure is reliable to the degree that it supplies consistent results" (Cooper, 2003). This research would be reliable if another student would arrive at the same result when researching the same core problem. The situation of the food banks is complex and many different approaches exist to tackle the core problem. Perhaps different approaches might, in the end, yield better results. However, with the current information available, arguments have been given for the chosen problem-solving approach, main research question, and sub-questions. This is the only way to increase the reliability of the research. Therefore, it is important to keep providing clear arguments for the decisions made within the remainder of this research.

**Scope**

Through contact with relevant stakeholders, the general situation regarding transport for the food banks could be outlined. However, given the complexity of the subject, the present research has the aim to focus exclusively on the analysis of products transportation from the RDC to the food banks, Outside of this scope are aspects like inventory management improvement of both the RDC and the facilities and communication improvement with third-party organizations. Also, this research aims at investigating if other transport network design options might perform better than the current situation. However, the interpretation of the day-to-day operations needed to execute this new design option is outside of this scope. Finally, this research should provide a recommendation to the food banks with regards to their organization of transport within ten weeks.

# 2 Context analysis

This chapter analyses the context of the problem and explains the relevant aspects that should be taken into account when developing the reference model and analysing scenarios for a collective transport network. §2.1 provides general information about the region Twente-Salland. §2.2 describes the processes at the RDC. §2.3 describes relevant characteristics of the food banks. Lastly, §2.4 outlines the characteristics of transport between food banks and RDC which should be taken into account.

## 2.1 Region Twente-salland

The region Twente-Salland consists of 11 food banks and one RDC located in Deventer. Figure 4 shows their locations. The map only displays ten food bank locations because one of the food banks is located next to RDC and is called food bank Deventer. The transport of products from the RDC to Deventer is not taken into account since they practically operate next to each other. All the food banks together provided support to around 2300 households. Table 1 shows that food banks differ in the number of households that they support.

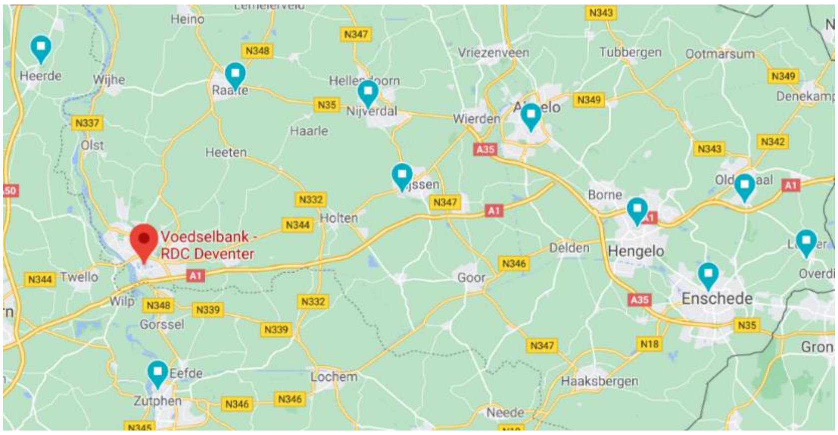

*Figure 4: Map of the locations of the food banks and the RDC in the region Twente-Salland*

| ***Food bank*** | **Households** | **Portion** |
|---|---|---|
| *VB Enschede* | 408 | 20,68% |
| *VB Midden Twente* | 304 | 15,41% |
| *VB Deventer e.o.* | 270 | 13,68% |
| *VB Zutphen* | 208 | 10,54% |
| *VB Almelo* | 200 | 10,14% |
| *VB Raalte* | 165 | 8,36% |
| *VB Oost Twente* | 150 | 7,60% |
| *VB Hellendoorn* | 76 | 3,85% |
| *VB Vaassen* | 74 | 3,75% |
| *VB Rijssen Holten* | 68 | 3,45% |
| *VB Losser* | 50 | 2,53% |

*Table 1: Number of households supported by a food bank in 2020*



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## 2.2 RDC characteristics

The operational activities of the RDC can be divided into three parts, input, storage and division of food.

**Input**

The ten RDC`s receive products from the national donors (§1.1). The donations are divided amongst the RDC based on the total number of households that are supported within the region. All the food banks combined supported around 39,750 households in 2020. Food banks in Twente-Salland supported around 2300 households in 2020. Therefore, the RDC is entitled to 39750/(2300*100) = 5,80% of the total amount of products donated by national donators. §1.1 also explained that, in general, RDC`s across the Netherlands bear the responsibility of collecting donations within the region (regional level of donors). However, this RDC is not active within the region and receives most of its products via national donors. There were over 120 national donors in the year 2020 that transported food to the RDC. The donors differ on the amount of food they donate in a year in the frequency of donations. For example, the top 22 donors accounted for 80,1% of the total amount of food donated. Some donors like Ahold agreed on a fixed day on which they visit the RDC while others only donate a couple of times per year on random moments.

Aside from variations in the amount of food donated by donors, a single donor fluctuates in the amount of food donated each time since the “waste food.” Of an organization or company is never constant. The supply chain created by the flow of food from donors to RDC and from RDC to the food banks is supply-driven as the RDC completely relies on whatever is being donated to them. The variability in donations, therefore, poses some challenges to the RDC to make sure that each food bank receives an order of food that consists of a variety of nice products every week. Table 2 shows an overview of the weight of donations that arrived at the RDC per day of the week in the year 2020. Most products were donated on Wednesdays and Thursdays, the other days have substantial fewer donations. 9Appendix A shows how these donations are divided amongst the different products groups.

| ***Day of the Week*** | **Sum of Weight (kg)** |
|---|---|
| *Mon* | 10499,55 |
| *Tue* | 25475,601 |
| *Wed* | 753922,2853 |
| *Thu* | 282954,6853 |
| *Fri* | 29773,363 |
| *Sat* | 20572,75 |
| ***Total*** | **1123198,235** |

*Table 2: Kilograms of food received by the RDC per day of the week in 2020*

**Storage**

Donations that arrive, need to be stored in the appropriate place at the right temperature. The RDC distinguishes between four types of products: fresh produce (AGF), chilled food, frozen foods and dry groceries (DKW). The warehouse has a large freezer for the frozen food, a cold store for the chilled food and some of the fresh produce, this depends on the different storage requirements per product. Finally, all the fresh produce that does not have to be chilled and the dry groceries are stored in the remainder of the warehouse. The RDC have strict rules in place to determine whether certain types of products are allowed to be distributed after their use-by date and shelf-life. This depends on the type of food that has passed the expiring date. For example, products like chips, butter and bread toppings can be redistributed up to two months after the shelf-life date. Fresh produce can be judged visually to determine whether it could still be edible. Conversely, most of the chilled food like fresh meat, chicken and fish and day-fresh dairy products may never be handed out after their expiration date.

Since the RDC receives donated food, which has probably already been stored in another location for a while, it often happens that they receive a donation that needs to be handed out by the food banks within two to three days. These are difficult products to distribute as it depends on when food banks will pick up an order and when food banks hand out their packages to the households. This will be discussed in more detail in §2.3.

**Division**
The RDC divides the received donations into so-called orders for each food bank. The volume of the order, and thus the amount of food that a single food bank is eligible to is directly proportional to the number of households that that food bank provides help to. Table 1 shows these percentages. Food banks have fixed days on which they visit the RCD, and it is the responsibility of the RCD to make sure that the order is prepared for transport once a food bank arrives. The products of an order are always stacked on euro-pallets which are used to load the order in the truck of a food bank using a pallet truck. Regular, chilled and frozen food are all stacked together on the same pallet. To secure the cold chain for chilled and frozen products, the RDC tries to stack these pallets as late as possible to ensure that products do not get too warm. Most food banks have access to chill/freeze trucks to transport these products. However, it happens that food bank transports the products with regular trucks. This is allowed as long as the maximum temperature exceedance consists of 3 degrees and products have been outside the freezer for a maximum of two hours. Due to the short distances within the region, food banks manage to satisfy both these conditions.

The RDC does deviate from the fixed days of food banks when a donation arrives with a short use-by or shelf-life date. Food banks are contacted if they want to pick up these products even though it is not their fixed day of transport.

## 2.3 Foodbank characteristics

§1.1 explained the operational activities of food banks. This section explains the relevant characteristics of the food banks in this region and relates them to the problem of operating under a collective transport network.

**Autonomous stakeholders**
The most important characteristics of the food banks are that each of them is an autonomous organization to provide food packages to their subscribed households. This means that, within the border, they are free to decide how they organize their activities to achieve this goal. This includes the way they organize the transport of their products. Therefore, they cannot be forced to change this way of transporting products, even if it turns out to save costs. Besides this, there could be other internal reasons for food banks that makes them not willing to operate under a collective transport network. Some of them are mentioned in the next part but there could probably be more. This research does not aim at finding all the relevant wishes of the food banks as to how they would like the transport network to be designed. Instead, it tries to form an objective image of how the current transport network is operating and compares this with scenarios where collaborating on transport is taken into account.

**Volunteers**
Each food bank has a dedicated group of volunteers that work together to perform all the necessary activities to eventually provide good food packages to their households. They form the core of a food bank and without them, providing help would not be able. The organizational structure is therefore different in a food bank compared to an actual business. Volunteers are not paid and are there on their own initiative; hence, the expectations of a volunteer are different from the expectations of a paid employee. A food bank relies on the capacities of its volunteers and tailors its operational activities around these capacities. The pick-up day and hand-out day of the food banks are examples of how these activities are tailored to the volunteers at a food bank. On a pick-up day, the food bank should have volunteers available that can drive the truck and store the received donations in appropriate places. On hand-out days, volunteers should be present to make sure that the handing out of packages runs smoothly. The voluntary nature of this situation needs to be taken into account as it requires a different approach with different considerations throughout the process of altering the current routine of food banks.

**Differences between small and large food banks**
Table 1 shows that there is a big difference in the number of households that are attached to the largest food bank compared to the smallest food bank. Foodbank Enschede, therefore, receives eight times the amount of food that food bank Losser receives from the RDC. To process these amounts of food, the food bank Enschede needs more resources considering transport, amount of volunteers, storage capacity.

Another difference between the food banks is the degree to which a food bank can collect food from its local network. Some food banks have agreements with local supermarkets that enables them to receive a lot of good quality fresh products while others do not. This makes the dependency on food from the RDC different for each food bank. A food bank wishes to provide its households with a package containing diverse products. Since part of these products is collected via the individual network, which differs for each food bank, they require different kinds of food from the RDC.

**Hand-out day for packages**
The food packages can be picked up by households at their corresponding food bank on a certain day called the hand-out day. Each food bank is free to decide which day of the week this hand-out day is. Most food banks assign this to Friday but some have Tuesday or multiple days in the week. The hand-out day is important for the shelf-life date of chilled food and fresh produce discussed in §2.2. Namely, if a food bank has its hand-out day on a Friday, products that arrive at the RDC on Tuesday with a shelf life of two days cannot be transported to that food bank as they would be handed out to households too late. To prevent this situation from happening, several people within the organization proposed an idea to switch to a supermarket model where each food bank is open every workday for people to visit. This would solve the problem of expired products due to a late hand-out day but requires many resources for food banks, which some might not even have access to.

## 2.4 Transport characteristics

This research is concerned with the transport of products between the RDC and food banks. Therefore the relevant aspects are explained in this part to understand this process and the direction that this research should move in.

**Trucks**
The food banks either own or lease smaller transport trucks that are used for the transport of food from the RDC. These trucks have a maximum weight and volume capacity. Therefore, the food bank requires this kind of information before collecting an order from the RDC to know how many trucks are needed. Since all the orders from the RDC are stacked on euro-pallets, the volume capacity is expressed in pallets. Weight consists of the weight of products and the additional weight of a pallet. Conversations with food banks show that it sometimes occurs that an order from the RDC exceed the weight capacity of a truck but are still transported. This is an undesired situation as it places the safety of the driver at risk. Besides this, the drive could lose his/her driving licence when being controlled. Besides transport food from the RDC, food banks also use trucks to collect all food from the local network.

**Costs**
Transport accounts for a substantial part of the total expenses of a food bank. The costs made with transport can be split up into variable and fixed costs. Fixed costs consist of the expenses made with owning/leasing a truck. Examples include insurance, maintenance and depreciation costs. These costs do not increase or decrease when a truck is being used more or less often. Variable costs however do relate to the usage of a truck. Since food banks operate solely with the help of volunteers, variable costs only consist of the expenses made on fuel. This is directly related to the number of kilometres driven by a truck.

**Pick-up days at RDC**
Depending on its size each food bank has one or two fixed pick-up days per week at the RDC. Depending on the number of pallets and weight of the order, a food bank comes with the appropriate number of trucks to collect the order. These pick-up days are not chosen at random. Instead, a food

bank relies on the availability of volunteers to drive the trucks for transport and to store the food at the appropriate places at the food bank. This is especially important for the smaller food banks as they do not have the capacity to open up each day of the week and they might not have a truck driver(s) available on each day of the week. Sometimes, the RDC receives a big donation with a short shelf-life date. Then, food banks are asked to drive another time in the week to pick up their part of this donation. This happens incidentally.

**Costs savings via transport**
Finally, the original plan with regards to cost saving is discussed. Most food banks use more than one transport truck to transport all their products. Each truck has the standard fixed costs that need to be paid by the food bank. Expected was that food banks would be able to operate with fewer trucks when responsibility for the transport of products from the RDC would actually be shifted to the RDC. Thereby, reducing the total expenses on fixed transport costs within the region. Besides this, the collective transport network would reduce variable costs since the supply routes can be constructed more efficient. However, the autonomous food banks cannot be forced into getting rid of trucks, even if they do not have to transport the products from the RDC.

## 2.5 Conclusion

The context analysis described the relevant characteristics of the RDC, food banks and the transport of products between them. These characteristics mentioned in this chapter are not all-encompassing but do provide the understanding needed to build the reference model and analyse scenarios taking collaborating on transport into account. Taking all the different aspects related to collaboration between food banks and the operating of a collective is not possible as this research would not have a clear direction to move towards. Therefore, the aim for the next chapters is as follows. Providing an objective analysis of how transport is performing in the current situation and the costs that are made with this transport. Comparing this network with alternative scenarios were collaborating on transport is taken into account based on the costs made with transport. The goal is to provide a recommendation to the food banks as to whether it is beneficial to collaborate on transport.

# 3 Theoretical framework

This section addresses the existing lecture on vehicle routing problems and collaborations in logistics. §3.1 describes the theory of the vehicle routing problem and different variations. The definition and formulation of a vehicle routing problem are discussed and heuristics and meta-heuristics used to solve the problem are explained. Finally, a model is suggested to solve the vehicle routing problem. §3.2 describes two approaches to collaboration on transport between different carriers. The questions addressed during this section are:

## 3.1 Vehicle routing problem

The Vehicle Routing Problem (VRP) consists of designing optimal delivery or collection routes from a central depot to a set of geographically scattered customers, subject to various constraints, such as vehicle capacity, route length, time windows, precedence relations between customers (Laporte, 2008). The VRP is generalized from the travelling salesman problem (TSP). Before understanding the VRP, an explanation of the TSP is needed.

**Travelling salesman problem**
The TSP considers a salesman that starts from a depot and needs to visit a given amount of customers. Given that there are *n* locations e.n., customers in cities. The TSP asks for the shortest route which visits each location exactly one time and returns to the original point of departure. The TSP is an NP-hard problem which refers to its computational complexity.

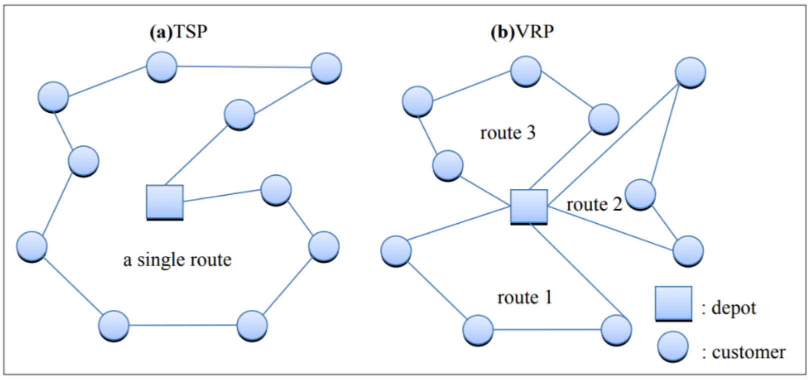


*Figure 5: Travelling Salesman Problem vs Vehicle Routing Problem*

**Vehicle routing problem**
The VRP is generalized from the TSP by enabling the salesman to return to the depot before starting another cycle to visit customers. Instead of a salesman, the VRP usually considers trucks that are sent from a depot to visit the customers. The difference between the TSP and VRP is shown in Figure 5. The three cycles from the VRP can be driven by one truck or by multiple trucks simultaneously.

A considerable amount of literature has been published on the VRP. These studies present different variations which can be applied to different real-life scenarios. This research confines itself to explaining two often used variations, the capacitated vehicle routing problem and the vehicle routing problem with time windows.

**Capacitated Vehicle Routing Problem**
The classical VRP aims at finding the least-cost vehicle routes to visit all customers. When this route should supply customers who have a known demand and uses a truck that has known capacity to transport the product, the problem becomes a CVRP. The problem consists of determining a set of *m* vehicle routes (1) starting and ending at the depot, and such that (2) each customer is visited by exactly

one vehicle, (3) the total demand of any route does not exceed the capacity of a vehicle and (4) the total routing cost is minimized (Laporte, 2017). Due to taking capacity constraints and customer demand into account, the CVRP is more useable to real-life problems and therefore more often used

**Vehicle Routing Problem with Time Windows**

The CVRP can be extended to the VRPTW which includes the additional constraint that service at each customer must commence within a certain time interval also called the time window (Bektas, 2017). This time window is often defined individually for each customer. The VRPTW also includes a service time for each customer which is the required time for a truck to stay at a customer before it can continue.

**Solution approaches**

There are two ways that a VRP can be solved, via exact algorithms or heuristics. The VRP is NP-hard meaning that "the most sophisticated exact algorithms for the VRP can only solve instances of up to about 100 customers, and with a variable success rate" (Laporte, 2007). The above formulated ILP needs to be solved with an exact algorithm which requires rather heavy mathematical programming machinery (Laporte, 2017). That is why "most of the research effort has concentrated on heuristics" (Laporte, 2007). "Heuristics were introduced as methods that can search for and produce near-optimal solutions in short computational times" (Bektas, 2017). The one drawback of heuristic algorithms is that they are unable to provide a guarantee of optimality. Heuristics are unable to confirm whether a found solution is optimal or provide any information as to the quality of the found solution.

Heuristics can be divided into two types, constructive heuristics, and improvement heuristics. A constructive heuristic is "used to identify a feasible, but not necessarily a near-optimal, solution of that problem" (Bektas, 2017). The goal of a constructive heuristic is to provide a quick solution that does not have to be optimal but that could be improved with an improvement heuristic. The most popular construction heuristic is the saving heuristic by Clarke and Wright. It assigns one single vehicle from the depot to each customer. It merges two customers on the same truck if their combined demand does not exceed the capacity of the truck. This decreases the total amount of trucks needed and the distance driven to supply the customers. The algorithm stops once none of the customers can be merged.

The solution provided by a constructive heuristic can be improved by an improvement heuristics. "Two types of improvement algorithms can be applied to VRP solutions. Intra-route heuristics post-optimize each route separately using a TSP improvement heuristic, e.g., 2-opt or 3-opt. Inter-route heuristics consist of moving vertices to different routes VRP" Laporte, 2007). Intra-route looks at a defined route of a vehicle formed by a constructive heuristic and seeks to optimize this route by changing the order of points that are visited by the vehicle. 2-opt refers to changing two routes whereas 3-opt changes three routes per time. Inter-route tries to improve a constructive heuristic by swapping points between routes instead of within.

Next to classical constructive and improvement heuristics, meta-heuristics have been developed to deal with optimization problems. "Meta-heuristics are a class of approximate methods, that are designed to attack hard combinatorial optimization problems where classical heuristics have failed to be effective and efficient" (Osman, 1996). The difference between heuristics and meta-heuristics lays in problem dependency. A heuristic is a problem-dependent technique meaning that it is adapted to a specific kind of problem. This enables a heuristic to take full advantage of this problem, but also incurs the risk of becoming too greedy. A greedy heuristic could be trapped in a local optimum resulting in a less optimum solution. Meta-heuristics are problem-independent and therefore not as greedy as heuristics. They might even accept a temporarily worse solution to explore possible better solutions. Therefore, it does not get trapped in a local optimum. The most popular meta-heuristics are classical neighbourhood search, simulated annealing, and tabu search.

**Modelling**

To solve a type of VRP with one of the above-described heuristics or meta-heuristics, it needs to be modelled using optimization software. Many software packages are commercial and need to be paid for before they can be used. However, there exist open-source software packages that are free to use. Marek Karkula (2019) evaluated the three most popular free packages: Google OR-Tools, VROOM and jsprit. The research concluded that VROOM turned out to be the most balanced one in terms of solution quality and execution time. Jsprit provided the best results but requires the longest execution time. Finally, OR-tools provided good quality results in many cases but lacked in performance in the more demanding cases. These cases involved around 100 customers to be served which is far more than required for this research. Besides this, OR-tools has the most options that can be configured concerning the generation of an initial solution and the main heuristic. It also can be used in multiple programming languages whereas the other two packages VROOM and jsprit are limited to C++ and Java languages respectively. Therefore, Google OR-tools was chosen as optimization software used to construct the solution model. The website explained that in general, the best results to a CVRP are provided by using the meta-heuristic “Guided Local Search”.

## 3.2 Collaborative logistics

According to Tolga Bektas (2017), “there exist two main types of collaborations within logistics and distribution. “ Vertical and horizontal collaboration. “Vertical collaboration, which typically arises in supply chains and entails collaboration between different levels of the chain, typically involving actors that have distinct and nonoverlapping roles within the chain”(Bektas, 2017). An example of this is cross-docking where products are not stored at an intermediate warehouse but instead directly transferred from one truck to the other. This way, no costs are incurred with operating a warehouse facility.

Horizontal collaboration entails the situation "where providers of the same (or similar) service share resources, such as network infrastructure and jointly plan the routes and schedules for the service they offer. The goal is to achieve better coordination of the assets, to gain a higher efficiency without detracting from the service quality" (Bektas, 2017). This type of collaboration can only take place if the actors within the collaboration perform fairly similar roles.

Bektas (2017) identified that for a collaboration to work effectively and sustain itself over a period of time, all the actors within the collaboration must get a fair share of the pain and gain. This relates to the value of collaboration. This value can be expressed as the total amount of profit or costs that the collaboration generates or incurs. There exist simple rules to calculate the share of each actor from the value of the collaboration like dividing the value equally over each partner or dividing it proportionally to the profits or costs that each partner brings in. Unfortunately, these rules do not always result in a fair allocation. Therefore, ways to achieve a more equal and fair distribution are discussed in a later part of this chapter.

Based on the above-mentioned types of collaboration in logistics and distribution. The situation of the food banks can be classified as a possible horizontal collaboration. Namely, each food bank operates a similar goal in the same stage, which is the transport from the RDC to the food bank. Therefore, the remainder of this part considers the existing literature on horizontal collaboration.

While vertical collaboration has been the focus of various research efforts, the literature on horizontal collaboration in logistics remains scarce and scattered. Therefore, Verdonck (2013) explored the topic in-depth on a practical and operational level from the perspective of road transportation companies and carriers. In general, there are two roles identified within a transport system, the role that is responsible for transport and the role that needs to receive the transported products. Verdonck (2013) uses the phraseology of “carrier” and “customer” accordingly to refer to these roles. The research concluded that existing scientific research can be divided into two main research streams, order sharing and sharing of vehicle capacities.

**Order sharing**
Order sharing is defined as: Carrier alliances in which customer requests or orders are exchanged between the participating organisations through various techniques. The main purpose of this request re-allocation is to achieve a better match between demanded and available transportation resources (Bloos & Kopfer, 2009). Through order sharing, carriers may improve their efficiency and profitability because of an increase in capacity utilisation, improved asset repositioning capabilities and a reduction in total transportation costs due to improved transportation planning (Dai & Chen, 2011; Kopfer &

Pankratz, 1999). Current research identifies different techniques to tackle the problem of order sharing. Two techniques applicable to this research are joint route planning and auction-based mechanisms.

In joint route planning, all the customer orders of the different carriers are combined and collected in one central place, after which efficient route schemes are set up for all these requests simultaneously using the theory on VRP`s explained in §3.1. This technique could result in reduced total travel distance, empty vehicle movement and the number of required trucks for the participating carriers. Thereby, improving efficiency and reducing the total amount of costs made (Verdonck, 2013). The desired situation as proposed by the food banks is similar to this joint route planning approach. All the different orders of food banks are collected at the RDC after which the most optimal routes are to be determined based on the available transport capacity.

Auction-based mechanisms work similarly to joint route planning. However, instead of first collecting all the customer orders from the carriers, each carrier first defines which customer request may be exchanged in a cost-efficient manner. The methods used for this are similar to the methods used in joint route planning. Next, the appropriate customer orders are shared employing various profit maximising auction mechanisms (Verdonck, 2013).

To explain how this auction-based mechanism works in real life an example of a mechanism is given. Song and Regan (2004) proposed the following general mechanism. Once a carrier receives a customer order, he has to decide whether the order is profitable enough to be executed by himself. To decide this, he uses VRP methods to create optimal routes. If the order is not profitable enough, the carriers have to determine a reservation price which he informs the other carriers about. This reservation price refers to the maximum price that the carrier is willing to pay to another carrier for executing this customers order. Once the other carriers are informed the auction starts and they can bid to claim the order.

A research used this auction-based mechanism to develop a Truck Appointment System the incorporates collaboration to lower transport costs and emissions (Schulte et al., 2015). They used components of the auction-based mechanism, that is, "truckers were able to announce empty capacities, and exporters announce their transport requirements for a specific service" (Schulte et al., 2015). Then, "A basic matching procedure checks origins, destinations, transport constraints and time windows to propose possible services for collaboration" (Schulte et al., 2015). The generated matching options are evaluated based on specific planning models with respect to the objectives. The proposed TAS was able to either explicitly search for a joint optimum that would result in the optimal solution, or implicitly, taking users preferences into account. The latter would be easier to implement. Results were created with a multi-objective mixed integer programming formulation considering costs, emissions, and user preferences to define a fixed plan for a specific time window. A discrete event simulation model was used to test the performance of the TAS. The results showed that a reduction in emission, which goes along with a reduction in transport costs, of 20% was achieved. However, the average waiting times of a truck was increased significantly as a result of the collaboration.

A difference between the auction-based mechanisms and the joint route planning technique is found in the way that the savings are being handled. In auction-based mechanisms, a collaborating carrier compensates its partners immediately for executing their transportation requests. On the contrary, with joint route planning, additional time has to be invested in the identification of a fair collaborative profit allocation scheme (Verdonck, 2013).

This auction-based mechanism might in the first place not directly seem applicable to the situation of the food banks. A food bank is not a transport carrier meaning that it does not want to bid certain orders from other food banks. Besides that, the auction-based mechanism appears as suited cooperation for competitors, but food banks are not each other competitors, instead, they would like to cooperate to operate a more efficient network. However, the division between profitable and non-profitable orders is relevant to take into account when looking at the food banks.

**Sharing of vehicle capacities**
Instead of sharing customer requests, carriers may also cooperate horizontally through the sharing of vehicle capacity. Since owning a transport vehicle involves considerable capital investment and low

capacity utilisation reduces a company's efficiency, logistic service providers may cooperate horizontally to share capacity and its associated costs (Agarwal & Ergun, 2010). Carriers pool their trucks to operate them together, thereby sharing the total truck capacity. An individual carrier that receives a customer request calculates an appropriate route to serve this customer. Then, from the pool of trucks, a suitable truck is assigned to this route. This way, truck utilisation improves and a single carrier may be able to offer a higher frequency of deliveries because he has more trucks at his disposal (Verdonck, 2013).

## 3.3 Conclusion

This chapter addressed the existing literature on the VRP. Two variants of the VRP were outlined: The CVRP and VRPTW. Given the scope and goal of this research, the collective transport network will be modelled as a CVRP. Google OR-Tools was introduced as open-source software packages that could be used to solve the CVRP. This tool makes use of heuristics and meta-heuristic which provide near-optimal solutions. Finally, the literature on collaborative logistics was addressed which provided insight into different techniques that could be used to improve the overall performance of a transport network through collaboration.

# 4 Data analysis of the current situation

This chapter introduces the quantitative data that was gathered to construct the reference model. §4.1 explains how the data from the ERP system is used to provide information on the timing, weight and volume of orders. §4.2 provides information on the transport resources of the food banks. §4.3 explains how data on the fixed and variable transport costs made by food banks was gathered. Finally, §4.4 shows the distances between the food banks.

## 4.1 Order rows output

Voedselbanken Nederland uses an ERP system to register the flow of products throughout the organization. The RDC uses this system to register orders that leave the RDC, called output order data. This data can be transferred into Excel sheets which contains order rows. Figure 6 shows an example of these order rows. Each row contains information on one product that was transported from the RDC to one of their customers(food banks).

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Datum document | ArtikelNaam | Artikelgroep | Hoeveelheid | Stuks gewicht | Gewichtseenheid | Gewicht | Klantsnaam | |
| 2 | 3-1-2020 | HARING | VA49 Vis vers | 230 | 1000 | g | 230 | VB Enschede | |
| 3 | 3-1-2020 | FRUIT VERPAKT | AA44 Fruit vers | 25 | 3000 | g | 75 | VB Enschede | |
| 4 | 3-1-2020 | VLEESWAREN | VA46 Vlees/gevogelte/vleeswaren vers | 111 | 1000 | g | 111 | VB Enschede | |
| 5 | 3-1-2020 | Lasagne | RA11 Rijst/pasta | 50 | 0,19 | Kg | 9,5 | VB Enschede | |
| 6 | 3-1-2020 | SLA VERPAKT | AA45 Groente vers | 16 | 2000 | g | 32 | VB Enschede | |
| 7 | 3-1-2020 | STAMPPOT | MA47 Maaltijd vers | 101 | 5000 | g | 505 | VB Enschede | |
| 8 | 3-1-2020 | CHIMICHURRI BURGER 16/215G | VA46 Vlees/gevogelte/vleeswaren vers | 9 | 3340 | g | 30,06 | VB Enschede | |
| 9 | 3-1-2020 | SOEPPAKKET | AA45 Groente vers | 16 | 1 | Kg | 16 | VB Enschede | |
| 10 | 3-1-2020 | GNOCCHI PAKKET | MA47 Maaltijd vers | 18 | 3000 | g | 54 | VB Enschede | |
| 11 | 3-1-2020 | GROENTE VERS | AA45 Groente vers | 20 | 5000 | g | 10 | VB Enschede | |
| 12 | 3-1-2020 | STOEMP | AA45 Groente vers | 9 | 5000 | g | 45 | VB Enschede | |
| 13 | 3-1-2020 | AH VERSPAKKET PASTINAAKSOEP 4/1100GR | AA45 Groente vers | 4 | 44001 | g | 176,004 | VB Enschede | |
| 14 | 3-1-2020 | AH VERS SAP 5/250ML | FA28 Frisdrank | 108 | 1250 | g | 135 | VB Enschede | |
| 15 | 3-1-2020 | AH VERS SAP 5/250ML | FA28 Frisdrank | 0 | 1250 | g | 0 | VB Losser | |
| 16 | 3-1-2020 | STOEMP | AA45 Groente vers | 2 | 5000 | g | 10 | VB Oost Twente | |
| 17 | 3-1-2020 | VLEESWAREN | VA46 Vlees/gevogelte/vleeswaren vers | 31 | 1000 | g | 31 | VB Oost Twente | |
| 18 | 3-1-2020 | Lasagne | RA11 Rijst/pasta | 14 | 0,19 | Kg | 2,66 | VB Oost Twente | |
| 19 | 3-1-2020 | STAMPPOT | MA47 Maaltijd vers | 28 | 5000 | g | 140 | VB Oost Twente | |
| 20 | 3-1-2020 | GROENTE VERS | AA45 Groente vers | 6 | 5000 | g | 30 | VB Oost Twente | |
| 21 | 3-1-2020 | HARING | VA49 Vis vers | 65 | 1000 | g | 65 | VB Oost Twente | |
| 22 | 3-1-2020 | SLA VERPAKT | AA45 Groente vers | 4 | 2000 | g | 8 | VB Oost Twente | |
| 23 | 3-1-2020 | AH VERSPAKKET PASTINAAKSOEP 4/1100GR | AA45 Groente vers | 1 | 44001 | g | 44,001 | VB Oost Twente | |
| 24 | 3-1-2020 | GNOCCHI PAKKET | MA47 Maaltijd vers | 5 | 3000 | g | 15 | VB Oost Twente | |
| 25 | 3-1-2020 | AH VERS SAP 5/250ML | FA28 Frisdrank | 30 | 1250 | g | 37,5 | VB Oost Twente | |
| 26 | 3-1-2020 | CHIMICHURRI BURGER 16/215G | VA46 Vlees/gevogelte/vleeswaren vers | 3 | 3340 | g | 10,02 | VB Oost Twente | |
| 27 | 3-1-2020 | FRUIT VERPAKT | AA44 Fruit vers | 7 | 3000 | g | 21 | VB Oost Twente | |
| 28 | 3-1-2020 | SOEPPAKKET | AA45 Groente vers | 5 | 1 | Kg | 5 | VB Oost Twente | |
| 29 | 3-1-2020 | SOEPPAKKET | AA45 Groente vers | 11 | 1 | Kg | 11 | VB Midden Twente | |
| 30 | 3-1-2020 | CHIMICHURRI BURGER 16/215G | VA46 Vlees/gevogelte/vleeswaren vers | 6 | 3340 | g | 20,04 | VB Midden Twente | |
| 31 | 3-1-2020 | Lasagne | RA11 Rijst/pasta | 36 | 0,19 | Kg | 6,84 | VB Midden Twente | |
| 32 | 3-1-2020 | VLEESWAREN | VA46 Vlees/gevogelte/vleeswaren vers | 79 | 1000 | g | 79 | VB Midden Twente | |
| 33 | 3-1-2020 | AH VERS SAP 5/250ML | FA28 Frisdrank | 76 | 1250 | g | 95 | VB Midden Twente | |
| 34 | 3-1-2020 | AH VERSPAKKET PASTINAAKSOEP 4/1100GR | AA45 Groente vers | 3 | 44001 | g | 132,003 | VB Midden Twente | |
| 35 | 3-1-2020 | STOEMP | AA45 Groente vers | 6 | 5000 | g | 30 | VB Midden Twente | |
| 36 | 3-1-2020 | FRUIT VERPAKT | AA44 Fruit vers | 18 | 3000 | g | 54 | VB Midden Twente | |
| 37 | 3-1-2020 | GNOCCHI PAKKET | MA47 Maaltijd vers | 13 | 3000 | g | 39 | VB Midden Twente | |
| 38 | 3-1-2020 | SLA VERPAKT | AA45 Groente vers | 11 | 2000 | g | 22 | VB Midden Twente | |

2018 | 2019 | 2020

*Figure 6: Screenshot of the dataset of the output order rows from the RDC in 2020*

A brief description of the information per column is given:

- Column A: Date on which the product was transported
- Column B: Name of the product
- Column C: Product group that a product belongs to
- Column D: The transported quantity of the product.
- Column E: Weight of one item of that product
- Column F: Unit of measurement for the weight per product. This is either kilogram (kg) or grams (g)
- Column G: The weight of the total quantity of products in the order row. This number is always in kg
- Column H: The customer's name

Order rows of the output were gathered for the years 2018, 2019 and 2020. They were compared to investigate if the year 2020 provided unusual results because of the effects of covid. The results for 2020 were in line with the dataset for 2019 and 2018 and analysing all three datasets takes an extensive amount of time. Therefore, the dataset for 2020 was used for the construction of the reference model and the solution analysis. The order rows provide information on the dates on which food banks transported orders from the RDC and the weight of these orders. The total dataset contained 25897 order rows.

**Order customers**

Column H contains the name of the customer that transported the product. This research is concerned with the ten food banks in the region but column H also contains the names of fourteen other customers amongst which other RDC`s in the Netherland and several companies. The quantities shipped to these other customers are a fraction compared to the food banks in the region and the order timings to these customers are sporadic. It is therefore not relevant, and also not part of the original questions posed by the food banks to take these orders into account when analysing the transport network. Therefore, the following assumption is made:

*Assumption 1: Orders from the RDC to food banks in the region are assumed to be the only orders coming from the RDC.*

**Order dates**

The next type of information that needs to be derived from the dataset is the dates on which food banks transported an order from the RDC. The dataset consists of order rows referring to the quantity of one specific product that was transported from the RDC to a food bank on a specific date, which is shown in column A. §2.2 explained that the RDC stacks all the orders for food banks on euro-pallets. Therefore, one complete order for a food bank consists of all the order rows containing the same date and food bank name. For example, Figure 6 shows multiple order rows on the same date that were transported to food bank Enschede. It is assumed that the products in the order rows going to Enschede on that day were combined in one order. To generalize this, the following assumption is defined to understand the definition of an order:

*Assumption 2: Multiple order rows going to the same food bank on the same date are defined as one order*.

**Order weight**

The definition of an order is provided. The next step is to collect information about the weight of this order. Column G contains the total weight of the products in an order row. The total weight of one order is the sum of all the values in column I of the rows that make up the order. The reference model uses this number to calculate how many trucks a food bank needed to transport the order. However, §2.4 stated that it occurs that food banks exceed the weight limits of their truck. It is not known how often this happens, and how much the weight limit is exceeded. To make calculations in the reference model, the following assumption is made:

*Assumption 3: Food banks do not exceed the weight capacity of trucks to transport orders from the RDC.*

This assumption means that if weight actually exceeds the capacity of one truck, the food bank will always use a second truck for transport.

**Order volume**

The RDC stated that in general, weight is the predominant capacity constraint over volume for the trucks used by the food banks. However, the solution analysis might consider types of trucks where volume is predominant over weight. Therefore, the reference model should calculate the volume of orders. Since each order is stacked on euro-pallets, the volume of an order is expressed in the number of pallets that were used for stacking. Unfortunately, the output dataset does not contain information on the number of pallets used to transport an order. The RDC also does not store these values in a different system. Therefore, the number of pallets per order had to be estimated. First, the products and product groups were consulted to see if an accurate estimation could be made based on one of them.

Each product is assigned to a corresponding product group. In total, there are 2262 different products assigned to 42 product groups. Estimating the volumes of 2262 products is unrealistic and making that



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many assumptions will likely make the result unusable. The 42 product groups seemed like a better alternative but unfortunately, the products within a product group differentiated too much making it hard to provide an accurate value as an estimation. Amongst the 42 product groups, there are two groups called "998 kratten" and "997 pallets". These are packing materials (emballage) that are used to transport products. These packing materials have standardized volumes which could prove helpful in estimating the order volumes. However, they were only registered for orders going to other customers than the food banks. These orders did not contain enough information to generalize a good estimation.

Each year, Voedselbanken Nederland provides a report to each food bank containing information about the donated food on the national level. Since the year 2020, this report also includes information about the total amount of kilograms of products that were donated per order group and the total number of pallets that these products were delivered on in the year 2020. The first three columns in Table 3 shows these numbers. This was the only information found that gave an indication of the volume of products on a pallet. Therefore, this weight/pallet ratio was used to estimate the number of pallets that were used to transport and order.

| ***Productgroup*** | **Amount of CE (Kg)** | **Amount of pallets** | **Pallets/Kg** |
|---|---|---|---|
| *AGF* | 2282793 | 3255 | 0,001425885 |
| *AH koelvers* | 3226347 | 3305 | 0,001024378 |
| *Babyvoeding* | 90801 | 58 | 0,000638759 |
| *Broodbeleg* | 13788 | 18 | 0,001305483 |
| *Conserven* | 436419 | 333 | 0,000763028 |
| *Drank* | 1848871 | 1691 | 0,000914612 |
| *Graanproducten* | 703365 | 719 | 0,001022229 |
| *Kruidenierswaren* | 9684157 | 8264 | 0,000853353 |
| *Maaltijden* | 135561 | 87 | 0,000641778 |
| *Maaltijden diepvries* | 379974 | 461 | 0,001213241 |
| *Non-Food* | 1187013 | 1308 | 0,001101926 |
| *Snacks* | 4131822 | 3792 | 0,000917755 |
| *Snacks diepvries* | 614793 | 620 | 0,00100847 |
| *Supplementen* | 2004 | 1 | 0,000499002 |
| *Vis en Vlees* | 57748 | 46 | 0,000796564 |
| *Vis en Vlees diepvries* | 199968 | 213 | 0,00106517 |
| *Zuivel* | 2571564 | 4489 | 0,00174563 |
| *Zuivel diepvries* | 5000 | 3 | 0,0006 |

*Table 3: Relation weight/pallets per product group*

This resulted in the following assumption:

*Assumption 4: Each product in an order group follows the same weight/pallet ratio as provided by the annual report of Voedselbanken Nederland*

Note that preferably, a more accurate number was used to calculate the number of pallets per order. To minimize the error caused by this assumption, the results of the reference model are validated in §5.2 by stakeholders from the food bank. This enables this estimation to be adjusted if necessary.

## 4.2 Trucks

Students from the University of Tilburg held a survey amongst the food banks in the region Twente-Salland. Food banks were asked what type of truck they used along with the pallets and weight capacities of this truck. An almost complete overview of the different trucks that food banks used was created. The students allowed this data to be used within this research. Two food banks did not fill out the survey but their data could be collected via personal conversations. Table 4 lists this information.

Most food banks use two or more trucks for transport but they do not keep a record of when which truck was used. Since food banks benefit from minimal transport costs, the reference model assumes that trucks are used in the most optimal way possible by using the minimal number of required trucks for transport.

*Assumption 5: Food banks will always use the minimum amount of trucks needed to transport food from the RDC.*

| ***Food bank*** | **Type of truck** | **Capacity(Kg)** | **Capacity (euro pallets)** |
|---|---|---|---|
| *VB Almelo* | Bestelbus Koel/Vries | 1200 | 4 |
| | Bestelbus Koel/Vries | 1200 | 4 |
| | BE-Combi Koel/Vries | 1600 | 6 |
| *VB Enschede* | Bestelbus Koel/Vries | 1500 | 4 |
| | Bestelbus Koel/Vries | 1500 | 4 |
| | Bestelbus Koel/Vries | 1500 | 3 |
| *VB Hellendoorn* | Bestelbus Koel/Vries | 1500 | 3 |
| *VB Losser* | Bestelbus Koel/Vries | 1500 | 3 |
| *VB Midden Twente* | Bestelbus Koel/Vries | 1256 | 3 |
| | Bestelbus Koel/Vries | 1360 | 4 |
| | Bestelbus Koel/Vries | 1054 | 5 |
| *VB Oost Twente* | Bestelbus Koel/Vries | 3500 | 4 |
| *VB Raalte* | BE-Combi Koel/Vries | 2800 | 6 |
| | Bakwagen Koel / Vries | 400 | 3 |
| *VB Vaassen* | BE-Combi Koel/Vries | 2500 | 7 |
| | Bakwagen Koel / Vries | 500 | 5 |
| *VB Rijssen Holten* | Bestelbus | 3500 | 4 |
| *VB Zutphen* | Bestelauto | 1400 | 4 |
| | Bestelbus Koel/Vries | 1100 | 3 |

*Table 4: Overview of the transport resources and capacities per food bank*

## 4.3 Transport costs

Each food bank has an ANBI-status (Algemeen nut beogende instelling) which requires them to publicise their yearly expenses in an annual report. These reports include the costs made with transport in a given year. The detail of these reports differs per food bank. Some only state transport as a whole without further allocation of these costs to different components. Others allocate costs between fuel, lease/depreciation and maintenance costs. From these statements, the fixed costs of owning a truck and the variable costs of driving the truck can be derived. It is assumed that food banks that did not provide an allocation of their transport costs, follow the same fixed/variable costs ratio as the other food banks.

*Assumption 6: Food banks will have similar transport costs allocations of their trucks.*

## 4.4 Distances between food banks and the RDC

The variable costs that food banks make with transport are only allocated to fuel costs since food banks do not have to pay a wage to a driver. The fuel costs relate directly to distance so, therefore, the distance between food banks themselves and between them and the RDC was obtained. Table 5 shows the distance matrix created using Bing Maps key that returns the total distance in kilometres.



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| ***Distance in km*** | **Depot** | **Almelo** | **Enschede** | **Hellen-doorn** | **Losser** | **Midden Twente** | **Oost Twente** | **Raalte** | **Rijssen Holten** | **Vaassen** | **Zutphen** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Depot** | 0,00 | 46,71 | 60,01 | 31,72 | 64,97 | 47,83 | 58,17 | 19,92 | 29,92 | 25,41 | 12,81 |
| **Almelo** | 45,53 | 0,00 | 28,55 | 17,71 | 33,51 | 16,37 | 26,71 | 30,08 | 17,72 | 67,48 | 55,00 |
| **Enschede** | 59,40 | 27,49 | 0,00 | 38,61 | 11,04 | 9,42 | 12,19 | 50,98 | 38,62 | 81,35 | 68,87 |
| **Hellen-doorn** | 33,49 | 18,27 | 39,29 | 0,00 | 44,25 | 27,11 | 37,45 | 12,49 | 9,81 | 55,44 | 42,96 |
| **Losser** | 64,81 | 32,91 | 11,07 | 44,03 | 0,00 | 18,41 | 10,10 | 56,40 | 44,04 | 86,77 | 74,28 |
| **Midden Twente** | 48,61 | 16,71 | 9,37 | 27,83 | 23,07 | 0,00 | 16,27 | 40,20 | 27,83 | 70,56 | 58,08 |
| **Oost Twente** | 58,37 | 26,47 | 12,13 | 37,59 | 10,06 | 11,96 | 0,00 | 49,95 | 37,59 | 80,32 | 67,84 |
| **Raalte** | 19,95 | 30,63 | 51,65 | 12,45 | 56,61 | 39,46 | 49,81 | 0,00 | 24,70 | 47,65 | 32,19 |
| **Rijssen Holten** | 29,97 | 18,13 | 39,15 | 10,73 | 44,11 | 26,96 | 37,31 | 25,69 | 0,00 | 51,93 | 39,44 |
| **Vaassen** | 27,40 | 69,16 | 82,47 | 61,95 | 87,43 | 70,28 | 80,63 | 48,55 | 52,37 | 0,00 | 30,06 |
| **Zutphen** | 12,89 | 55,17 | 68,47 | 47,96 | 73,44 | 56,29 | 66,64 | 34,56 | 38,38 | 30,20 | 0,00 |

*Table 5: Distance matrix of food banks and RDC*

## 4.5 Conclusion

This chapter obtained the different pieces of data needed to build the reference model and analyse the performance of the current transport network. The dataset containing the output order rows of the RDC functions as the basis for the reference model as it contains information on the actual orders. An assumption about the volume of orders had to be made since this data is not present. This assumption was derived from the weight/pallets ratio of products donated on a national level. Preferably, a more accurate number was used within the reference model. To minimize the error caused by this assumption, the results are validated by stakeholders from the food bank. Still, it is important to be aware of these assumptions when basing conclusions on the found results. Especially the volume assumption, as it is important for this analysis. The information on the capacities of trucks enables the model to calculate how many trucks were used for transport. Finally, costs estimations can be derived from the annual reports and distances between food banks were obtained using a Bing Maps key.

# 5 Reference model

This chapter introduces the reference model, constructed in Excel, of the current transport network. The model serves two purposes: The transport costs calculated in the model will be the standard against which collective transport scenarios in the solution analysis will be measured. Second, customer demand should be known to solve the CVRP for the food banks in the solution analysis. Therefore, the model should provide output data on the timing, weight and volume of orders to food banks in 2020. This data will be used as input in the solution analysis. §5.1 introduces the different sheets of the model. §5.2 reflects on the model validation by the logistic coordinator of food bank Almelo. §5.3 discusses the effects of the expected increase in demand on the transport network and explains how these effects are processed into the reference model. Finally, §5.4 presents the findings of the model

## 5.1 Datasheets

The model was created in Excel and contains several sheets of data described in Chapter 4. VBA code and Excel functions are used to process the data into one overview table that contains information per order. Screenshots of the different sheets, as well as the VBA code and pseudocode, are provided in 9Appendix B.

**Order rows**
The first sheet contains the output order rows of the year 2020 introduced in §4.1. This sheet is the basis of the model since it contains data on the timing and quantities of orders that were transported by food banks. §4.1 explained that this research only considers orders going to the food banks in the region except for food bank Deventer. Therefore, the rows that contained customer names other than these food banks were deleted. One extra column called "pallets" was added. It contains data about the number of pallets needed to transport an order. The next section explains how these numbers were calculated.

**Pallets**
To estimate the number of pallets per order, a second sheet was created which contained the weight/pallet ratio of product groups explained in §4.1. These ratios specify the number of pallets used to transport a number of kilograms of a product in a product group. These values can also be interpreted as the fraction of a pallet that is taken by one kilogram of a product. Table 3 shows these values in the column pallets/kg. For example, 1 kilogram of a product in the AGF group takes 0,001425885 pallets, 15 kilograms of the same product takes 0,001425885 * 15 = 0,0213883 pallet. Using this information, the "pallets" column can be filled with the fraction of a pallet that is filled by the products in that order row. Then, the total number of pallets used to transport order is the sum of all these fractions of products within that order. Figure B-1 shows a screenshot of the volume sheet. Column A contains the product groups and column B shows the pallet/kilogram ratio per group The VBA code in Figure B-2 fills the "pallets" column by multiplying the weights per order with the pallets/kg ratio of the corresponding product group. Figure B-3 shows the order rows sheet after executing the VBA code.

**Overview part one**
So far, a complete table with order rows for the year 2020 containing information on the volume and weight is constructed. §4.1 explained that a complete order of a food bank consists of all order rows going to that food bank on the same date. Therefore, these order rows should be combined into complete orders in the overview table. To manage this, a pivot table from this data was created whose output provided the sum of weight and sum of pallet fraction of each order row for a food bank on a specific date. Figure 7shows this output combined into the overview table. To clarify, the first row shows the weight and sum of pallets for food bank Enschede on the 3rd of January, which is the sum of column "Gewicht" and the sum of column "Pallets" for the order rows going to food bank Enschede in Figure 6.

| | A | C | D | E | F |
|---|---|---|---|---|---|
| 1 | Date | FoodBank | Weight | SumOfPallets | Pallets |
| 2 | 03/01/2020 | VB Enschede | 1428,564 | 1,328564818 | 2 |
| 3 | 03/01/2020 | VB Midden Twente | 1076,883 | 1,035781452 | 2 |
| 4 | 03/01/2020 | VB Oost Twente | 419,181 | 0,399769205 | 1 |
| 5 | 08/01/2020 | VB Almelo | 2013,7 | 2,573781916 | 3 |
| 6 | 08/01/2020 | VB Enschede | 3027,666 | 4,320716698 | 5 |
| 7 | 08/01/2020 | VB Hellendoorn | 461,393 | 0,63676478 | 1 |
| 8 | 08/01/2020 | VB Losser | 359,098 | 0,492383127 | 1 |
| 9 | 08/01/2020 | VB Midden Twente | 2244,942 | 3,199913139 | 4 |
| 10 | 08/01/2020 | VB Oost Twente | 914,84 | 1,285712906 | 2 |
| 11 | 08/01/2020 | VB Raalte | 975,207 | 1,375894417 | 2 |
| 12 | 08/01/2020 | VB Rijssen Holten | 822,963 | 1,076857091 | 2 |
| 13 | 08/01/2020 | VB Vaassen | 337,331 | 0,391582277 | 1 |
| 14 | 08/01/2020 | VB Zutphen | 2128,383 | 2,786451488 | 3 |
| 15 | 09/01/2020 | VB Almelo | 379,04 | 0,359373723 | 1 |
| 16 | 09/01/2020 | VB Enschede | 1365,716 | 1,282833546 | 2 |
| 17 | 09/01/2020 | VB Hellendoorn | 217,764 | 0,204784162 | 1 |
| 18 | 09/01/2020 | VB Losser | 149,345 | 0,14156507 | 1 |
| 19 | 09/01/2020 | VB Midden Twente | 999,607 | 0,937723793 | 1 |
| 20 | 09/01/2020 | VB Oost Twente | 419,109 | 0,393156463 | 1 |
| 21 | 09/01/2020 | VB Raalte | 447,184 | 0,418573566 | 1 |
| 22 | 09/01/2020 | VB Rijssen Holten | 151,2 | 0,143180803 | 1 |
| 23 | 09/01/2020 | VB Vaassen | 104,079 | 0,09427968 | 1 |
| 24 | 09/01/2020 | VB Zutphen | 444,8 | 0,422221734 | 1 |
| 25 | 10/01/2020 | VB Enschede | 428,2 | 0,414830163 | 1 |
| 26 | 10/01/2020 | VB Midden Twente | 305,52 | 0,296471389 | 1 |
| 27 | 10/01/2020 | VB Oost Twente | 126,64 | 0,121480096 | 1 |
| 28 | 15/01/2020 | VB Almelo | 1471,292 | 1,95743862 | 2 |
| 29 | 15/01/2020 | VB Enschede | 2837,767 | 4,156080301 | 5 |
| 30 | 15/01/2020 | VB Hellendoorn | 377,437 | 0,548754449 | 1 |
| 31 | 15/01/2020 | VB Losser | 307,49 | 0,451121124 | 1 |
| 32 | 15/01/2020 | VB Midden Twente | 2100,112 | 3,073464878 | 4 |
| 33 | 15/01/2020 | VB Oost Twente | 881,625 | 1,282441038 | 2 |
| 34 | 15/01/2020 | VB Raalte | 925,38 | 1,353498022 | 2 |
| 35 | 15/01/2020 | VB Rijssen Holten | 593,194 | 0,793534841 | 1 |
| 36 | 15/01/2020 | VB Vaassen | 483,802 | 0,731855293 | 1 |
| 37 | 15/01/2020 | VB Zutphen | 1682,9245 | 2,243656671 | 3 |
| 38 | 16/01/2020 | VB Almelo | 150 | 0,135758356 | 1 |
| 39 | 16/01/2020 | VB Enschede | 441,28 | 0,451529589 | 1 |
| 40 | 16/01/2020 | VB Hellendoorn | 144,03 | 0,179835866 | 1 |

Orderrows | Volume | Busses | Buscombinations | Overview | DistanceMatrix

*Figure 7: Screenshot of the first part of the overview table*

The sum of the pallet fraction is a decimal number which in reality is not possible since whole pallets are used for stacking. If the number exceeds an integer, a whole extra pallet is needed for transport. Therefore, the extra column “Pallet total” was added which rounds up the decimal numbers to the next whole integer. This results in the correct number of pallets used per order.

**Truck combination**

Data about the number of pallets and weight of all the orders in a year is known. Next, data about the available transport resources for each food bank is added. This data is listed in the sheet “Trucks”. Per food bank is listed how many trucks they have and the pallet and weight capacity of each truck. The food banks combined use nineteen trucks for transport. This information was derived from the survey discussed in §4.2. Figure B-4 and Figure B-5 show the truck's sheet.

§1.2 explained that food banks sometimes need multiple trips and therefore use multiple trucks to transport an order from the RDC. This happens if the order exceeds the pallet capacity or the weight capacity of a truck. The model should calculate how many trucks a food bank needed to ship an order based on the capacities of the trucks and the weight and number of pallets of the order. Assumed is that a food bank will always use the minimal number of trucks needed to ship an order. For example, if food bank Almelo needs to transport orders from the RDC consisting of five pallets that weigh 1200 kg, Almelo will use their single truck that is able to transport the complete order in one trip.

Depending on the weight and pallets of an order, one or a combination of trucks is needed for transport. The sheet “Truck combinations” consists of the most efficient combinations of trucks for each food bank until a max of ten trucks. For the food banks that have only one truck, these combinations consist of multiples of that truck. Each combination can transport orders with a maximum number of pallets and a maximum weight. Figure B-6 and Figure B-7 show screenshots of this sheet. The "many" row is added to prevent an infinite loop from occurring in the VBA code.

**Overview part two**
At this point, the overview table contains the weight and amount of pallets of an order to a food bank. The model should be based on these numbers, identify the minimal truck combination that was needed to transport the order. An extra column is added to the overview table where these numbers should be listed. Figure B-8 and Figure B-9 show the VBA code used to fill the column with the correct number of trucks needed to transport an order. Figure 8 shows the overview table after executing this VBA code. Column G contains the number of trucks needed to transport the order.

| | A | C | D | E | F | G |
|---|---|---|---|---|---|---|
| 1 | Date | FoodBank | Weight | SumOfPallets | Pallets | Trucks |
| 2 | 03/01/2020 | VB Enschede | 1428,564 | 1,328564818 | 2 | 1 |
| 3 | 03/01/2020 | VB Midden Twente | 1076,883 | 1,035781452 | 2 | 1 |
| 4 | 03/01/2020 | VB Oost Twente | 419,181 | 0,399769205 | 1 | 1 |
| 5 | 08/01/2020 | VB Almelo | 2013,7 | 2,573781916 | 3 | 2 |
| 6 | 08/01/2020 | VB Enschede | 3027,666 | 4,320716698 | 5 | 3 |
| 7 | 08/01/2020 | VB Hellendoorn | 461,393 | 0,63676478 | 1 | 1 |
| 8 | 08/01/2020 | VB Losser | 359,098 | 0,492383127 | 1 | 1 |
| 9 | 08/01/2020 | VB Midden Twente | 2244,942 | 3,199913139 | 4 | 2 |
| 10 | 08/01/2020 | VB Oost Twente | 914,84 | 1,285712906 | 2 | 1 |
| 11 | 08/01/2020 | VB Raalte | 975,207 | 1,375894417 | 2 | 1 |
| 12 | 08/01/2020 | VB Rijssen Holten | 822,963 | 1,076857091 | 2 | 1 |
| 13 | 08/01/2020 | VB Vaassen | 337,331 | 0,391582277 | 1 | 1 |
| 14 | 08/01/2020 | VB Zutphen | 2128,383 | 2,786451488 | 3 | 2 |
| 15 | 09/01/2020 | VB Almelo | 379,04 | 0,359373723 | 1 | 1 |
| 16 | 09/01/2020 | VB Enschede | 1365,716 | 1,282833546 | 2 | 1 |
| 17 | 09/01/2020 | VB Hellendoorn | 217,764 | 0,204784162 | 1 | 1 |
| 18 | 09/01/2020 | VB Losser | 149,345 | 0,14156507 | 1 | 1 |
| 19 | 09/01/2020 | VB Midden Twente | 999,607 | 0,937723793 | 1 | 1 |
| 20 | 09/01/2020 | VB Oost Twente | 419,109 | 0,393156463 | 1 | 1 |
| 21 | 09/01/2020 | VB Raalte | 447,184 | 0,418573566 | 1 | 1 |
| 22 | 09/01/2020 | VB Rijssen Holten | 151,2 | 0,143180803 | 1 | 1 |
| 23 | 09/01/2020 | VB Vaassen | 104,079 | 0,09427968 | 1 | 1 |
| 24 | 09/01/2020 | VB Zutphen | 444,8 | 0,422221734 | 1 | 1 |
| 25 | 10/01/2020 | VB Enschede | 428,2 | 0,414830163 | 1 | 1 |
| 26 | 10/01/2020 | VB Midden Twente | 305,52 | 0,296471389 | 1 | 1 |
| 27 | 10/01/2020 | VB Oost Twente | 126,64 | 0,121480096 | 1 | 1 |
| 28 | 15/01/2020 | VB Almelo | 1471,292 | 1,95743862 | 2 | 1 |
| 29 | 15/01/2020 | VB Enschede | 2837,767 | 4,156080301 | 5 | 2 |
| 30 | 15/01/2020 | VB Hellendoorn | 377,437 | 0,548754449 | 1 | 1 |
| 31 | 15/01/2020 | VB Losser | 307,49 | 0,451121124 | 1 | 1 |
| 32 | 15/01/2020 | VB Midden Twente | 2100,112 | 3,073464878 | 4 | 2 |
| 33 | 15/01/2020 | VB Oost Twente | 881,625 | 1,282441038 | 2 | 1 |
| 34 | 15/01/2020 | VB Raalte | 925,38 | 1,353498022 | 2 | 1 |
| 35 | 15/01/2020 | VB Rijssen Holten | 593,194 | 0,793534841 | 1 | 1 |
| 36 | 15/01/2020 | VB Vaassen | 483,802 | 0,731855293 | 1 | 1 |
| 37 | 15/01/2020 | VB Zutphen | 1682,9245 | 2,243656671 | 3 | 2 |
| 38 | 16/01/2020 | VB Almelo | 150 | 0,135758356 | 1 | 1 |
| 39 | 16/01/2020 | VB Enschede | 441,28 | 0,451529589 | 1 | 1 |
| 40 | 16/01/2020 | VB Hellendoorn | 144,03 | 0,179835866 | 1 | 1 |

Orderrows | Volume | Busses | Buscombinations | **Overview** | DistanceMatrix | PivotTable | Shee

*Figure 8: Screenshot of the second part of the overview table*

**Distance matrix**

The distance matrix introduced in §4.4 is copied in the distance matrix sheet (Figure B-10). In the current situation, each food bank always makes a single return trip to the RDC. The second table in the sheet contains these return trip distances per food bank. These numbers will be used to calculate the number of kilometres driven by food banks to transport the orders.

**Transport costs**

The model should calculate the costs made with transport by each food bank. To determine these costs, a value for costs per kilometre is needed. This value can be calculated focussing only on both variable and fixed costs, or only on variable costs. To include both, the fixed costs are calculated over the period of a year and divided by the total driving distance in that year to calculate the fixed costs per kilometre. This number is added to the variable costs per kilometre and the sum can be used to calculate transport costs based on a given number of kilometres. This way, the fixed costs of owning a truck are also taken into account. This approach was considered in this research but the decision was made to focus on variable costs only within the reference model for the following reason. §1.1 explained that food banks use their trucks for transport to the RDC and transport within their local network. This means that food banks will have to keep using their trucks, even if the orders from the RDC are transported via a collective network. Even if it would theoretically possible for food banks to lower their number of the truck as a result of the collective network, they cannot be forced to do so due to their autonomy. It is also outside the scope of this research to investigate whether a particular food bank can reduce its number of trucks when it is not responsible for the transport of products from the RDC. Therefore, the calculations in the reference model are based on variable costs only. However, to provide insights into the total costs made with transport, the fixed costs of transport are listed in the next part.

§4.3 introduced the annual reports containing information about the costs made with transport per food bank. From nineteen trucks used by all the food banks, detailed specification of these expenses was given for ten. The specifications showed the proportion of expenses allocated to fixed and variable costs. The top table in Figure B-11 shows the known fixed costs for these ten trucks. The average fixed costs per truck are 3700 euros. This research assumed that the trucks without further specification follow this average number. Using this assumption, the lower table in the sheet contains the information on fixed costs for all food banks. In the year 2020, the fixed transport costs for all food banks was estimated to be 70309 euros

The variable costs only include fuel costs since the trucks are driven by volunteers. Therefore, the fuel consumption of the trucks should be calculated. First, the annual statements were consulted since several food banks provided specific fuel expenses per year. Foodbank Almelo spent 8289 euros on fuel in the year 2020. The logistics coordinator estimated that around half is allocated to transport to the RDC, 4144,50 euros. The model showed that food bank Almelo drove 11806 kilometres in total. This results in 4144,50/11806= 0,351 euros per kilometre on fuel costs. In 2020, the average fuel costs were 1,237 euro per litre Diesel (CBS, 2020). Using these numbers, Almelo drove 3,5 kilometres per litre of fuel which is unrealistically inefficient. Also, applying this number to other food banks resulted in costs that exceeded their annual statements. Therefore, another way to calculate transport costs was used.

MIT provided a report in which they researched the effect of weight on fuel consumption for small trucks (Figure 9).

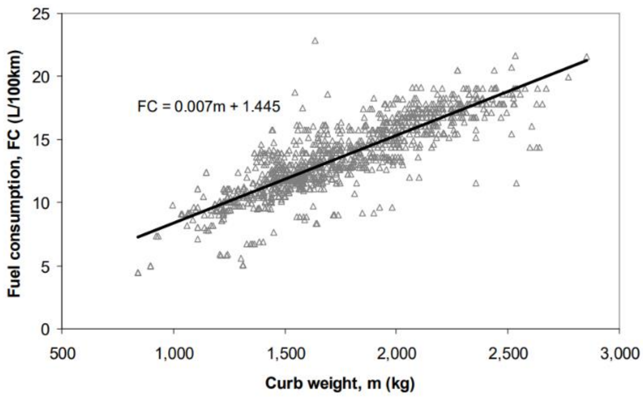


*Figure 9: Curb weight and fuel consumption of U.S. model year 2005 vehicles (MIT, 2008)*

Based on the weight and fuel consumption of trucks in city/highway environments they arrived at the following formula:

$$FC = 0{,}007m + 1{,}445 \quad (1)$$

*FC* is the fuel consumption per 100 kilometres and *m* the curb weight or total weight of the truck. Using this formula and the average fuel costs in 2020, the transport costs per order can be calculated. The average empty weight of these trucks ranges from 1600 to 2000 kilograms (Connekt, 2017). It is assumed that each truck weighs 1900 kilograms and that food banks drive empty to the RDC and loaded with an order. Then, the total costs per kilometre can be calculated via:



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$$\frac{Costs}{km} = ((0{,}5 * (0{,}007 * 1900 + 1{,}445)) + (0{,}5 * (0{,}007 * (1900 + w)) + 1{,}445))/100) * 1{,}237$$

Where () calculates the L/100km fuel of an empty truck, and () calculates the L/100km fuel for a loaded truck with the weight of an order given by $w$. This number is divided by 100 to get the L/km fuel and this is multiplied with the average price per litre fuel to generate the costs per kilometre for a certain trip to the RDC. Using this number, the trucks of the food bank on average drove 5.8 kilometres per litre of fuel and the costs per kilometre were on average 0,21 cents which is a more realistic number

**Overview complete**

With the extra data, the overview table could be completed. Figure B-12 shows the VBA code that fills an extra column in the overview table with the total driven kilometres by food banks to transport an order. This depends on the distance between the food bank and the RDC and the number of trucks needed to transport the order.

Another column is added which lists the costs made to transport an order. This column contains the previously explained formula. The variable $w$ is adjusted for each weight of the order. Finally, to analyse the current transport network, one extra column was added which contains the day of the week on which the order was transported. Figure 10 shows the first rows of the complete overview table.

| Date | FoodBank | Weight | SumOfPallets | Pallets | Trucks | Kilometres | Costs | DayOfWeek |
|---|---|---|---|---|---|---|---|---|
| 03/01/2020 | VB Enschede | 1428,564 | 1,328564818 | 2 | 1 | 119,4 | € 41,79 | Fri |
| 03/01/2020 | VB Midden Twente | 1076,883 | 1,035781452 | 2 | 1 | 96,4 | € 33,75 | Fri |
| 03/01/2020 | VB Oost Twente | 419,181 | 0,399769205 | 1 | 1 | 116,5 | € 40,79 | Fri |
| 08/01/2020 | VB Almelo | 2013,7 | 2,573781916 | 3 | 2 | 184,5 | € 64,56 | Wed |
| 08/01/2020 | VB Enschede | 3027,666 | 4,320716698 | 5 | 3 | 358,2 | € 125,38 | Wed |
| 08/01/2020 | VB Hellendoorn | 461,393 | 0,63676478 | 1 | 1 | 65,2 | € 22,83 | Wed |
| 08/01/2020 | VB Losser | 359,098 | 0,492383127 | 1 | 1 | 129,8 | € 45,42 | Wed |
| 08/01/2020 | VB Midden Twente | 2244,942 | 3,199913139 | 4 | 2 | 192,9 | € 67,51 | Wed |
| 08/01/2020 | VB Oost Twente | 914,84 | 1,285712906 | 2 | 1 | 116,5 | € 40,79 | Wed |
| 08/01/2020 | VB Raalte | 975,207 | 1,375894417 | 2 | 1 | 39,9 | € 13,95 | Wed |
| 08/01/2020 | VB Rijssen Holten | 822,963 | 1,076857091 | 2 | 1 | 59,9 | € 20,96 | Wed |
| 08/01/2020 | VB Vaassen | 337,331 | 0,391582277 | 1 | 1 | 52,8 | € 18,48 | Wed |
| 08/01/2020 | VB Zutphen | 2128,383 | 2,786451488 | 3 | 2 | 51,4 | € 17,99 | Wed |
| 09/01/2020 | VB Almelo | 379,04 | 0,359373723 | 1 | 1 | 92,2 | € 32,28 | Thu |
| 09/01/2020 | VB Enschede | 1365,716 | 1,282833546 | 2 | 1 | 119,4 | € 41,79 | Thu |
| 09/01/2020 | VB Hellendoorn | 217,764 | 0,204784162 | 1 | 1 | 65,2 | € 22,83 | Thu |
| 09/01/2020 | VB Losser | 149,345 | 0,14156507 | 1 | 1 | 129,8 | € 45,42 | Thu |
| 09/01/2020 | VB Midden Twente | 999,607 | 0,937723793 | 1 | 1 | 96,4 | € 33,75 | Thu |
| 09/01/2020 | VB Oost Twente | 419,109 | 0,393156463 | 1 | 1 | 116,5 | € 40,79 | Thu |
| 09/01/2020 | VB Raalte | 447,184 | 0,418573566 | 1 | 1 | 39,9 | € 13,95 | Thu |
| 09/01/2020 | VB Rijssen Holten | 151,2 | 0,143180803 | 1 | 1 | 59,9 | € 20,96 | Thu |
| 09/01/2020 | VB Vaassen | 104,079 | 0,09427968 | 1 | 1 | 52,8 | € 18,48 | Thu |
| 09/01/2020 | VB Zutphen | 444,8 | 0,422221734 | 1 | 1 | 25,7 | € 8,99 | Thu |
| 10/01/2020 | VB Enschede | 428,2 | 0,414830163 | 1 | 1 | 119,4 | € 41,79 | Fri |
| 10/01/2020 | VB Midden Twente | 305,52 | 0,296471389 | 1 | 1 | 96,4 | € 33,75 | Fri |
| 10/01/2020 | VB Oost Twente | 126,64 | 0,121480096 | 1 | 1 | 116,5 | € 40,79 | Fri |
| 15/01/2020 | VB Almelo | 1471,292 | 1,95743862 | 2 | 1 | 92,2 | € 32,28 | Wed |
| 15/01/2020 | VB Enschede | 2837,767 | 4,156080301 | 5 | 2 | 238,8 | € 83,58 | Wed |
| 15/01/2020 | VB Hellendoorn | 377,437 | 0,548754449 | 1 | 1 | 65,2 | € 22,83 | Wed |
| 15/01/2020 | VB Losser | 307,49 | 0,451121124 | 1 | 1 | 129,8 | € 45,42 | Wed |
| 15/01/2020 | VB Midden Twente | 2100,112 | 3,073464878 | 4 | 2 | 192,9 | € 67,51 | Wed |
| 15/01/2020 | VB Oost Twente | 881,625 | 1,282441038 | 2 | 1 | 116,5 | € 40,79 | Wed |
| 15/01/2020 | VB Raalte | 925,38 | 1,353498022 | 2 | 1 | 39,9 | € 13,95 | Wed |
| 15/01/2020 | VB Rijssen Holten | 593,194 | 0,793534841 | 1 | 1 | 59,9 | € 20,96 | Wed |
| 15/01/2020 | VB Vaassen | 483,802 | 0,731855293 | 1 | 1 | 52,8 | € 18,48 | Wed |
| 15/01/2020 | VB Zutphen | 1682,9245 | 2,243656671 | 3 | 2 | 51,4 | € 17,99 | Wed |
| 16/01/2020 | VB Almelo | 150 | 0,135758356 | 1 | 1 | 92,2 | € 32,28 | Thu |
| 16/01/2020 | VB Enschede | 441,28 | 0,451529589 | 1 | 1 | 119,4 | € 41,79 | Thu |
| 16/01/2020 | VB Hellendoorn | 144,03 | 0,179835866 | 1 | 1 | 65,2 | € 22,83 | Thu |

Orderrows | Volume | Busses | Buscombinations | DistanceMatrix | Overview | PivotTable | Sheet1

*Figure 10: Screenshot of the complete overview table containing order information of the year 2020*

## 5.2 Model validation

The overview table is complete and contains information about volumes, weights and quantities of orders going from the RDC to the food banks as well as information about the costs that each food bank made with transport. This information is stored systematically in a table which enables to derive relevant output using Excels built-in tool called "pivot tables". Table 6 shows the complete output for each food bank. Food bank Almelo is used as an example to explain the different columns of information. In the year 2020, they spent 2567,18 euros on variable transport costs. They transported a total weight of 103631 kg of products on 174 pallets. Finally, the number of trips refer to the number of trucks that were used to transport a complete order. The number of orders can also be viewed as the number of days that a food bank visited the RDC. They made 128 trips to the RDC on 101 different days in the year. This resulted in a total driven distance of 11806 km

| | **Costs (€)** | **Weight (kg)** | **Pallets** | **Trips** | **Orders** | **Distance (km)** |
|---|---|---|---|---|---|---|
| *VB Almelo* | € 2.567,18 | 103631 | 174 | 128 | 101 | 11806 |
| *VB Enschede* | € 5.848,36 | 229719 | 330 | 214 | 113 | 25553 |
| *VB Hellendoorn* | € 1.336,19 | 35098 | 107 | 104 | 104 | 6782 |
| *VB Losser* | € 2.650,70 | 25172 | 107 | 106 | 106 | 13757 |
| *VB Midden Twente* | € 3.574,66 | 139963 | 223 | 170 | 109 | 16394 |
| *VB Oost Twente* | € 2.727,39 | 68694 | 142 | 112 | 112 | 13053 |
| *VB Raalte* | € 888,81 | 76832 | 146 | 104 | 104 | 4146 |
| *VB Rijssen Holten* | € 1.166,62 | 41275 | 102 | 97 | 97 | 5809 |
| *VB Vaassen* | € 1.075,44 | 36457 | 107 | 103 | 103 | 5439 |
| *VB Zutphen* | € 805,67 | 117565 | 193 | 144 | 100 | 3700 |
| ***Total*** | **€ 22.641,02** | **874405** | **1631** | **1282** | **1049** | **106441** |

*Table 6: Findings per food bank of the reference model before validation*

These results were presented to the director and the logistics coordinator of food bank Almelo to validate if they were accurate. The numbers for Almelo looked representative apart from the number of pallets. They estimated this number to be around two to three times higher. To adjust the model correctly, an understanding is needed why the number of pallets deviates so much from reality. Recall from §4.1 how the number of pallets was estimated. The weight/pallet ratio per product group was used to calculate the fraction of a pallet that is filled by one kilogram of a product. This ratio was calculated based on input products from donors that were stacked on pallets. However, a single donor is likely to have many uniform products that enable them to stack a pallet more efficient than the RDC, which needs to combine products from different donors on one pallet. Therefore, donors stack more products on a single pallet resulting in a higher weight/pallet ratio which means that relatively, a kilogram of these products takes less space of a pallet. Since these numbers were used for the pallet stacking to the food banks, the results show fewer pallets than actually were needed.

With this information, the model was adjusted to provide a more accurate result. Recall that the number of pallets per order is calculated by rounding up the sum of the fractions of pallets that the products in that order fill. An order that fills 1,315 pallets is rounded up to two pallets. Therefore, the final numbers of pallets in Table 6 cannot be multiplied by two or three as it would provide incorrect results. Instead, the kg/pallet ratios in Figure B-1 were multiplied with different factors ranging from two to five and the model is run for each multiplication to see which number of multiplication should be used in the remainder of this research. A multiplication of 3,5 provided the most accurate pallet numbers. Therefore, the remainder of this research uses these pallet fractions for calculations.

## 5.3 Effects of the expected increase in demand

The reference model of the current situation is complete. §1.5 explained that one of the reasons for food banks to analyse their current transport network was the notification during the general assembly of members meeting that stated that food banks should prepare for a possible increase in demand of 50%.

Now that the reference model is complete, the next step is to investigate how this number of 50% was established and how this increase would affect the transport of products from the RDC to process this into the reference model. Qualitative data was gathered via semi-formal interviews.

Each year, Voedselbanken Nederland expects an increase of 10% to 15% in demand, referred to as the growth number. This expectation is based on the large number of people in the Netherlands that are eligible for the support of food banks but do not make use of this prerogative. Food banks actively try to reach these people by launching campaigns and with success as Figure 11 shows that the number of people supported by food banks grew each year except for 2014-2016 which showed a decrease.

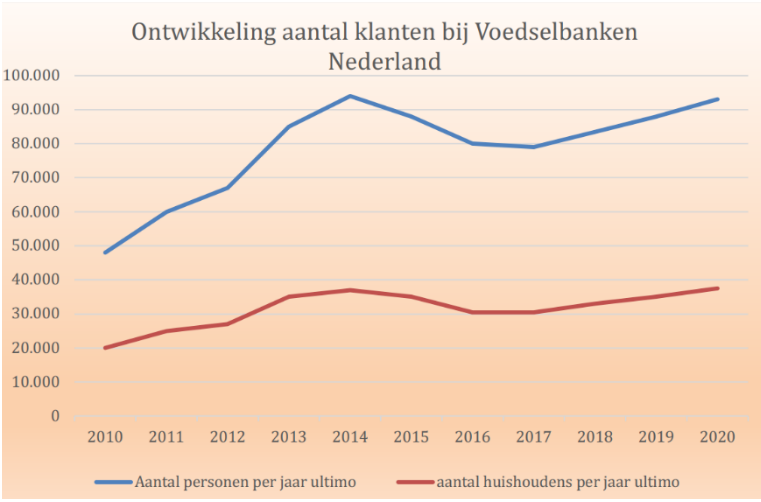


*Figure 11: Development of the number of people supported by food banks over de last decade (Voedselbanken Nederland, 2020).*

The general assembly of members took place in September 2020, a period in which the covid pandemic situation in the Netherlands was desperate. Figure 12 shows the decrease in the gross domestic product in the year 2020.

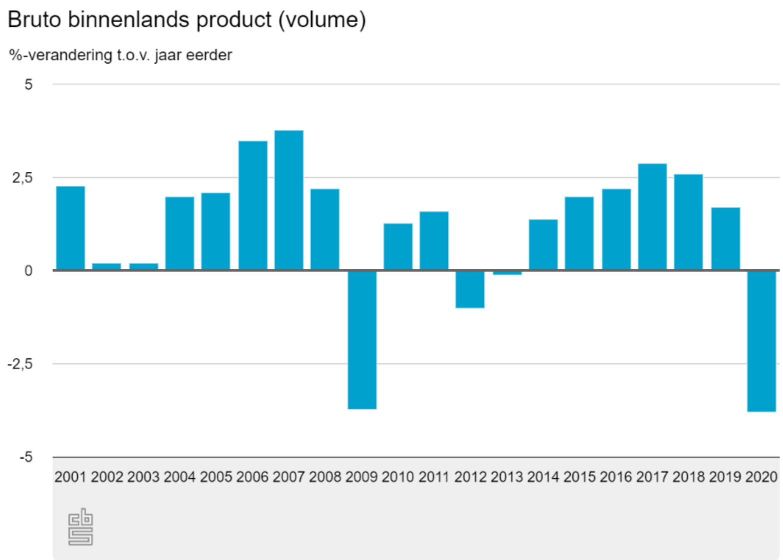


*Figure 12: Change in percentages of the gross domestic product of the Netherlands (CBS, 2020)*

High unemployment rates and bankrupt companies were expected as a result of this pandemic. More households would become eligible for the support of food banks and thus the growth rate would increase. Based on this expectation and the regular increase food banks already encounter,


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Voedselbanken Nederland alerted food banks for a possible increase in future demand. To prepare for this increase, food banks should make plans for a short term increase of 10%, 25% and 50%.

Currently, with retroactive effect, it can be concluded that these expectations were, luckily, too pessimistic. The total growth of food banks since the start of 2021 is 8 % and is only noticed in the larger regions located in the western regions of the Netherlands. Twente-Salland actually noticed a decrease in the number of households. The amount of variables within a country that influence this growth rate is huge and it is not the goal of this research to make a more accurate prediction on how this number will develop over time. However, even though the prediction did luckily not happen, Voedselbanken Nederland still tries to alert food banks to make preparations for future increases. Even if there or no consequences due to covid, the 10% yearly increase would result in a 50% total increase within five years. It is therefore still relevant to make an upscaling plan for the mentioned percentages.

**Food collection**
Assuming that a food bank wants to provide packages with a consistent amount of products. Then, an increase in demand means an increase in the number of products that a food bank has to collect to fill the packages for the extra households. This research only focuses on the transport of products from the RDC, which distributes food donated on a national and regional level. To calculate plausible growth scenarios in the reference model an understanding is needed of how food banks expect that these extra products will be collected, either via the local network or via the RDC. There are three aspects identified that influence the proportion of locally collected and RDC collected food in a package from a food bank.

*The region*
Each food bank depends on the availability of companies and organizations in their surroundings to acquire local food donors for their network. Suitable companies include supermarkets and food producers. These companies are not evenly located through the Netherlands, region Groningen located hardly any food companies, as a result, food banks struggle to find enough local donors. The region Twente-Salland however is home to many of these companies which make efficient donors. Therefore, the food banks are successful in acquiring big quantities of food via their local network compared to other regions.

*The network*
§1.2 explained that the local network of a food bank is often maintained by some logistic coordinator and exists via many personal relationships in the field. The ability of this coordinator to acquire donors has a lot of influence on the total amount of products that are received from the local network. Within the region, a difference is noticed between food banks based on the effect of this logistic coordinator. Indicating that this role actually makes a difference in the number of products received from the local network.

*The number of products in a package*
According to Voedselbanken Nederland, a food bank should strive to provide packages with around 25 products that should provide three meals. However, this is not a strict limit and as an autonomous organization food banks may provide a lot more products per package if they have the resource to collect the required amount of food. The food banks in the region Twente-Salland often provide packages containing 35 to 40 products. They can do so because of the number of products that are received from the local network. However, a food bank could always decide to lower this number back to 25 products and thereby putting less effort into collecting food from the local network.

The above-mentioned aspects are in favour of food banks located in the region Twente-Salland as it is considered to be a rich region. However, also in this region, it is noticed that the products offered by local companies and supermarkets are decreasing and thus the proportion of products in a package that comes from the RDC increases. Local companies are becoming more aware of the importance of decreasing waste. Initiatives like big discounts on products that are almost expired decrease the amount of food that companies donate to food banks. It is expected that this trend continues in the future and that the flow of products via the RDC will increase and become more important. This means that the extra amount of products needed to satisfy an increase in demand will be transported via the RDC.

However, this is a rough estimate which again lacks quantitative data for support. Making these predictions is difficult if not impossible.

**Implementation of results**
The original 50% increase will probably not be realized soon. If an increase would occur, it is expected that extra products will be collected via the RDC instead of the local network. However, this is again a rough estimation and the food banks in the region Twente-Salland benefit from the many possibilities when it comes to food donors for the local network. Due to the many uncertainties, it is still useful to work out scenarios in case of an actual increase in demand. Therefore, the research performs an analysis of 10%, 25% and 50% increase taking the data collected of 2020 as a basis. This increase is simulated by adding 10%, 25% and 50% to the weights of the existing products in the data set. Note that the pallets are directly calculated from these weights so they will automatically increase as well

## 5.4 Findings

The reference model is complete and the data can be analysed. Recall from the original goal that the reference model should provide information about the costs made with transport and about the order timings/weights/volume per food bank. First, the costs are presented. Table 7 shows the yearly output of the reference model for each food bank in the year 2020.

| | Costs (€) | Weight (kg) | Pallets | Trips | Orders | Distance (km) |
|---|---|---|---|---|---|---|
| *VB Almelo* | € 2.634,47 | 103631 | 468 | 132 | 101 | 12175 |
| *VB Enschede* | € 8.048,07 | 229719 | 1003 | 315 | 113 | 37613 |
| *VB Hellendoorn* | € 1.419,46 | 35098 | 201 | 111 | 104 | 7239 |
| *VB Losser* | € 2.698,04 | 25172 | 159 | 108 | 106 | 14017 |
| *VB Midden Twente* | € 3.873,69 | 139963 | 628 | 187 | 109 | 18034 |
| *VB Oost Twente* | € 3.195,04 | 68694 | 340 | 134 | 112 | 15617 |
| *VB Raalte* | € 961,53 | 76832 | 376 | 114 | 104 | 4545 |
| *VB Rijssen Holten* | € 1.199,39 | 41275 | 212 | 100 | 97 | 5989 |
| *VB Vaassen* | € 1.075,44 | 36457 | 201 | 103 | 103 | 5439 |
| *VB Zutphen* | € 997,82 | 117565 | 517 | 185 | 100 | 4754 |
| ***Total*** | **€ 26.102,95** | **874405** | **4105** | **1489** | **1049** | **125421** |

*Table 7: Findings per food bank of the reference model after validation*

Figure 13 shows the proportion of fixed and variable transport costs. 73% of the total transport costs are directed to fixed transport costs. Even though, this part is substantial, the reason to focus on variable costs have been made clear in this chapter.

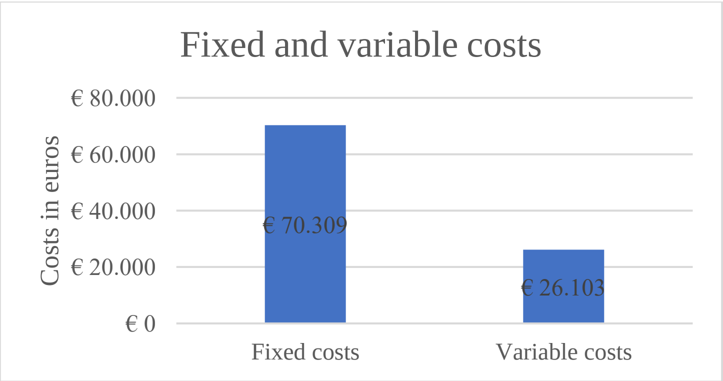


*Figure 13: The proportion of fixed and variable transport costs*

Table 8 shows the costs made by each food bank per increase in demand. The costs increase about 2/3 of the demand increases. 9Appendix C contains tables per demand increase with data on the weight, pallets, trips, orders and distances.



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| *Food banks:* | **normal demand** | **10% demand increase** | **25% demand increase** | **50% demand increase** |
|---|---|---|---|---|
| *VB Almelo* | € 2.634,47 | € 2.827,26 | € 3.141,68 | € 3.648,89 |
| *VB Enschede* | € 8.048,07 | € 8.798,43 | € 9.564,61 | € 11.407,84 |
| *VB Hellendoorn* | € 1.419,46 | € 1.453,16 | € 1.551,29 | € 1.659,33 |
| *VB Losser* | € 2.698,04 | € 2.712,18 | € 2.757,07 | € 2.910,79 |
| *VB Midden Twente* | € 3.873,69 | € 4.195,98 | € 4.705,79 | € 5.379,58 |
| *VB Oost Twente* | € 3.195,04 | € 3.357,25 | € 3.664,32 | € 4.154,86 |
| *VB Raalte* | € 961,53 | € 996,60 | € 1.096,48 | € 1.231,42 |
| *VB Rijssen Holten* | € 1.199,39 | € 1.231,94 | € 1.302,61 | € 1.449,53 |
| *VB Vaassen* | € 1.075,44 | € 1.083,78 | € 1.096,28 | € 1.126,75 |
| *VB Zutphen* | € 997,82 | € 1.076,51 | € 1.180,49 | € 1.372,53 |
| ***Total*** | **€ 26.102,95** | **€ 27.733,08** | **€ 30.060,62** | **€ 34.341,52** |

*Table 8: Overview of fuel costs per food bank for different increases in demand*

**Order information**

Using pivot tables, the information about the orders can be derived from the overview table. Figure 17 and Figure 18 show examples of how this data can be processed into a complete overview containing the weight and pallet values per date per food bank. This kind of data is needed in the solution model. The demand pattern of the food banks is analysed to understand how this output should be modelled within the solution model. §2.4 explained that foodbanks have fixed days on which they visit the RDC. Table 9 shows how often food banks visited the RDC per day of the week. Both Wednesday and Thursday are fixed days for each food bank. On Friday, Enschede, Midden-Twente and Oost-Twente did transport several orders and all the other day's transport was performed incidentally. This research assumed that these days remain fixed as this historical data is used in the solution analysis. It is therefore outside the scope of this analysis to investigate if it would be more beneficial for food banks to transport on other days

| | **Mon** | **Tue** | **Wed** | **Thu** | **Fri** | **Sat** | **Total** |
|---|---|---|---|---|---|---|---|
| *VB Almelo* | 3 | 3 | 50 | 40 | 3 | 2 | 101 |
| *VB Enschede* | 3 | 3 | 50 | 41 | 14 | 2 | 113 |
| *VB Hellendoorn* | 3 | 3 | 47 | 45 | 4 | 2 | 104 |
| *VB Losser* | 3 | 3 | 49 | 45 | 4 | 2 | 106 |
| *VB Midden Twente* | 3 | 3 | 49 | 39 | 14 | 1 | 109 |
| *VB Oost Twente* | 3 | 3 | 49 | 41 | 14 | 2 | 112 |
| *VB Raalte* | 3 | 3 | 47 | 45 | 4 | 2 | 104 |
| *VB Rijssen Holten* | 3 | 3 | 48 | 39 | 3 | 1 | 97 |
| *VB Vaassen* | 3 | 3 | 49 | 43 | 3 | 2 | 103 |
| *VB Zutphen* | 3 | 3 | 49 | 40 | 3 | 2 | 100 |
| ***Total*** | **30** | **30** | **487** | **418** | **66** | **18** | **1049** |

*Table 9: Overview of the number of times that food bank visited the RDC per day of the week*

Since Wednesday and Thursday are by far the busiest days, The demand patterns on those days are investigated first. Figure 14 and Figure 15 show the total number of pallets transport from the RDC to the food banks on Wednesday and Thursday.

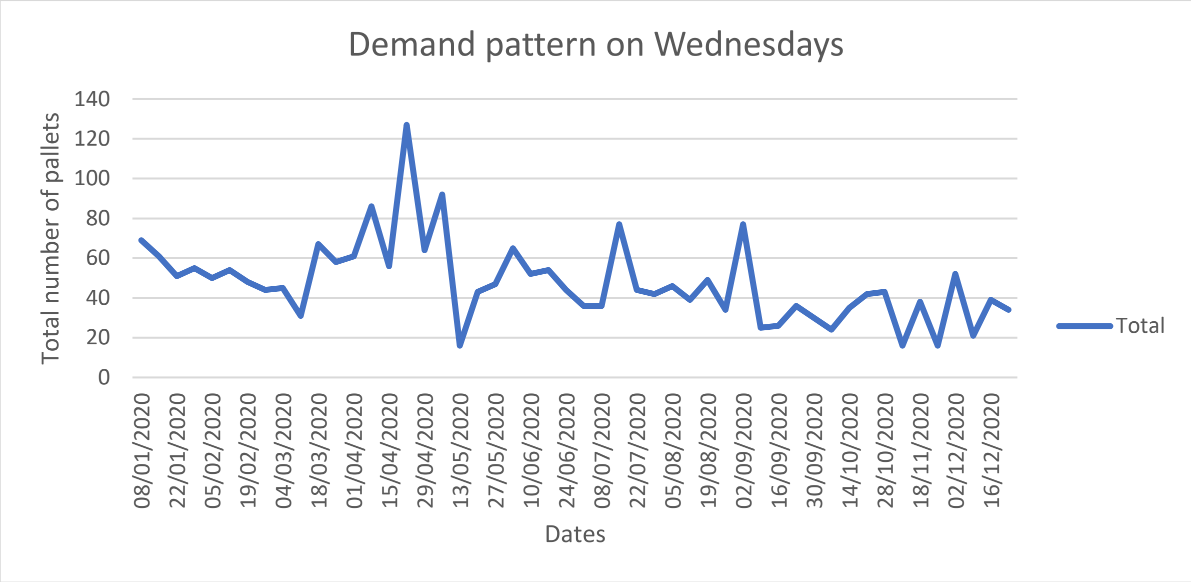


*Figure 14: Cumulative pallet demand on Wednesdays in 2020*

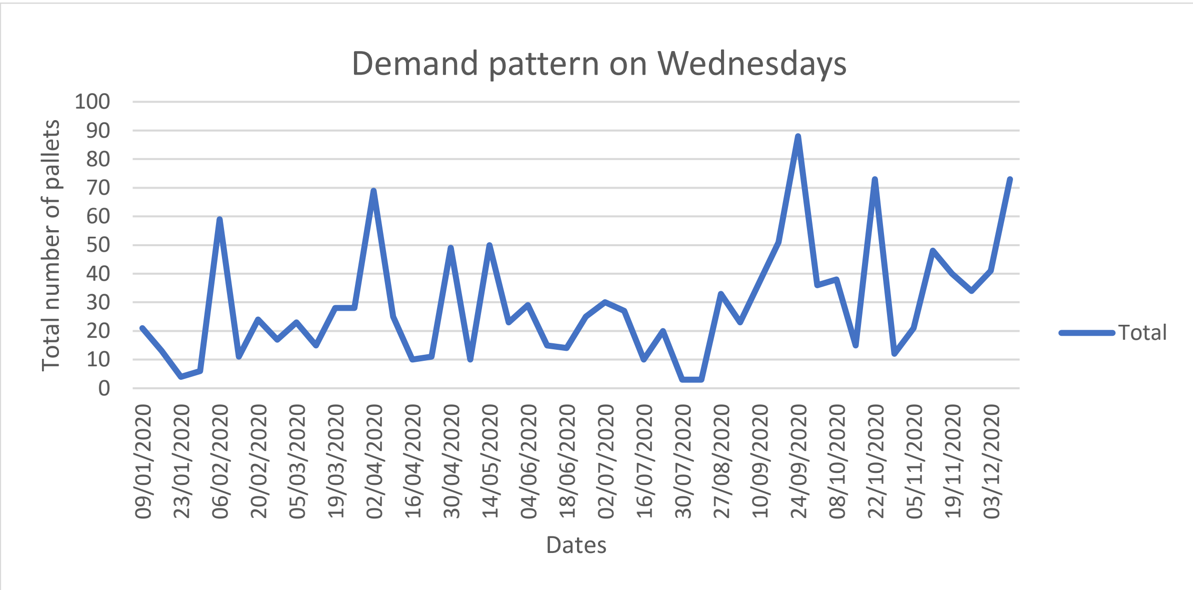


*Figure 15:Total pallet demand of all food banks on Thursdays in 2020*

A 95% confidence interval was constructed for both days to investigate how variable this demand is. Table 10 shows that both intervals ley around eleven pallets. This is too broad to use average demand input values for the solution analysis as the results would not accurately reflect the variable behaviour of order sizes. This variety can be explained by the supply-driven flow of donations. Because of this, the input parameters of the solution models should be adjusted to the values stored in the reference model.

| | **Wednesday** | **Thursday** |
|---|---|---|
| *Mean* | 47,940 | 29,022 |
| *Upper bound (95%)* | 53,790 | 34,987 |
| *Lower bound (95%)* | 42,090 | 23,056 |
| *Confidence interval* | 11,700 | 11,931 |

*Table 10: 95% confidence interval of the total number of pallets on Wednesdays and Thursdays*

## 5.5 Conclusion

This chapter explained how the collected data in Chapter 4 is ordered into various sheets of the reference model. Using VBA code and Excel functions, this data is step by step used to construct the overview table. Each row in this table refers to one complete that was transported from the RDC to a food bank. The information in a row specifies the following data for each order:

- The date on which the order was transported
- The food bank that transported the order
- The number of pallets on which the order was stacked
- The total weight of the order
- The number of trucks a particular food bank needed to transport the order
- The total kilometres that are driven to transport the order
- The fuel costs made with transport

This data is used for two aspects: The costs made with transport can be used to compare alternative solution scenarios against. The decision was made to leave the fixed costs out of the model's calculations and concentrate on variable costs only. The reference model also contains information about the timing, weight and volume of each order. This information will be used as input in the solution analysis.

Even though only the variable costs are used for calculations, data about the fixed costs of using a truck were gathered to provide insights into how the transport costs are allocated. However, since it is not sure how these fixed costs will change when a collective solution has been found due to the autonomous organizations, they were not included in the costs per kilometre. The first model was discussed with the logistics coordinator and director of food bank Almelo to validate its findings. Hereafter, the model was adjusted to increase the number of pallets used to transport an order.

The variable costs per kilometre were first calculated based on the fuel costs by food bank Almelo and the total driven kilometres calculated by the model. However, this number provided inaccurate results for other food banks. Therefore, a formula was used to calculate the fuel expenses for each trip by a food bank taking the weight of the order into account. However, this number remains an estimation which is something that should be kept in mind once conclusions are based on the results of the reference model.

Finally, the data concerning the weight/volume and timing of orders for each food bank was analysed. Wednesday and Thursday were identified as fixed days for each food bank. On Fridays, three of the ten food banks transported products several times in the previous. On other days of the week, the food banks visited incidentally. Since Wednesdays and Thursdays are fixed days, the demand pattern on those days was analysed. The order sizes vary too much to use average values in the solution analysis as it would not accurately represent the variability in order sizes that food banks have to deal with. Therefore, to compare the performance of the current transport network with a solution scenario. The solution model should use the input per order rows to analyse its performance.

# 6 Solution analysis

This chapter presents the solution model used to solve the CVRP and test different collective transport scenarios. §6.1 provides a formal mathematical formulation of the CVRP. §6.2 explains the solution model. §6.3 outlines the different collective transport scenarios that are modelled. §6.4 presents the results of each scenario and compares them with the findings of the reference model.

## 6.1 Mathematical formulation

The CVRP is formulated as a mixed-integer linear program (MILP) using the Miller-Tucker-Zemlin (MTZ) formulation (Miller, 1960). The parameters, variables, objective function and constraints of the CVRP are described.

**Parameters**
Recall from §0 that the CVRP constructs routes for trucks that start from a single depot (RDC) denoted by 0, and visits a set of *n* points representing the customers (food banks). The total set of customers is denoted by *N* = {1,2…,*n*}. Each customer has a nonnegative known demand given by $q_i \geq 0$ where $i \in N$. Furthermore, $q_0 = 0$ since a depot does not have a demand. For this problem, $q_i$ is two dimensional and contains two values referring to the weight and pallet demand of the customer orders. The homogeneous fleet K= {1,2…, |K|} consists of similar trucks with capacity $Q > 0$. $Q$ is also a two-dimensional value that contains the weight and pallet capacity of the vehicles. A truck that visits a subset $S \subseteq N$ starts at the depot, travels to each customer and ends at the depot. A truck moving from customer *i* to *j* incurs travel costs $c_{ij}$. Since costs are directly related to distances between the customers, $c_{ij}$ equals the distance between customer *i* and *j*.

Using this information, the CVRP can be described using a directed graph *G* = (*V*, *A*). Where *V* = {0,1,…,*n*} is the set of vertices containing the depot and the customers. The arc set $A = \{(i, j) \in V \times V: i \neq j\}$ contains the distances $c_{ij}$ for $(i, j) \in A$. to clarify, these are the distances listed in the distance matrix described in §4.4. The complete CVRP is uniquely defined by a directed graph $G = (V, A, c_{ij}, q_i)$ together with |K| trucks (Toth,2014). The objective of the above-defined CVRP is to determine a set of routes that visit each customer exactly once and minimizes the total amount of costs.

**Variables**
The two-index vehicle flow formulation uses a binary decision variable $x_{ij}$ for $\{i, j\} \in A$ to indicate if a vehicle drove from custom *i* to *j* in the optimal solution. Whenever $x_{ij}$ =1, indicated that the truck drove from customer *i* to *j*, if $x_{ij}$=0 indicates that the truck did not. The second variable $u = (u_1,\ldots, u_n)$ where $u_i$ indicates the accumulated demand $u_i$ already distributed by the vehicle when arriving at customer $i \in$ N.

**Objective function**
The goal is to construct routes in the optimal solution that minimize the total amount of costs. Since the costs $c_{ij}$ are defined as the distances between customers, the goal is to minimize the tot driven distance by the trucks. Therefore, the model aims at minimizing the objective function:

$$\text{(2)} \qquad \text{minimize} \qquad \sum_{i \epsilon V} \sum_{j \epsilon V} c_{ij} x_{ij}$$



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**Constraints**

The variables in the objective function are subjected to several constraints:

(3) s.t. $$\sum_{i \epsilon V} x_{ij} = 1 \qquad \forall j \in N$$

$$\sum_{j \epsilon V} x_{ij} = 1 \qquad \forall i \in N$$

(4) $$\sum_{j \epsilon V} x_{0j} \leq |K|$$

(5) $$u_i - u_j + Qx_{ij} \leq Q - q_j \qquad \forall (i,j) \in A(N) \;\; s.t. d_i + d_j \leq Q$$

(6) $$q_i \leq u_i \leq Q \qquad \forall i \in N$$

(7) $$x_{ij} \in \{0,1\} \qquad \forall (i,j) \in A.$$

Constrains (2) ensure that each customer is visited by exactly one truck. Constraint (3) ensures that no more routes are constructed than available trucks. The ≤ sign allows the model to not use all available vehicles. Constraint (4) ensures that no sub tour is created that does not contain the depot. Constraint (5) ensures that the capacity of a truck is not exceeded. Finally, constraint (6) ensure that $x_{ij}$ remains a binary variable.

## 6.2 Solution model

The previous section provided the mathematical formulation of the CVRP for the food banks. §0 explained that Google OR-Tools is used to solve the problem. Google OR-tool is written in C++ but can be exported to Java, C# and Python. For the ease of programming Python was chosen. The tool provides a basic model which can be used to solve a CVRP (“Vehicle routing”, 2021). This part briefly explains how this model works. However, before this explanation, Figure 16 shows an overview of how data flows between the two models constructed in this thesis.

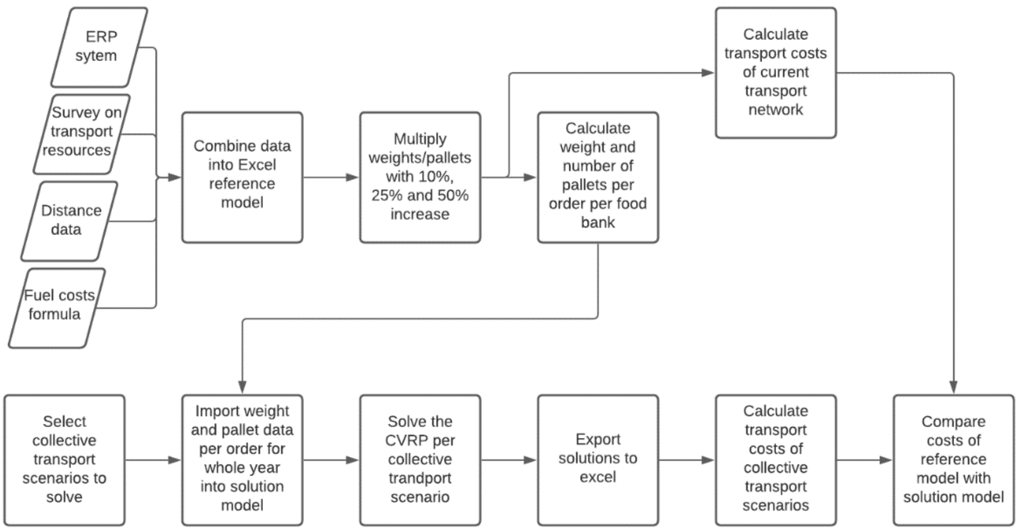


*Figure 16: Schematic overview of the flow of data between the reference model and the solution model*



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The goal of the solution model is identical to the goal of the previously explained CVRP: Finding routes that minimize the objective value while satisfying all customers demand without exceeding the capacity of a truck. To solve this problem, the tool needs several pieces of information called input data:

- Distances between customers and between customers and depot
- The demand per customer
- The capacity of the trucks
- The number of available trucks

A maximum of one route per truck can be constructed. To make sure that a feasible solution exists, the cumulative capacity of all trucks should be greater than or equal to the customers' cumulative demand. Furthermore, the user can adjust parameters that influence the objective value to adjust the focus of optimization. Since the goal of this problem is to minimize the total distance of the routes, the objective value consists of the sum of all routes. Besides this, the model should minimize the number of used trucks. To ensure this, a fixed cost per truck is specified. Finally, a heuristic or meta-heuristic is chosen which decides the search strategy of the model. The output of the model contains the objective value (the total distance of all routes), the set of routes, the distance and load per route.

**Final model**
The basic CVRP model of Google OR-tools is created in such a way that the user can add code to customize the model. Several adjustments were made to create the solution model that could be used to test collective transport scenarios. The platform GitHub has a wide variety of discussions about specific questions from users of Google OR-Tools about the coding of specific scenarios. The code in these discussions was used directly or served as inspiration for the solution model. The next part describes the adjustments and search strategy.

First, the capacity of a truck is expressed in both weight and volume (pallets). Therefore, an extra capacity constraint was added. Also, the demand of customers should be given in both pallets and weight. Each constructed route should satisfy both capacity constraints.

Second, §5.5 concluded that the demand patterns of food banks are too variable to use average values. Therefore, the customer demand input should be adjusted to the weight and pallet values stored in the reference model for each new day. Figure 17 and Figure 18 show overviews of how the weight and pallet data is stored in the demand input sheet. Each column refers to a food bank and each row contains values for a specific date. Column A represents the RDC and the other food banks are represented in alphabetical order. The model loops over each row and adjusts the demand input to the correct values before constructing routes. This way, the model can be used to analyse each day in the year 2020 to provide accurate results that can be compared with the results of the reference model.

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Dates | RDC | VB Almelo | VB Enschede | VB Hellendoorn | VB Losser | VB Midden Twente | VB Oost Twente | VB Raalte | VB Rijssen Holten | VB Vaassen | VB Zutphen |
| 2 | 08/01/2020 | 0 | 2013,7 | 3027,666 | 461,393 | 359,098 | 2244,942 | 914,84 | 975,207 | 822,963 | 337,331 | 2128,383 |
| 3 | 15/01/2020 | 0 | 1471,292 | 2837,767 | 377,437 | 307,49 | 2100,112 | 881,625 | 925,38 | 593,194 | 483,802 | 1682,9245 |
| 4 | 22/01/2020 | 0 | 1492,37336 | 2707,73756 | 388,35876 | 287,26084 | 1976,96296 | 792,4996 | 881,07252 | 612,87376 | 485,97876 | 1534,27128 |
| 5 | 29/01/2020 | 0 | 1892,203 | 3689,583 | 472,767 | 438,69 | 2816,91 | 1131,736 | 1227,139 | 842,118 | 699,533 | 2099,997 |
| 6 | 05/02/2020 | 0 | 1785,815 | 3376,936 | 479,344 | 349,898 | 2534,658 | 1015,253 | 1097,52 | 742,522 | 612,361 | 2186,922 |
| 7 | 12/02/2020 | 0 | 1857,572 | 2614,32 | 522,234 | 538,196 | 2149,48 | 978,118 | 1159,738 | 625,912 | 641,564 | 2063,382 |
| 8 | 19/02/2020 | 0 | 1485,05 | 3080,346 | 461,841 | 227,435 | 2660,878 | 1061,016 | 791,356 | 514,024 | 465,545 | 1274,903 |
| 9 | 26/02/2020 | 0 | 1465,271 | 2139,378 | 377,512 | 226,598 | 1799,252 | 734,058 | 842,474 | 608,028 | 452,31 | 1639,528 |
| 10 | 04/03/2020 | 0 | 1218,106 | 2667,285 | 373,216 | 281,092 | 1784,043 | 720,923 | 801,683 | 521,616 | 446,736 | 1362,223 |
| 11 | 11/03/2020 | 0 | 899,73 | 1833,178 | 239,648 | 188,36 | 1252 | 506,526 | 583,586 | 397,154 | 358,65 | 1026,986 |

*Figure 17: Screenshot weight input values for solution model*

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Dates | RDC | VB Almelo | VB Enschede | VB Hellendoorn | VB Losser | VB Midden Twente | VB Oost Twente | VB Raalte | VB Rijssen Holten | VB Vaassen | VB Zutphen |
| 2 | 08/01/2020 | 0 | 10 | 16 | 3 | 2 | 12 | 5 | 5 | 4 | 2 | 10 |
| 3 | 15/01/2020 | 0 | 7 | 15 | 2 | 2 | 11 | 5 | 5 | 3 | 3 | 8 |
| 4 | 22/01/2020 | 0 | 6 | 12 | 2 | 2 | 9 | 4 | 4 | 3 | 3 | 6 |
| 5 | 29/01/2020 | 0 | 7 | 13 | 2 | 2 | 10 | 4 | 4 | 3 | 3 | 7 |
| 6 | 05/02/2020 | 0 | 6 | 11 | 2 | 2 | 9 | 4 | 4 | 3 | 2 | 7 |
| 7 | 12/02/2020 | 0 | 7 | 11 | 2 | 2 | 9 | 4 | 5 | 3 | 3 | 8 |
| 8 | 19/02/2020 | 0 | 6 | 12 | 2 | 1 | 10 | 4 | 4 | 2 | 2 | 5 |
| 9 | 26/02/2020 | 0 | 6 | 9 | 2 | 1 | 7 | 3 | 4 | 3 | 2 | 7 |
| 10 | 04/03/2020 | 0 | 5 | 11 | 2 | 2 | 8 | 3 | 4 | 2 | 2 | 6 |
| 11 | 11/03/2020 | 0 | 4 | 7 | 1 | 1 | 5 | 2 | 3 | 2 | 2 | 4 |

*Figure 18: Screenshot of pallets input values for solution model*

Third, the output of the model should be presented in an Excel file for further analysis (see Figure 19). The output was modified in such a way that all the values could be separated using Excel`s built-in function "text to columns". The first column shows for which demand row these routes were constructed. Column B shows the constructed routes to the food banks who are represented by numbers in alphabetical order. Column D shows the total distance of the routes and column F shows the pallet load of the route.

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | 1 | 0 Load(0) -> 9 Load(1) -> 10 Load(3) -> 0 Load(3) | Distance | 77m | Load | 3 |
| 2 | 1 | 0 Load(0) -> 8 Load(1) -> 5 Load(4) -> 2 Load(8) -> 4 Load(9) -> 6 Load(11) -> 1 Load(13) -> 3 Load(14) -> 7 Load(16) -> 0 Load(16) | Distance | 169m | Load | 16 |
| 3 | 2 | 0 Load(0) -> 9 Load(1) -> 10 Load(2) -> 8 Load(3) -> 5 Load(5) -> 2 Load(7) -> 4 Load(8) -> 6 Load(9) -> 1 Load(10) -> 3 Load(11) -> 7 Load(12) -> 0 Load(12) | Distance | 233m | Load | 12 |
| 4 | 3 | 0 Load(0) -> 9 Load(1) -> 10 Load(1) -> 8 Load(1) -> 5 Load(1) -> 2 Load(1) -> 4 Load(2) -> 6 Load(2) -> 1 Load(2) -> 3 Load(3) -> 7 Load(4) -> 0 Load(4) | Distance | 233m | Load | 4 |
| 5 | 4 | 0 Load(0) -> 9 Load(1) -> 10 Load(1) -> 8 Load(1) -> 5 Load(1) -> 2 Load(1) -> 4 Load(2) -> 6 Load(2) -> 1 Load(2) -> 3 Load(3) -> 7 Load(4) -> 0 Load(4) | Distance | 233m | Load | 4 |
| 6 | 5 | 0 Load(0) -> 6 Load(4) -> 5 Load(13) -> 1 Load(18) -> 0 Load(18) | Distance | 140m | Load | 18 |
| 7 | 5 | 0 Load(0) -> 7 Load(5) -> 3 Load(7) -> 9 Load(10) -> 10 Load(16) -> 0 Load(16) | Distance | 138m | Load | 16 |
| 8 | 5 | 0 Load(0) -> 4 Load(2) -> 2 Load(15) -> 8 Load(18) -> 0 Load(18) | Distance | 152m | Load | 18 |

*Figure 19: The output of the solution model in a CSV file*

With these adjustments, the model can solve the CVRP for the food banks for each day on which products were transported and thereby provides yearly results that can be compared with the reference model. The different scenarios can be modelled by either changing the input parameters to model different types of trucks or the customer demand data to model the different increases in demand explained in §5.3. To ensure that a feasible solution exists, fifteen trucks are given as input. However, due to the penalty for using an extra truck, the model will not use an unnecessarily large number of trucks. Finally, a heuristic or meta-heuristic had to be chosen. §3.1 explained that Google OR-Tools identified the meta-heuristic: “Guided-Local-Search” as the most efficient metaheuristic. Therefore, this metaheuristic was chosen to solve the CVRP.

**Limitations**

Two limitations should be considered before presenting the results of the model. The first limitation refers to the general rule of a CVRP which states that a single customers demand can never exceed the capacity of a truck. The larger food banks have several days in the year on which their pallet demand exceeds the capacity of the considered trucks. The model does not construct routes to these food banks on those days. To solve this problem, the demand for these food banks was reduced to the maximum of the considered truck to make sure that it was still being visited on that day. This means that some orders have fewer weight/pallet values than those derived from the reference model.

Second, the model debugs when the input value for the demand of a food bank is empty. Table 9 showed that food banks did equally visited the RDC on Wednesdays and Thursdays which leaves empty cells in the demand input sheets. To prevent the model from debugging, these cells were filled with 0 values so they do not influence the total capacity of the truck on these days. However, the truck does visit these customers and thereby makes unnecessary kilometres. Due to the computational complexity, this problem could not be solved. The Friday shows a clear distinction between Enschede, Midden-Twente and Oost-Twente so for that day, a separate model with adjusted input parameters was developed.

## 6.3 Scenarios description

Different scenarios are modelled to investigate the performance of a collective transport network given these circumstances. These scenarios consider two different types of trucks and two different groups of food banks in the solution analysis. Each scenario is modelled using the current demand of food banks and the 10%, 25% and 50% increase in demand.

**Food banks**
The food banks initial solution contained a centralized transport network that supplies each food bank. However, the findings of the reference model revealed that there is a lot of diversity between food banks in terms of transport costs. Food bank Enschede incurs more costs than the lowest five food banks combined. Therefore, the potential savings for food bank Enschede is more than food bank Raalte. The five food banks with the biggest expenses: Enschede, Midden-Twente, Oost-Twente, Almelo and Losser (hereafter called the top five food banks) are also located relatively close to each other. Therefore, a second scenario is tested which includes only the top five food banks in the solution analysis. The results of this scenario are only compared to the fuel costs made by these five food banks in the reference model. The other food banks are assumed to keep operating their own trucks. It would be unnecessary to include their costs in the comparison as it would add the same values to the reference model output and the solution model output.

**Trucks**
The solution analysis considers large trucks that are currently not at the disposal of food banks. To choose the kind of trucks modelled in the solution analysis, the trucks are first subdivided into different categories. The mode of the constitution of the autonomous and non-autonomous parts of vehicles makes it possible to classify trucks into two main types: single-unit trucks and combination trucks. A single-unit truck (e.g., I in Figure 20) has fixed autonomous and non-autonomous parts, and the two parts cannot be separated. Combination trucks include truck tractor-semitrailer combinations (e.g., III in Figure 20) and trucks or truck tractors with semitrailers in combination with full trailers (e.g., II and IV in Figure 20) (Li et al, 2012).

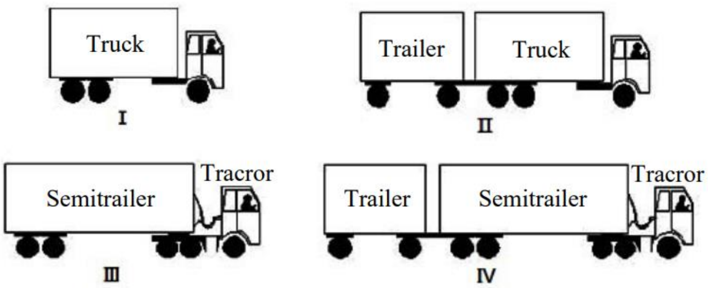


*Figure 20: The basic types of road freight vehicles (Li et al., 2012)*

Before deciding on the trucks considered within this research, the laws concerning driver licenses are discussed. The Netherlands use two types of truck driving licenses, the C and C1 licence. A C license allows for driving with trucks exceeding 3500 kg of gross weight while a C1 license only allows driving with trucks up to a gross vehicle weight of 7500 kg (Rijksoverheid, 2020). The exams for both licenses are the same but the costs of schooling for a C1 license is lower. The gross vehicle weight of 7500 kilograms consists of the sum of the base curb weight (empty vehicle weight) and the cargo weight. The average base curb is half the gross vehicle weight leaving only around 3750 kilograms maximum cargo weight. The average weight of orders on Wednesdays and Thursdays is more than 3 times this number. The solution analysis therefore only considers trucks for which a C truck driving license is needed.

This research does not considers trailers and focuses on the distinction between single-unit trucks and semi-trailer trucks. The chassis of the single-unit truck combines the cab, sleeper and cargo box while the semi-trailer truck can detach the semi-trailer from the tractor unit. The single-unit truck is easier to drive and handle but sacrifices some versatility and cargo load option compared to the semi-trailer truck. The single-unit truck has due to its simplicity:

- Lower start-up and operational costs
- Less moving parts
- Having a fixed cargo box
- Lower maintenance costs

The larger single-unit trucks on average have a pallet capacity from twelve to eighteen pallets and 4000 to 9000 kilograms weight capacity. Due to the large number of pallets that were calculated in the reference model, the model uses the weight and pallets capacity of the DAF CF truck which can take 18 pallets and 9000 kg of payload[4].

Semi-trailer trucks are used by companies like Ahold to supply their supermarkets in urban areas. However, due to the increased complexity of operating them, it might be difficult to reach certain food banks. This research assumes that all food banks can be visited by a semi-trailer truck. The truck considered in the solution analysis has 33 pallets capacity and 24000 kg payload[5].

The output of the solution model is the distances of the constructed routes. To compare the costs of transport in the solution model with the reference model, a costs per kilometres value is needed. The earlier mentioned formula can only be used for smaller transport trucks and could therefore not be applied to the solution model. A report written by Panteia containing a detailed breakdown of fixed and variable costs for different types of temperature-controlled trucks was used to calculate the transport costs (Panteia, 2018). Table 11 shows an overview of the fixed costs (in euros/year) and variable costs (in euro/km) for both trucks derived from this report.

| | | | Single-unit truck | Semi-trailer truck |
|---|---|---|---|---|
| Fixed costs (€ per year) | | Total fixed costs | **€13387,-** | **€29567,-** |
| Variable costs (€ per km) | Fuel/tires | Fuel | 0,2928 | 0,3589 |
| | | Tires | 0,0201 | 0,0282 |
| | | **Total** | **€0,3129** | **€0,3871** |
| | Other variable costs | Depreciation | 0,1498 | 0,2106 |
| | | Maintenance | 0,0504 | 0,076 |
| | | **Total** | **€0,2002** | **€0,2866** |
| | | Total variable costs | 0,5132 | 0,6737 |
| Personnel costs (€ per hour) | | Costs | €27,55 | €27,55 |

*Table 11: Overview of variable and fixed coss parameters per truck (Panteia, 2018).*

The reference model distinguishes between fixed costs and fuel costs. The food banks included depreciation and maintenance in their fixed costs even though they are listed here as variable costs. Therefore, to accurately compare the results of both models, the results of the solution model are first multiplied with fuel and tire costs only. This equals 0,3129 euros/km for the single-unit truck and 0,3871 euros/km for the semi-trailer truck. However, to provide insights for the food banks into the total costs made with these larger trucks. The result section also provides an overview of a situation where both depreciation and maintenance costs are considered together with fuel and tires costs which would equal 0,5132 euros/km for the single-unit truck and 0,6737 euros for the semi-trailer truck. Lastly, the situation is calculated where food banks also would have to pay for personnel which costs 27,55 euros per hour.

Finally, a baseline scenario is modelled to show the fastest route to supply each food bank given that a truck has no capacity limit. To conclude, the following scenarios are modelled:

(1) Baseline scenario
(2) A single-unit truck supplying each food bank.

[4] https://www.daf.nl/nl-nl/trucks/daf-cf#downloads
[5] http://bestshippingservice.co.uk/types-of-trucks-and-trailers/

(3) A semi-trailer truck supplying all food banks.
(4) A single-unit truck supplying the five biggest food banks.
(5) A semi-trailer truck supplying the five biggest food banks.

For each scenario, the model is run for the normal demand and the situations where demand increase by 10%, 25% and 50%.

## 6.4 Results

This part presents the results of the solution model for each scenario. Furthermore, the results are compared with the results of the reference model. First, the results of the baseline scenarios are presented. Then, for each scenario, an overview table is given stating the outputs of the model in the current demand situation. After this, scenarios (2 and 3) and (4 and 5) are grouped together for comparison with the reference model. The presented results show both the distance and fuel costs savings. Another graph is included which shows the costs that would be made if all variable costs and personnel costs as stated in Table 11 are considered. Finally results about the length of the created routes are presented.

**Baseline scenario**
The baseline scenario calculates the fastest route to supply all food banks without taking truck capacity into account.

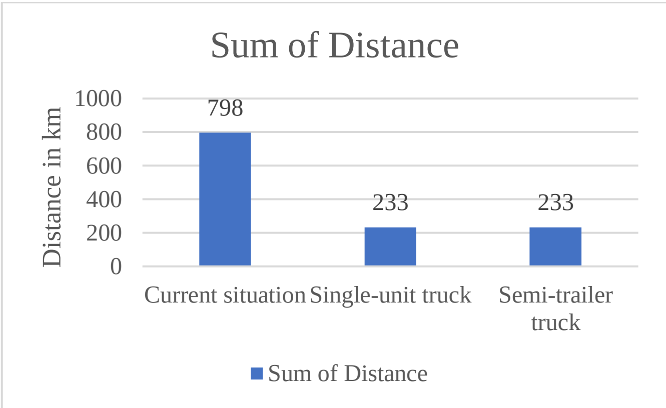


*Figure 21: Results baseline scenario, the fastest route to supply all food banks*

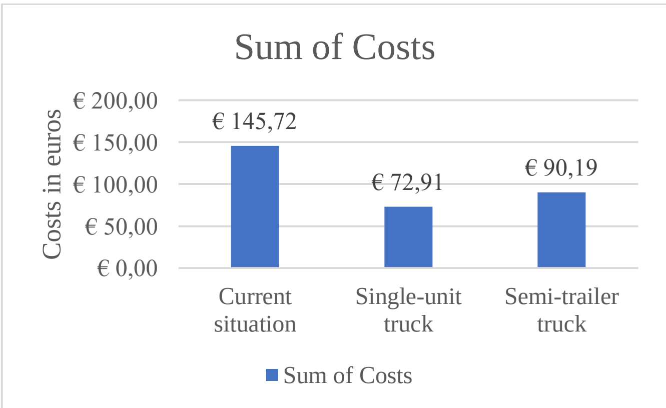


*Figure 22: Results baseline scenario, fuel/tire costs of the fastest route to supply all food banks*

As expected the single-unit truck and semi-trailer truck both cover 233 kilometres since they supply all food banks in one route. The model calculated the fastest route to supply all food banks as:

Depot > Vaassen > Zutphen > Rijssen Holten > Midden-Twente > Enschede > Losser > Oost-Twente > Almelo > Hellendoorn > Raalte > Depot

The food banks all perform a direct delivery to the RDC which means that together, they drive a total of 798 kilometres as a minimum to supply each food bank. Finally, the single-unit truck operates with fewer fuel costs to drive the complete route.

Figure 23 and Figure 24 show the same results for the scenario which only considers the top five food banks in the collective transport network. The fastest route to supply the top five food banks takes 158 kilometres. This route is:

Depot > Losser > Enschede > Oost-Twente > Midden-Twente > Almelo > Depot

The total driven distance by all food banks in the current situation is 554 kilometres. The costs allocation follows the same trend as previous graphs.

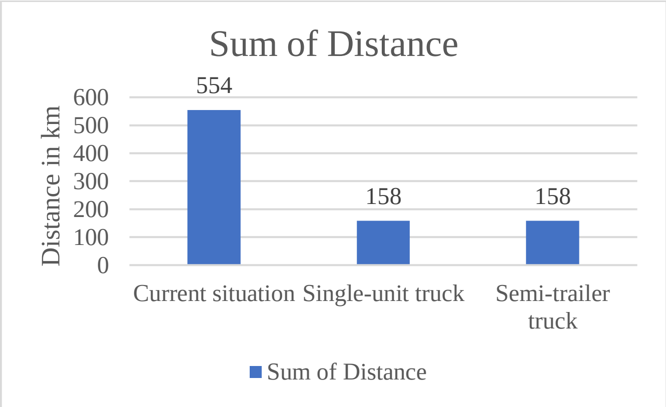


*Figure 23: Results baseline scenario, the fastest route to supply the top five food banks*

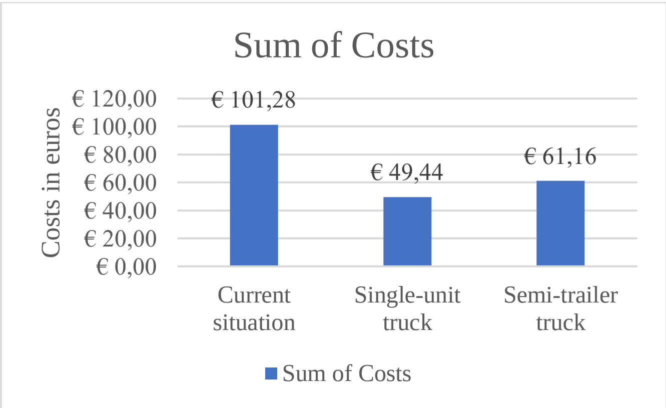


*Figure 24: Results baseline scenario, fuel/tire costs of the fastest route to supply the top five food banks*

**Output scenarios**

Besides the baseline scenario, four different scenarios are analysed. Table 12, Table 13, Table 14 and Table 15 show the outputs of the model for each scenario given the current demand. The outputs for the different demand scenarios can be found in 9Appendix D. Note that due to the limitations described in §6.2 the total number of pallets per scenario is lower than the reference model.



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| | Mon | Tue | Wed | Thu | Fri | Sat | Total |
|---|---|---|---|---|---|---|---|
| *Trips* | 4 | 7 | 155 | 96 | 17 | 5 | 284 |
| *Distance sum (km)* | 785 | 932 | 19515 | 14241 | 2506 | 728 | 38707 |
| *Distance avg (km)* | 196 | 133 | 126 | 148 | 147 | 146 | 136 |
| *Pallets sum* | 54 | 85 | 2361 | 1327 | 157 | 76 | 4060 |
| *Pallets avg* | 13,5 | 12,1 | 15,2 | 13,8 | 9,2 | 15,2 | 14,3 |
| *Weight sum* | 7178 | 15346 | 540856 | 260178 | 33595 | 17253 | 874405 |
| *Weight avg* | 1794 | 2192 | 3489 | 2710 | 1976 | 3451 | 3079 |
| *Costs* | € 245 | € 291 | € 6.106 | € 4.456 | € 784 | € 227 | € 12.111 |

*Table 12: Output solution model. Single-unit truck supplying all food banks*

| | Mon | Tue | Wed | Thu | Fri | Sat | Total |
|---|---|---|---|---|---|---|---|
| *Trips* | 4 | 4 | 99 | 65 | 15 | 4 | 191 |
| *Distance sum (km)* | 712 | 780 | 14571 | 11714 | 2356 | 587 | 30720 |
| *Distance avg (km)* | 178 | 195 | 147 | 180 | 157 | 147 | 161 |
| *Pallets sum* | 54 | 85 | 2393 | 1335 | 157 | 77 | 4101 |
| *Pallets avg* | 13,5 | 21,3 | 24,2 | 20,5 | 10,5 | 19,3 | 21,5 |
| *Weight sum (kg)* | 7178 | 15346 | 540856 | 260178 | 33595 | 17253 | 874405 |
| *Weight avg (kg)* | 1794 | 3836 | 5463 | 4003 | 2240 | 4313 | 4578 |
| *Costs* | € 275 | € 301 | € 5.640 | € 4.534 | € 912 | € 227 | € 11.891 |

*Table 13: Output solution model: Semi-trailer truck supplying all food banks*

| | Mon | Tue | Wed | Thu | Fri | Sat | Total |
|---|---|---|---|---|---|---|---|
| *Trips* | 4 | 4 | 107 | 68 | 15 | 4 | 202 |
| *Distance sum (km)* | 562 | 608 | 14060 | 9679 | 2100 | 531 | 27540 |
| *Distance avg (km)* | 141 | 152 | 131 | 142 | 140 | 133 | 136 |
| *Pallets sum* | 31 | 53 | 1496 | 802 | 125 | 48 | 2555 |
| *Pallets avg* | 7,8 | 13,3 | 14,0 | 11,8 | 8,3 | 12,0 | 12,6 |
| *Weight sum (kg)* | 4444 | 10072 | 351206 | 162463 | 26498 | 11349 | 566032 |
| *Weight avg (kg)* | 1111 | 2518 | 3282 | 2389 | 1767 | 2837 | 2802 |
| *Costs sum* | € 175 | € 190 | € 4.399 | € 3.028 | € 657 | € 166 | € 8.617 |

*Table 14: Output solution model: Single-unit truck supplying top five food banks*

| | Mon | Tue | Wed | Thu | Fri | Sat | Total |
|---|---|---|---|---|---|---|---|
| *Trips* | 3 | 4 | 67 | 51 | 14 | 3 | 142 |
| *Distance sum (km)* | 474 | 562 | 9589 | 7806 | 1992 | 424 | 20847 |
| *Distance avg (km)* | 158 | 141 | 143 | 153 | 142 | 141 | 147 |
| *Pallets sum* | 31 | 53 | 1526 | 810 | 128 | 49 | 2597 |
| *Pallets avg* | 10,3 | 13,3 | 22,8 | 15,9 | 9,1 | 16,3 | 18,3 |
| *Weight sum (kg)* | 4444 | 10072 | 351206 | 163610 | 27601 | 11349 | 568282 |
| *Weight avg (kg)* | 1481 | 2518 | 5242 | 3208 | 1972 | 3783 | 4002 |
| *Costs sum* | € 183 | € 217 | € 3.711 | € 3.021 | € 771 | € 164 | € 8.069 |

*Table 15: Output solution model: Semi-trailer truck supplying top five food banks*

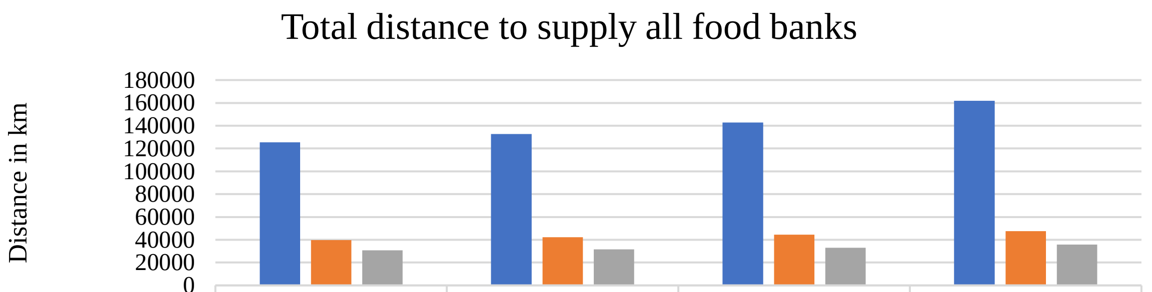
The output of the models for the different scenarios has been introduced. These outputs are compared to the results of the reference model. To accurately compare the outputs of both models, the limitations of the solution model should be minimized as much as possible. One limitation stated that customer demand cannot exceed the capacity of a truck. This was solved by reducing demand to the capacity of the truck. Table 16 shows how often this happened per foodbank per scenario. As demand levels increase, the number of times that the capacity of a truck is exceeded increases as well. This would result in lower costs for the solution scenarios as less demand needs to be transported. Therefore, to make a more accurate comparison, the assumption is made that if demand exceeds a truck's capacity, that truck will make a second drive to that food bank alone. The resulting extra kilometres are listed in the last column. They are added to the results of the model to make an accurate comparison with the reference model. Unfortunately, the other limitation could not be solved due to the increased complexity of adjusting the model. Because of this, the results of the solution model are slightly worse than when these limitations would have been cared for.

| | **Almelo** | **Enschede** | **Midden-Twente** | **Zutphen** | **Extra distance (km)** |
|---|---|---|---|---|---|
| *Retour trip (km)* | 92 | 119 | 96 | 26 | |
| ***Single-unit truck:*** | | | | | |
| *Normal demand* | 0 | 8 | 0 | 1 | 981 |
| *Demand + 10%* | 1 | 12 | 0 | 1 | 1551 |
| *Demand + 25%* | 1 | 19 | 1 | 1 | 2483 |
| *Demand + 50%* | 2 | 22 | 5 | 2 | 3345 |
| ***Semi-Trailer truck:*** | | | | | |
| *Normal* | 0 | 1 | 0 | 0 | 119 |
| *Demand + 10%* | 0 | 1 | 0 | 0 | 119 |
| *Demand + 25%* | 0 | 1 | 0 | 0 | 119 |
| *Demand + 50%* | 0 | 4 | 0 | 0 | 478 |

*Table 16: Number of times that the order of a food bank exceeded the capacity of a truck*

**Cost results of scenarios**

First, the results for the scenario where all food banks are supplied are discussed. Figure 25 compares the total driven distances to supply all food banks per truck per demand scenario. Figure 26 shows an overview of the costs made with transport for the different trucks. Note that these costs only consists of the fuel costs in the reference model and the fuel and tire costs in the solution scenarios. The results of the reference model (in blue) always refer to the current transport situation where each food bank individually transport its order from the RDC.




| | Normal demand | Demand + 10% | Demand + 25% | Demand + 50% |
|---|---|---|---|---|
| Reference model | 125421 | 132589 | 142696 | 161744 |
| Single-unit truck | 39688 | 42112 | 44597 | 47688 |
| Semi-trailer truck | 30839 | 31652 | 33019 | 35695 |

*Figure 25: Distance outputs of the reference model and solution model considering all food banks*



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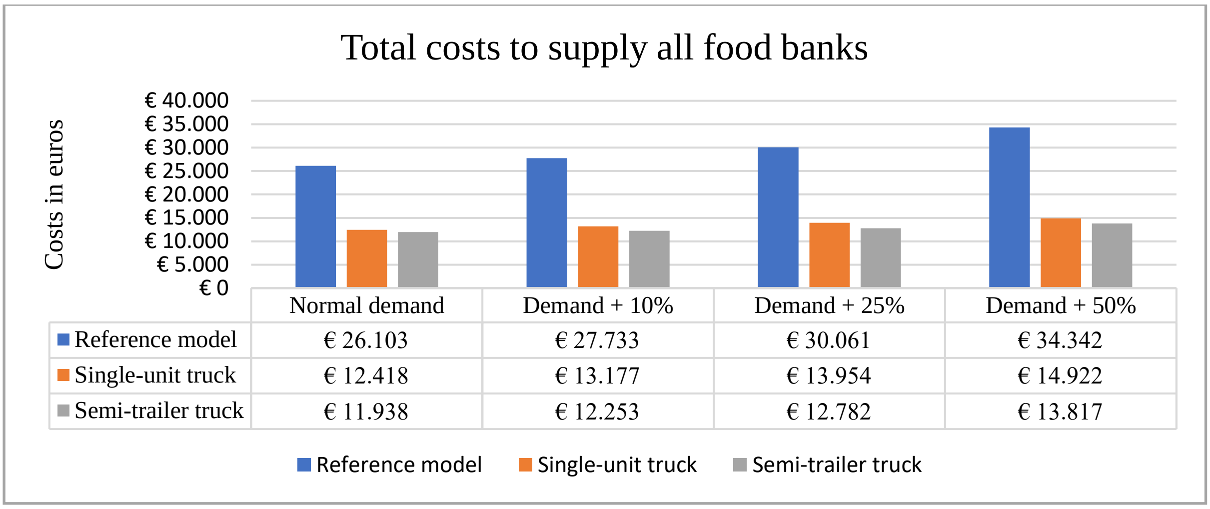


*Figure 26: Costs output of the reference model and solution model considering all food banks*

A comparison of the results reveals that both collective transport scenarios were able to supply all food banks covering less distance and making fewer costs. Considering normal demand, the single-unit truck reduces 68% in total distance and the semi-trailer truck reduced 75% in total distance. This result may be explained by the fact that the semi-trailer truck has the largest capacity and therefore needs fewer trips to visit all food banks which minimizes the total driven kilometres. The costs saving for the single-unit truck are 13685 euros (52%) and 14165 euros (54%) compared to the reference model. The costs savings is lower than the distance savings which is a result of higher fuel costs per kilometre for the larger trucks compared to the small trucks used in the reference model. Furthermore, the difference between the single-unit truck and the semi-trailer truck is levelled because the fuel costs per kilometre are higher for the semi-trailer truck. Finally, Table 17 shows the costs increase in percentages for the different demand scenarios.

| ***Demand increase:*** | **Demand + 10%** | **Demand + 25%** | **Demand + 50%** |
|---|---|---|---|
| *Reference model* | 106,25% | 115,16% | 131,56% |
| *Single-unit truck* | 106,11% | 112,37% | 120,16% |
| *Semi-trailer truck* | 102,64% | 107,07% | 115,74% |

*Table 17: Costs increase in % per demand scenario considering all food banks*

The costs made with the current transport network grows fastest as demand increases. Followed by the single-unit truck which increases 20,16% against a demand increase of 50%. Finally, the semi-trailer truck performs best, only increase 15,74% in costs when demand increases by 50%. This could be explained by looking at the average pallets per trip in Table 13 which lays around 20. This means that the semi-trailer has a lot of space and therefore did not have to construct many new routes when demand increased. Note that even though the semi-trail truck performed best, the difference between the single-unit truck is always less than 1000 euros.

Next are the same two charts for the scenarios that considered the top five food banks in the collective transport network. The output of the solution model is compared with the costs made by these five food banks in the reference model. Figure 27 shows the distance covered to supply these top five food banks and Figure 28 compares the fuel costs of the top five food banks in the reference model with the fuel and tire costs made by the collective trucks when the top five food banks are supplied.

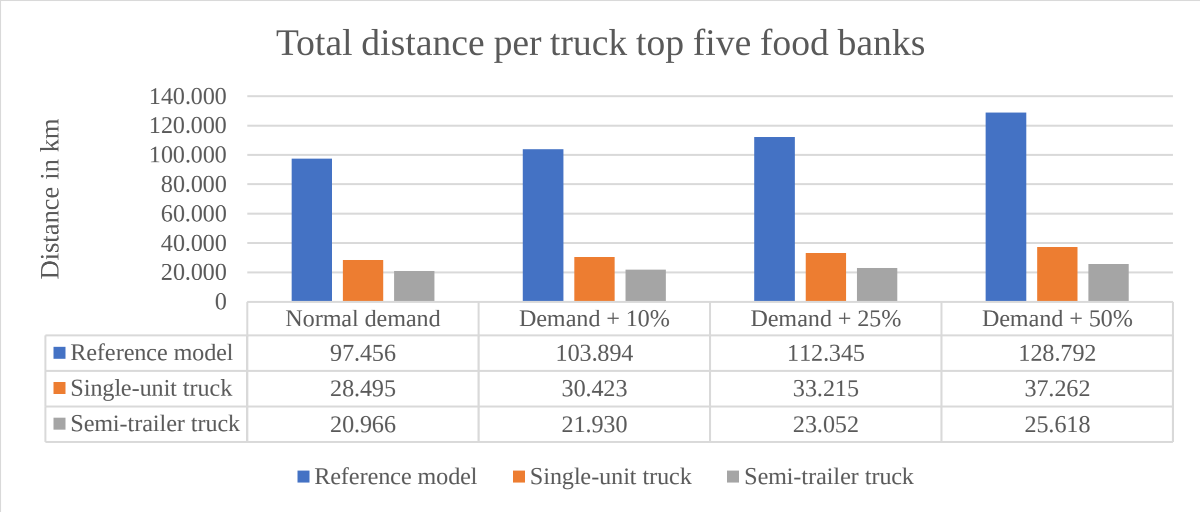


*Figure 27: Distance output of the reference model and solution model considering the top five food banks*

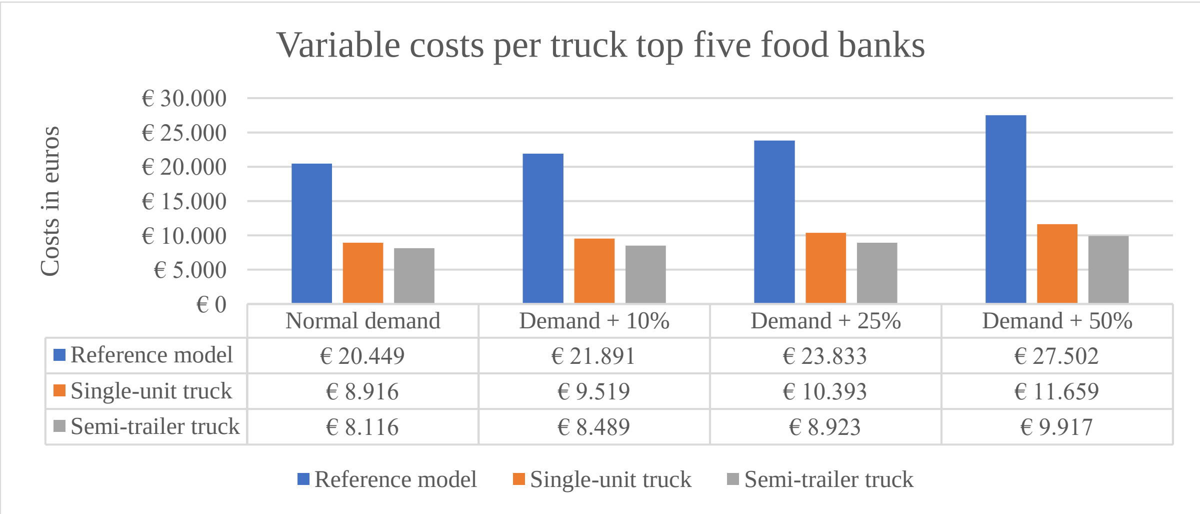


*Figure 28: Cost outputs of the reference model and solution model considering the top five food banks*

The costs savings in kilometres for the five biggest food banks are 12333 (56%) euros for the single-unit truck and 11533 (60%) for the semi-trailer truck in the current demand situation. Taking Figure 26 into account, it can be concluded that considering the top five food banks only still results in 85% of the costs savings. For Almelo, Enschede, Midden-Twente and Oost-Twente, these savings can be explained due to their size which required multiple trips to the RDC to transport one order. The costs for Losser, as one of the smaller food banks, originated from their distance to the RDC which resulted in substantial transport costs and thus large potential savings. Table 18 show the costs increase in percentages for the different increases in demand.

| ***Demand increase:*** | **Demand + 10%** | **Demand + 25%** | **Demand + 50%** |
|---|---|---|---|
| *Reference model* | 107,05% | 116,55% | 134,49% |
| *Single-unit truck* | 106,77% | 116,56% | 130,77% |
| *Semi-trailer truck* | 104,60% | 109,95% | 122,19% |

*Table 18: Costs increase in % per demand scenario, top five food banks supplied*

Identical as the previous scenario, the costs of the current transport network grows fastest. However, this time the single-unit truck also increases by 30,77%. This could be explained by the assumption that if demand exceeds the capacity of a truck, the truck will make an extra trip to that food bank. Table 16 shows that this occurs most often for the single-unit truck for the food banks Enschede and Midden-

Twente. As demand increases, the number of times that this occurs increases as well. Furthermore, since only five food banks are considered in this scenario, the added distances have more effect on the total driven kilometres.

Given that considering only the top five food banks in the collective network still provides 85% of costs savings that would be achieved when all food banks are considered, it might be more desirable to first consider these five food banks in a collective transport network for the following reasons. The contextual analysis explained that food banks included in a collective transport network need to accommodate their schedules to each other with regards to the days and timings on which orders are being transported. A food bank can only receive an order if it has available volunteers on that day/time available. First, considering only five instead of ten food banks makes it easier to agree on these days. Second, the group of five contains four of the larger food banks which are accustomed to being open on multiple days and for larger times per week. This makes them more flexible to operate under a collective network. Finally, the savings per food bank would be higher when only the top five food banks are considered.

The fuel costs of the reference model have been compared with the fuel and tire costs of the different collective transport scenarios, which was the focus of this research. It has been concluded that collaborating on transport results in substantially lower fuel costs for both the single-unit truck and the semi-trailer truck. The semi-trailer truck performed slightly better than the single-unit truck but the differences were minimal. Next, to this comparison on fuel costs, Table 11 provided values for other variable cost parts included in operating a larger truck as well as the fixed costs of these trucks. These numbers are used in the next part to provide insights into the total cost overview of operating the larger trucks. The different costs presented are:

- Fuel and tire costs (same numbers as previously presented)
- All variable costs (fuel, tire, depreciation and maintenance costs)
- All variable and fixed costs
- All variable, fixed and personnel costs (27,55 euros/hour)

Assumed is that a driver is needed for three days per week working eight hours per day for 48 weeks per year resulting in 1152 working hours to supply all food banks. To supply the top five food banks, around two-thirds of the distance is driven so it is assumed that two-thirds of the total number of hours is needed. These results need to be interpreted with caution as they are broad averages derived from the report.

Figure 29 compares the different costs when all food banks are supplied and Figure 30 compares the costs when only the top five food banks are supplied.

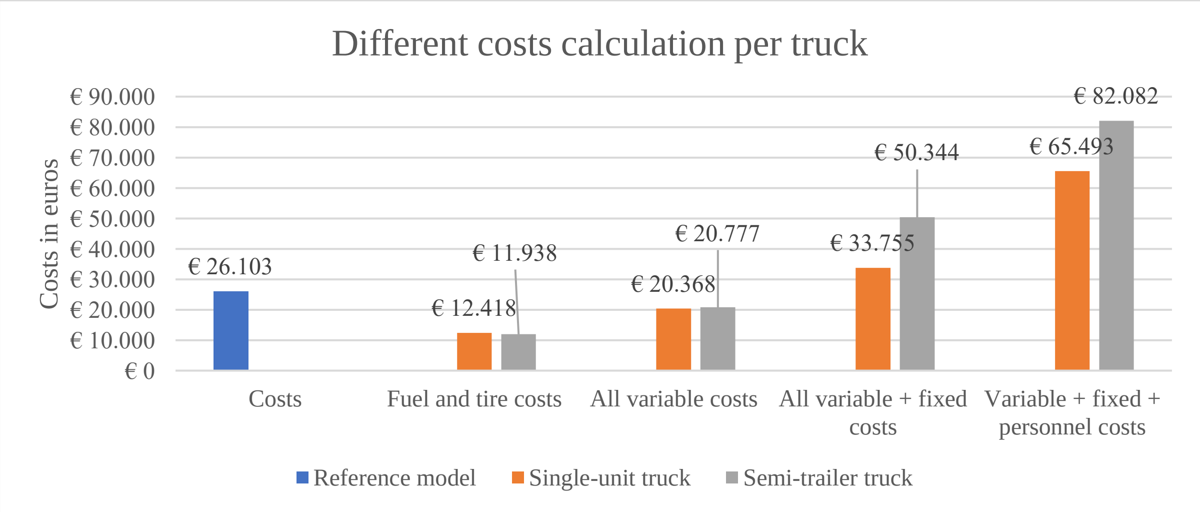


*Figure 29: Different cost calculation of solution model compared with costs output of the reference model considering all food banks*



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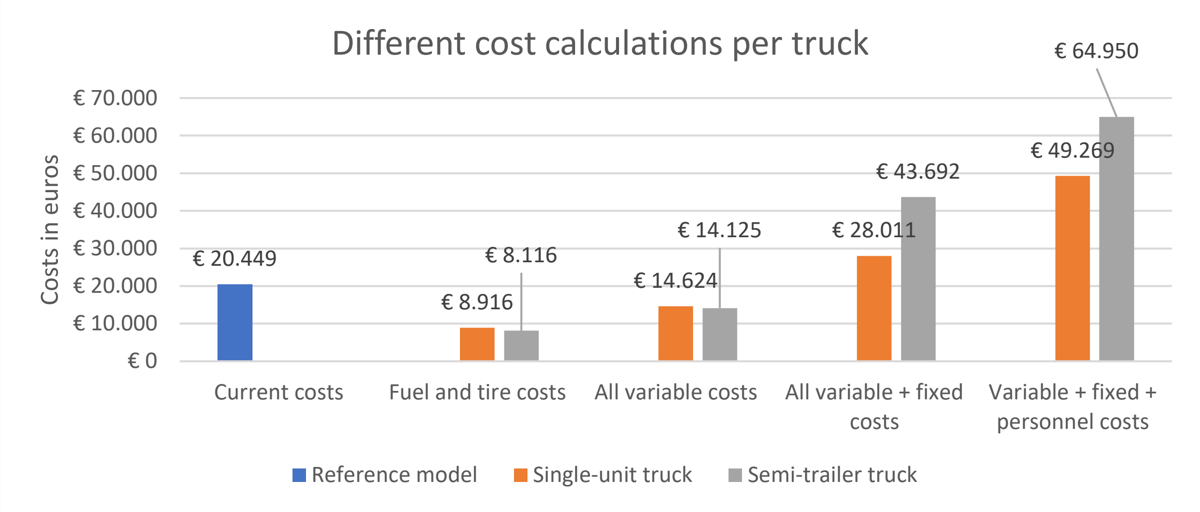


*Figure 30: Different cost calculations of solution model compared with costs output of the reference model considering the top five food bank*

Finally, Table 19 shows the allocation of the costs to its components.

| | Single unit truck | | Semi-trailer truck | |
|---|---|---|---|---|
| | All food banks | Top five | All food banks | Top five |
| Fixed | €13387 | €13387 | €29567 | €29567 |
| Fuel and tire | €12418 | €8916 | €11938 | €8116 |
| Depreciation | €5945 | €4269 | €6495 | €4416 |
| Reparation and maintenance | €2001 | €1436 | €2344 | €1593 |
| Personnel costs (1driver, three workdays) | €31738 | €21258 | €31738 | €21158 |
| **Total** | €65493 | €49269 | €82082 | €64950 |

*Table 19: Allocation of all costs to different components*

When all variable costs are considered supplying all food banks costs €20368 with the single-unit truck and €20777 with the semi-trailer truck which is around 80% of current fuel costs. When the top five food banks are supplied, these numbers are €14642 and €14125, around 75% of the current fuel costs. When both fixed and variable costs are taken into account, supplying all food banks with the single-unit truck sums up to €33751 and with the semi-trailer truck: €50344. Supplying only the top five food banks results in €28008 and €43692 respectively. Here, a clear distinction exists between the single-unit truck and the semi-trailer truck as a result of the larger fixed costs for the semi-trailer truck. Subtracting the fuel costs in the current situation from the total fixed and variable costs of the single-unit truck, the remaining costs when all food banks are supplied is 7652 euros and when the top five food banks are supplied it is 7552 euros. This equals the current fixed costs of two small trucks operated by food banks. If they could reduce fixed costs by disposing of two or more of their small trucks, the savings could be used to cover these final costs and make the collective network more efficient.

The depreciation costs were included in the variable costs which provided different total results for each scenario. For the single-unit truck, this resulted in yearly depreciation costs of €4269,-. This number however depends on the kind of truck that will eventually be bought/leased. Therefore, the different cost items were made comprehensible to provide the possibility of calculating a total cost overview when different prices are used. Finally, an issue that emerges from these findings is the personnel costs. When they are included, the costs of operating each of the collective transport scenarios grows too big. Therefore, one prerequisite of operating a collective transport network is the existence of a volunteer with the correct driver's licence to operate the truck.

**Distances**

All the cost results have been discussed and it can be concluded that substantial savings can be achieved via the collective transport network. The final results contain information about the distances of orders and trips. Recall that an order in the collective transport network refers to all the products that were shipped on a single day. A trip refers to a single route of a truck. An order can be transported either via one or multiple trips. This data is relevant since the distance that can be driven by one truck and driver per day is limited. The maximum continuous driving time should not exceed 4.5 hours. After 4,5 hours of driving, a mandatory break of 45 minutes should be held (Rijksoverheid, 2021).

The following scenarios are considered in this order: The single-unit truck supplying all food banks, the semi-trailer truck supplying all food banks and the single-unit truck supplying the top five food banks. Per scenario, three graphs are used to provide information about the distances. Finally, normal demand is considered for each scenario.

First, the single-unit truck supplying all food banks is considered. Figure 31 shows a scatter plot containing the distances of all the individual trips. The x-axis counts the trips and the y-axis shows the distance in kilometres per trip. The average distance per trip is 136 kilometres. The maximum distance of a trip equals the minimum distance to supply all food banks in one trip, 233 kilometres. Assuming a truck drives an average of 50 kilometres per hour and loading times per food bank are 20 minutes. It would result in a total of 8,5 hours without the mandatory break and 9 hours and 15 minutes with the break to supply all the food banks. This is little more than an average workday and if the food banks want to use volunteers for transport, likely, working days of more than 9 hours are not desirable.

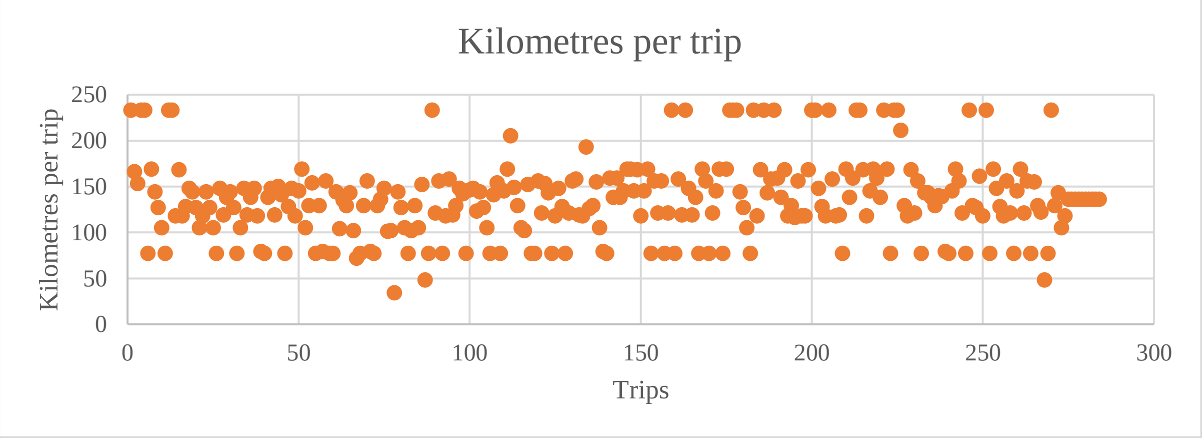


*Figure 31: Distance per trip for the single-unit truck considering all food banks*

Figure 32 shows a histogram that counts how many orders were transported in a certain kilometres interval. Note that the maximum distance of a single trip equals 233 kilometres which means that all the orders in an interval higher than this number are transported by multiple trips. As explained above, trips that supplies all food banks already take long if one truck is used for the complete day. This means that the orders that take 300 km or more are not possible to transport with on truck on one day. Note that these big orders consist of multiple independent trips and therefore this problem can be approached in two ways. Using one truck and dividing the trips amongst multiple days in the week. This requires both the availability of food at the RDC to maintain these continuous shipments as well as the accessibility of different food banks to process orders on multiple days per week. A second truck could be used as well. However, this would increase fixed costs as well as the need for an extra driver.



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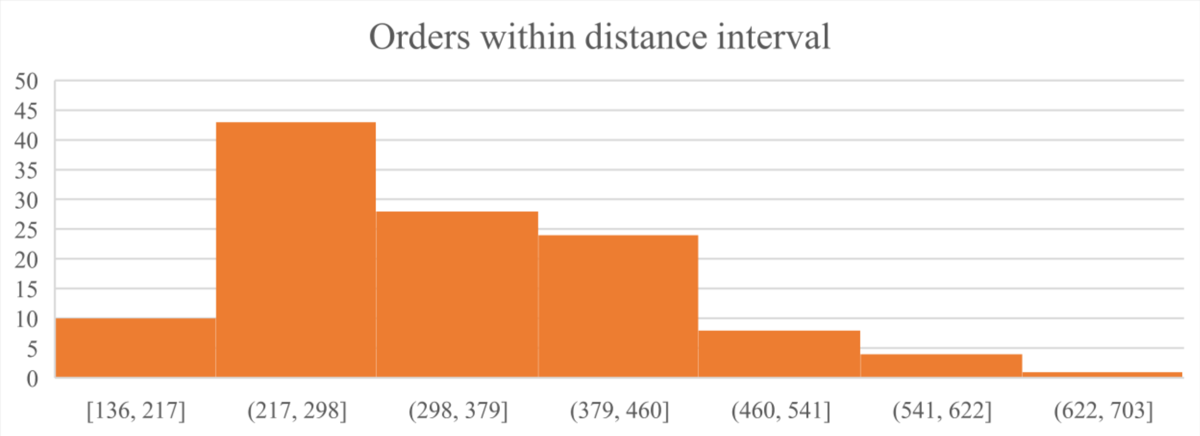


*Figure 32: Count of the number of orders within a distance interval for the single-unit truck considering all food banks*

Next, the same two graphs are presented for the scenario that considers the semi-trailer truck supplying all the food banks. Figure 33 shows the distances per trip. For the semi-trailer truck supplying all food banks, the average distance per trip was 160 kilometres. More often, a route was constructed that supplied all food banks together. This can be explained by the larger capacity of the semi-trailer truck which enables it to transport more orders together on a single trip. However, an increase in the number of routes that supply all food banks means that the semi-trailer truck would more often face the problem of having to perform these large trips that require more than nine hours to execute.

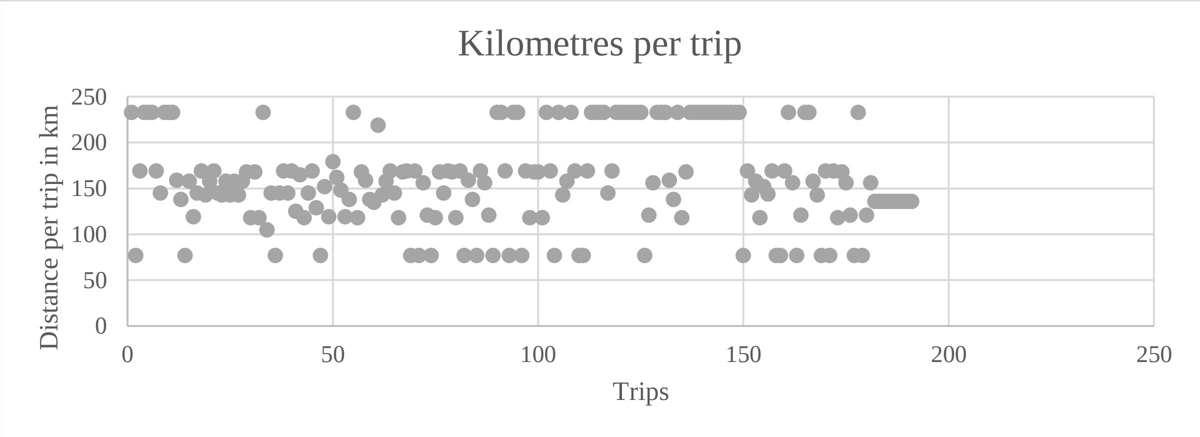


*Figure 33: Distance per trip for the semi-trailer truck considering all food banks*

Figure 34 shows the number of total orders transported within a certain kilometre interval. More orders were transported covering less distance compared to the single-unit truck.

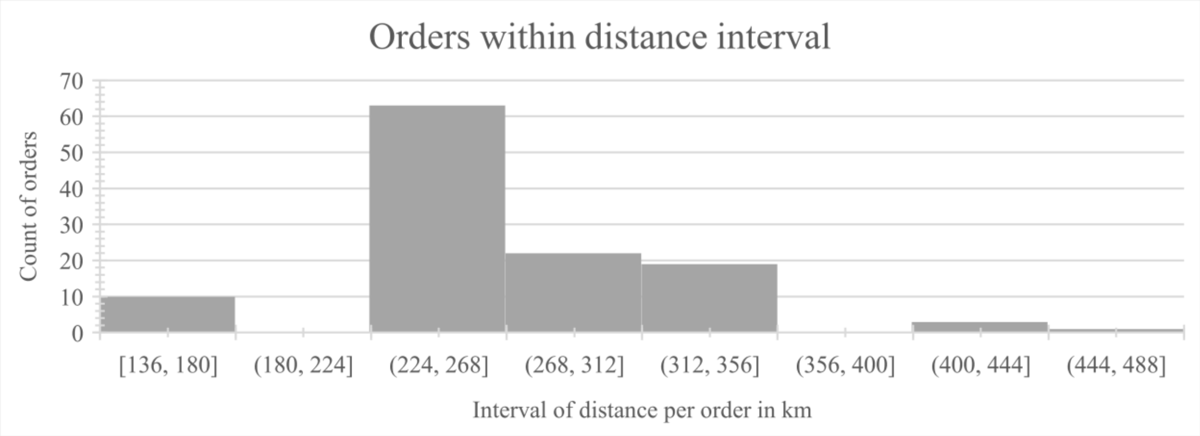


*Figure 34: Count of the number of orders within a distance interval for the semi-trailer truck considering all food banks*

Finally, the scenario considering the top five food banks supplied by a single-unit truck is presented. Figure 36 shows the distances per trip which, instead of 233 kilometres, only equals 158 kilometres. Therefore, to supply the top five food banks with an average speed of 50 kilometres per hour and loading times of 20 minutes per food bank would result in a duration of 5 hours. Therefore, a break of 45 minutes should be added which results in a total of 5 hours and 45 minutes to supply the top five food banks. A large reduction compared to the 9 hours and 15 minutes in the scenarios where all food banks were supplied.

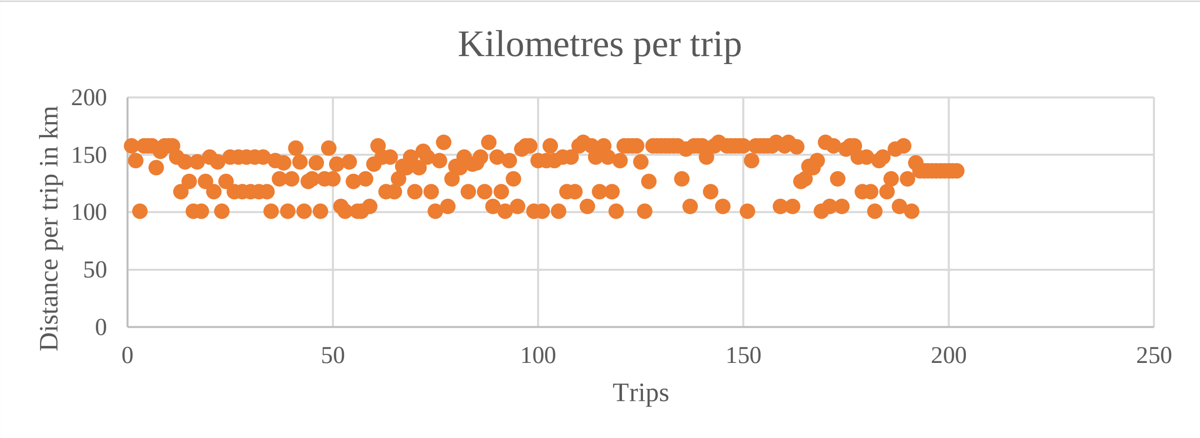


*Figure 35: Distance per trip for the single-unit truck considering the top five food banks*

Figure 35 shows that most of the orders were transported using one trip. Note again that the orders containing more than 158 kilometres had to be transported on multiple trips. However, since fewer food banks are considered in this scenario, it is easier to split up an order into multiple trips while still being able to transport all the orders with one truck without using an unrealistic amount of time for transport.

Therefore, from the perspective of the length of the constructed routes, the scenario considering only the top five food banks is chosen more desirable over the scenario where all food banks are supplied.

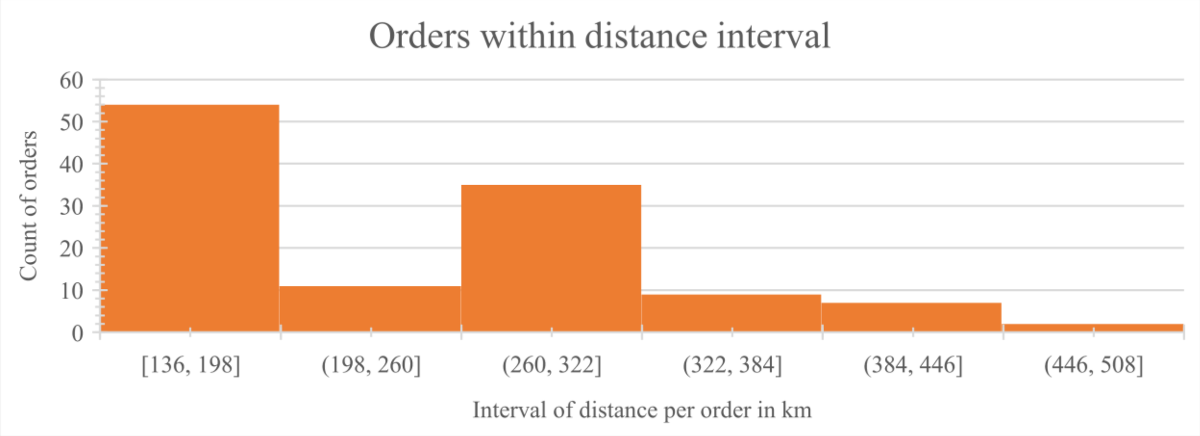


*Figure 36: Count of the number of orders within a distance interval for the single-unit truck considering the top five food banks*

All the results from the model have been presented and discussed. Finally, a discussion on several important aspects related to this solution model is provided.

The model uses the output from the reference model to test how alternative transport scenarios would perform given the same demand by food banks. It thereby focuses only on constructing routes with minimal distance which minimizes the variable transport costs. Given a certain input, the model functions accordingly and thus provides a feasible output. However, to construct the input parameters, several big estimations were made to continue this research. These estimations were made as accurate as possible given the available information but should be made aware of when interpreting and discussing the results. The first estimation considers the number of pallets per order calculated in the reference model. The context analysis explained that on average, weight and not pallets was the limiting constraint in transport. However, for the trucks considered in this solution analysis pallets is often the limiting factor. Table 12 shows the average amount of pallets per trip for the single-unit truck on Wednesday to be 15,2 (84% of capacity) while the weight on average is 3498 kilograms (38% of capacity). This makes the estimated number of pallets in the reference model much more important in the solution analysis.

The second estimation relates to the costs per kilometre. The output of the model contains distances and to calculate the variable costs, a single variable was multiplied with these distances. The usage of such an average is not desirable when the number is of such importance. However, the real variable transport costs are likely to lay somewhere around the values computed in this research.

The model had several limitations which influenced its outcome. The limitations were either solved in favour of the current transport network or left the way they were. Thereby preventing false results from the solution analysis that makes the collective transport network seems better than it is.

The solution model constructed the optimal route/routes to supply each food bank given a certain demand. Since these demands are constantly changing, the model constructed many different routes to supply food banks. In real life, this might not be a desirable situation. Constructing different routes means that food banks receive their order at different times each week. To make this work, a food bank needs to be able to process an order in a wide time interval per day. As explained, for the smaller food banks, this might cause problems due to their dependency on a limited pool of volunteers.

Finally, given the scope, this research limited the number of analysed scenarios to four considering two types of trucks and two groups of food banks. Given a scenario, the model calculated the optimal results. However, there is no evidence that the four chosen scenarios are the optimal scenarios for collaborating on transport. It could be that alternative scenarios considering other groups of food banks or other types of trucks would result in better outputs of the model.

**Leading scenario**

The problem-solving approach stated that part of the result delivery included a recommendation on the best scenario. Based on the discussion above, the single-unit truck supplying the top five food banks is identified as the most desirable scenario to operate a collective transport network for the following reasons:

- Compared to the semi-trailer truck:
    - The variable costs savings are almost the same
    - The truck is easier to operate
    - The fixed costs are lower
- Compared to supplying all food banks:
    - The operational activities are easier to plan for less/larger food banks
    - Ensured that one truck is sufficient to supply the food banks as a result of the lower total distance that needs to be covered.
    - Total costs savings is around 2000 euros less but proportional cost savings is greater meaning that the savings per food bank are greater

The best performing scenario is identified. Finally, the results of this scenario compared against the fuel costs of the current top five food banks are summarized.

- Considering only fuel costs, the single-unit truck saved 12333 euros.
- Considering all variable costs, the single-unit truck saved 5825 euros
- Considering the fixed and variable costs, the single-unit truck costs 7562 euros more

## 6.5 Conclusion

This chapter introduced the solution model that was used to solve the CVPR for the food banks. First, a formal definition of the CVRP was provided. Then, the solution model was explained and its limitations were outlined. The different scenarios were outlined. Finally, the order data output of the reference model was used as input for the solution model to analyse and compare the performance of the different collective transport scenarios with the results of the cost from the reference model. The estimations made in the model were discussed along with the other points of attention when considering a collective network.

This discussion identified the single-unit truck supplying the top five food banks as the favourite collective transport scenario. It provides substantial fuel costs savings compared to the fuel costs in the current situation. The combined fixed and total costs of the single-unit truck do exceed the fuel costs made in the current situation. To decide if it would be beneficial to operate this collective transport network, information from the food banks is needed which should state whether they can reduce the number of small trucks to compensate for the fixed costs of the single-unit truck. Also, the different cost items were made comprehensible to provide the opportunity to the food banks to calculate the exact cost overview once the investments for such a single-unit truck are known. Finally, this analysis rests on one assumption: No personnel costs are made. The inclusion of personnel costs increases the costs of operating a collective transport network by more than 100% which makes it a less appealing alternative compared to the current situation.

# 7 Conclusions and recommendations

Within this thesis, a full step-by-step approach for improvising a transport network was executed. Through, qualitative data gathering the different processes affecting the transport network of the food banks were identified. Quantitative data was gathered and processed into a reference model which showed the performance of the current transport network. The desired solution was identified as a CVRP and a solution model was used to test collective transport scenarios over historical data. The performance of these scenarios was compared with the results of the reference model. Each step provided answers to the sub-questions formulated in the introduction. §7.1 answers the main research question of this thesis. §7.2 outlines the limitations of this research. §7.3 provides recommendations to the food banks. §7.4 explains the scientific contribution of this research. Finally, §7.5 explains the directions for future research.

## 7.1 Main research questions

The food banks proposed the desired situation consisting of one collective transport network that would supply all the food banks. The goal of this research is to provide an answer to the main research question:

*What are the needs to promote transport collaboration via a collective transport network among food banks in the region Twente-Salland?*

This research showed the complex environment in which the problem exists and the different aspects that influence the answer to this question. Because of the scope and the limitations of this research, the decision was made to provide an analysis of the performance of the current transport network and compare those results with collective transport scenarios. This analysis left the operational activities, needed to make collaborating on transport work, out of consideration. Without an understanding of how these operational activities should be performed, the research question cannot be answered completely. However, this research did provide a first indication of the efficiency of a collective transport network compared to current transport. Therefore, the remainder of this answer is constructed from the perspective of the analysis performed in this research. This should be interpreted as general advice on the direction food banks should head regarding collaboration on transport. §7.3 will list the operational implications that need further investigation or detailed interpretation by the food banks before making the final decision to operate a collective transport network.

The results of the reference model provided insights into the costs that were made with transport as well as the volumes of orders that were transported from the RDC under different demand scenarios. The solution model showed how a collective transport network could have performed considering the same demand scenarios. By comparing the results of the reference model with the results of the solution model, this research showed that operating a collective transport network results in lower variable costs for each considered collective scenario. The single-unit truck supplying the top five food banks was chosen as the most desirable scenario for the following reasons:

- Compared to the semi-trailer:
  - The variable costs savings are almost the same
  - The truck is easier to operate
  - The fixed costs are lower
- Compared to supplying all food banks:
  - The operational activities are easier to plan for less/larger food banks
  - Ensured that one truck is sufficient to supply the food banks
  - Total costs savings is around 2000 euros less but proportional cost savings is greater meaning that the savings per food bank are greater

Currently, the top five food banks spent 20449 euros on fuel costs for transport to the RDC. Operating a single-unit truck to supply these five food banks would reduce fuel costs by 11533 euros. When demand increased to 50%, total savings on fuel costs increased to 15643 euros indicating that the collective transport network is better resistant against demand increases. Comparing all variable costs of a single-unit truck with solely the fuel costs of the current transport, the single-unit truck still saved 5825 euros. An estimation of personnel costs was provided since a C driver license is needed to operate the single-unit truck. These costs were estimated to be 21258 euros, already more than food banks currently spent on fuel. Therefore, food banks should find a way to remove or reduce these costs by finding a volunteer with the correct driver license. The fixed costs incurred with operating the single-unit truck were estimated to be 13387. The top five food banks together spent around 42000 on fixed costs. As an autonomous organization, each food bank is free to decide what to do with its trucks. However, if the top five food banks would be willing to allocate one-third of their fixed costs to the collective transport network by disposing of some of their trucks, the fixed costs of this network are covered. Therefore, the final decision on whether a collective transport network is actually more efficient depends on the ability and willingness of the individual food banks to reduce their own number of trucks to cover the fixed costs. All in all, this research showed that substantial reduction in variable costs can be achieved through collaboration on transport which indicates that further research on this topic is worthwhile. Supplying the top five food banks with a single-unit truck was identified as the most desirable scenario. However, this conclusion is only valid when assumed that no personnel costs are included.

## 7.2 Limitations

The results of this thesis rely heavily on the quantitative data used in both the reference model and the solution analysis. It is unsure if the order data from the ERP systems are all-inclusive. Besides this, the lack of quantitative data on the number of pallets used for transport required estimations. The solution analysis showed that pallets were often the limiting capacity for the larger trucks which increased the importance of this estimation. To provide more accurate results, ideally, the number of pallets used for transport was included in the ERP data. Finally, the calculation of the costs in the reference model relied on a formula that included the weight of the truck. However, the solution analysis used broad costs per kilometres values to calculate costs. This means that weight was not taken into account when calculating these costs. Ideally, a more accurate and detailed way of calculating costs in the solution analysis was used.

This research was conducted at food bank Almelo and most of the contact was with people from the food bank Almelo. The reference model was validated only by stakeholders from food bank Almelo. This might have resulted in a bias on those results, thereby risking the possibility that the results do not represent all the food banks. It would be better to include all the food banks in the region throughout the process to take the different opinions into account and avoid any bias.

The generalizability of this research is limited. The whole process from gathering data into the reference model to calculate collective scenarios with the solution model has been explained. However, this process requires many manual computations within the process to make sure that certain parts of the codes are executed correctly. Not only does reproducing the complete research take a considerable amount of time. The code used in the model is often situation-specific. Therefore, the code should be modified if different quantities of data are used. This makes it difficult to generalize this research to other organizations without having a clear understanding of the complete process.

As already noticed in the previous section, not every aspect that is important in answering the main research question could be taken into account due to the scope of this research. The focus was placed on providing a broad overview of the costs made with the current transport network and the costs that would be made in the collective transport network. This neglects the qualitative aspects as well as the operational activities that influence the design of a collective transport network.

Finally, the effects of the expected increases in demand on the transport network from the RDC were investigated. This investigation concluded that it was unsure if demand would actually increase and if it does, how the transport network would be affected by that. Therefore, scenarios were modelled which increased the weight values of the historical data by 10%, 25% and 50%. This approach assumes that the same days and timing of transport are used, even when demand increases by 50%. This resulted, for several large food banks, in an extremely high number of pallets per order. This is likely not the case in the actual situation as food banks would probably use other days for transport as well.

## 7.3 Recommendations

As explained in §7.1, the first part of the recommendations reflects on the operational implications of a collective transport network that should be further investigated:

Both a truck and driver should be found. This research showed that including personnel costs in the collective transport network results in a transport network that is too expensive. Therefore, a volunteer with a driving license C willing to operate the truck two or three times per week should be acquired. Once a single-unit truck is found, the depreciation costs in the results sections can be correctly adjusted to provide a more accurate costs overview.

The solution model of this research should be developed into a user-friendly tool that could be used by the RDC. This model should take demand data as input and provide optimal routes to supply the food banks accordingly. The amount of food that is supplied to the food banks varies a lot per week and the usage of this model gives control to the RDC to construct these routes and minimize costs.

Agree on the days within a week on which transport is performed. All parties should have enough volunteers available on those days to either prepare or process the orders. Then, the flexibility of the volunteers at the food banks on those days should be investigated. If enough volunteers are present throughout the whole day to process an order, the current model could be used as it does not take arrival timing at food banks into account. However, if food banks required the truck to arrive within a certain time interval as a result of the limited availability of volunteers. The problem transforms into a VRPTW and should therefore be modelled accordingly. This could be included in the tool used by the RDC which should add an option to specify time windows per food bank. Thereby providing certainty to food banks that the truck arrives within that time window.

Increase information sharing between the food banks and the RDC. Currently, information is shared through phone calls between the RDC and the logistics coordinators of the food banks. However, when a collective transport network is operated this is not a sustainable way of communicating. Aspects like the driven route, expected time of arrival and possible delays should be communicated to all food banks in the collective network in an efficient manner.

This research did not investigate how the savings achieved by the collective transport network are dividing amongst the participating food banks. Since the existence of a collaboration depends on the perception per food bank of gaining a benefit out of the collaboration, this is a vital part that should be discussed by the food banks.

Based on the performed research, the following general recommendations are made to the food banks:

All food banks, also the food banks not included in the collective transport network, should critically evaluate if the number of trucks they currently operate is really needed. This research estimated fixed costs to be around 70000 euros for all food banks together, which is 70% of total transport costs. A substantial amount of potential savings can be generated by reducing the number of trucks.

Improve data registration by keeping track of more variables. Data is crucial to get more insight into the transport process. To be precise, data should be collected on the number of pallets that are used to transport orders and the costs that are made with transport to the RDC. The presence of this data increases the accuracy and reliability of the results of further research.

Increase collaboration between smaller food banks. This research concluded that considering the top five food banks for the collective transport network is the most desirable scenario. However, the reference model showed that in the current situation, the smaller food banks often receive their order on one pallet. They should therefore aim at cooperating on transport using their own trucks. For example, the three smallest food banks could alternate in weekly shifts, making one of the three food banks responsible for transporting all orders together in a certain week. This way, they can keep using their own trucks while minimizing the variable transport costs.

Investigate other ways of using the single-unit truck. Currently, almost all orders are transported on Wednesdays and Thursdays. If food banks decide to buy or lease a truck, they could increase the received benefit of that truck by using it on the other days. A suggestion would be to increase the effort put into the acquisition of regional donors and use the large truck to transport those donations.

Finally, if the food banks decide to switch to a collective transport network and thereby using a larger truck, they should focus on reducing the number of pallets needed to stack orders. This research showed that for the larger trucks, volume is more often the limiting capacity instead of weight. Reducing the number of pallets for stacking increases the number of food banks that could be supplied in one route.

## 7.4 Scientific contribution

The scientific contribution of this thesis is limited due to the practical nature of the problem and the fact that VRP`s and collaboration via logistics are extensively studied topics. Therefore, a gap in research could not be found. The scientific contribution to the literature is primarily focused on the usage of a meta-heuristic via the solution model of Google OR Tools. Furthermore, a step-by-step approach for improving a transport network was used in practice. The solution model from Google OR-Tools was adjusted to the specific situation of the food banks and tested on a case study that analysed the performance of collective transport scenarios in practice based on historical demand.

## 7.5 Future research

Since this was the first time that transport for food banks within the region Twente-Salland was analysed, a considerable amount of effort was directed towards collecting and processing data for the referenced model. During this process, it became clear that several pieces of data were missing and estimations were used. For future research, it is advised to replicate this research with more accurate and complete input data to validate the results of this research. Most important would be the number of pallets that are used for the transport orders.

The recommendations already stated an addition to the model including the constraint of time windows. The model could be further extended by improving the way that costs are calculated. This research did not consider the differences in weight in the solution model to calculate transport costs. The Cumulative Vehicle Routing Problem however makes use of a curb weight variable that accumulates as routes are constructed. More information on this problem can be found in the research of Gil, Sánchez, Lalla-Ruiz and Castro(2020).

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# 9 Appendices

## Appendix A : Breakdown of donations per product group

| ***Product groups*** | **Total (kg)** |
|---|---|
| *AA44 Fruit vers* | 38410,885 |
| *AA45 Aardappelen* | 63731,2 |
| *AA45 Groente vers* | 137628,092 |
| *BA25 Babyvoeding* | 3195,52 |
| *BF01 Brood* | 7542,796 |
| *BJ02 Crackers* | 9738,936 |
| *BJ04 Ontbijtgranen/drank* | 26439,03 |
| *BN992 Broodbeleg houdbaar* | 15649,78 |
| *CA20 Fruit in blik/glas* | 110 |
| *CA21 Groente in blik/glas* | 13703,75 |
| *CA30 Fruit diepvries* | 170 |
| *CA31 Groente diepvries* | 7915,52 |
| *DV99 diverse non-food* | 24471,968 |
| *FA28 Frisdrank* | 166370,6173 |
| *HA51 Huishoudelijke producten* | 15898,311 |
| *KA10 Meel/gepureerd voedsel* | 3955,56 |
| *KA12 Fruit en groente gedroogd* | 387,072 |
| *KA17 Olieen en vetten* | 47053,4 |
| *KA19 Suiker* | 68,1 |
| *KA99 Overige kruidenierswaren* | 15532,94 |
| *KT03 Koffie/thee* | 14371,394 |
| *MA13 Soep* | 13302,035 |
| *MA24 Maaltijd in blik* | 711,48 |
| *MA34 Maaltijd diepvries* | 8934,02 |
| *MA47 Maaltijd vers* | 15996,487 |
| *PA67 Persoonlijke verzorging* | 10192,81 |
| *RA11 Rijst/pasta* | 11061 |
| *SA14 Kruiden en sauzen* | 14831,891 |
| *SF991 Snacks* | 15743,735 |
| *VA23 Vlees in blik* | 8308,272 |
| *VA32 Vis diepvries* | 380,28 |
| *VA33 Vlees/gevogelte diepvries* | 7810,7854 |
| *VA46 Vlees/gevogelte/vleeswaren vers* | 77464,9905 |
| *VA48 Vleesvervangende producten* | 27975,872 |
| *VA49 Vis vers* | 7097,15 |
| *ZA08 Toetjes* | 57206,71 |
| *ZA09 Melk* | 28769,048 |
| *ZA35 Toetjes diepvries* | 23368,824 |
| *ZA43 Kaas/melkproducten/eieren* | 77946,4564 |
| *ZW06 Zoetwaren* | 103751,517 |
| ***Total*** | **1123198,235** |

*Table A-1: Weights per product group per day of the week*

# Appendix B : Screenshots of the reference model

| | A | B | C |
|---|---|---|---|
| 1 | Productgroup | Pallet/Kg | |
| 2 | AA44 Fruit vers | 0,001425885 | |
| 3 | AA45 Aardappelen | 0,001425885 | |
| 4 | AA45 Groente vers | 0,001425885 | |
| 5 | BA25 Babyvoeding | 0,000638759 | |
| 6 | BF01 Brood | 0,001022229 | |
| 7 | BJ02 Crackers | 0,000853353 | |
| 8 | BJ04 Ontbijtgranen/drank | 0,001022229 | |
| 9 | BN992 Broodbeleg houdbaar | 0,001305483 | |
| 10 | CA20 Fruit in blik/glas | 0,000763028 | |
| 11 | CA21 Groente in blik/glas | 0,000763028 | |
| 12 | CA30 Fruit diepvries | 0,000853353 | |
| 13 | CA31 Groente diepvries | 0,000853353 | |
| 14 | DV99 diverse non-food | 0,001101926 | |
| 15 | FA28 Frisdrank | 0,000914612 | |
| 16 | HA51 Huishoudelijke producten | 0,001101926 | |
| 17 | KA10 Meel/gepureerd voedsel | 0,000853353 | |
| 18 | KA12 Fruit en groente gedroogd | 0,000853353 | |
| 19 | KA17 Olieen en vetten | 0,000853353 | |
| 20 | KA19 Suiker | 0,000853353 | |
| 21 | KA99 Overige kruidenierswaren | 0,000853353 | |
| 22 | KT03 Koffie/thee | 0,000853353 | |
| 23 | MA13 Soep | 0,000641778 | |
| 24 | MA24 Maaltijd in blik | 0,000641778 | |
| 25 | MA34 Maaltijd diepvries | 0,000641778 | |
| 26 | MA47 Maaltijd vers | 0,000641778 | |
| 27 | PA67 Persoonlijke verzorging | 0,001101926 | |
| 28 | RA11 Rijst/pasta | 0,000853353 | |
| 29 | SA14 Kruiden en sauzen | 0,000853353 | |
| 30 | SF991 Snacks | 0,000917755 | |
| 31 | VA23 Vlees in blik | 0,000763028 | |
| 32 | VA32 Vis diepvries | 0,00106517 | |
| 33 | VA33 Vlees/gevogelte diepvries | 0,00106517 | |
| 34 | VA46 Vlees/gevogelte/vleeswaren vers | 0,00106517 | |
| 35 | VA48 Vleesvervangende producten | 0,000796564 | |
| 36 | VA49 Vis vers | 0,000796564 | |
| 37 | ZA08 Toetjes | 0,00174563 | |
| 38 | ZA09 Melk | 0,00174563 | |
| 39 | ZA35 Toetjes diepvries | 0,00174563 | |
| 40 | ZA43 Kaas/melkproducten/eieren | 0,00174563 | |

Orderrows | **Volume** | Busses | Buscombinations

*Figure B-1: Screenshot of volume sheet with pallets/kg fraction per product group*

```
Sub pallets() 'this sub fills the pallets column in the orderrow sheet
Dim VG(1 To 40, 1 To 2) As Variant
Dim i As Integer
Dim j As Integer
Dim LastRow As Integer

For i = 1 To 40 'loop over each productgroup cell in volume sheet
    VG(i, 1) = Sheets("Volume").Cells(i + 1, 1) 'fill first dimension with productgroups
    VG(i, 2) = Sheets("Volume").Cells(i + 1, 3) 'fill second dimension with pallet/kg values

Next i

With Sheets("Orderrows")
        LastRow = .Cells(.Rows.Count, "A").End(xlUp).Row 'find last row in orderrow sheet
End With

For i = 1 To LastRow 'loop over each row in orderrow sheet
    For j = 1 To 40 'loop through each productgroup name in array
    If Cells(i + 1, 8) = VG(j, 1) Then 'check if ordergroup name in sheets equals name in array
    Cells(i + 1, 13) = Cells(i + 1, 12) * VG(j, 2) 'if yes, multiply pallet/kg value with weight orderrow
    End If
    Next j
Next i

End Sub
```

*Figure B-2: Screenshot of VBA code to calculate the total number of pallets per order*

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Datumdocument | ArtikelNaam | Artikelgroep | Hoeveelheid | Stuks gewicht | Gewichtseenheid | Gewicht | Pallets | Klantsnaam |
| 2 | 03/01/2020 | STAMPPOT | MA47 Maaltijd vers | 101 | 5000 | g | 505 | 0,324097639 | VB Enschede |
| 3 | 03/01/2020 | HARING | VA49 Vis vers | 230 | 1000 | g | 230 | 0,183209808 | VB Enschede |
| 4 | 03/01/2020 | AH VERSPAKKET PASTINAAKSOEP 4/1100GR | AA45 Groente vers | 4 | 44001 | g | 176,004 | 0,250961441 | VB Enschede |
| 5 | 03/01/2020 | AH VERS SAP 5/250ML | FA28 Frisdrank | 108 | 1250 | g | 135 | 0,123472649 | VB Enschede |
| 6 | 03/01/2020 | VLEESWAREN | VA46 Vlees/gevogelte/vleeswaren vers | 111 | 1000 | g | 111 | 0,118233917 | VB Enschede |
| 7 | 03/01/2020 | FRUIT VERPAKT | AA44 Fruit vers | 25 | 3000 | g | 75 | 0,106941365 | VB Enschede |
| 8 | 03/01/2020 | GNOCCHI PAKKET | MA47 Maaltijd vers | 18 | 3000 | g | 54 | 0,034655985 | VB Enschede |
| 9 | 03/01/2020 | STOEMP | AA45 Groente vers | 9 | 5000 | g | 45 | 0,064164819 | VB Enschede |
| 10 | 03/01/2020 | SLA VERPAKT | AA45 Groente vers | 16 | 2000 | g | 32 | 0,045628316 | VB Enschede |
| 11 | 03/01/2020 | CHIMICHURRI BURGER 16/215G | VA46 Vlees/gevogelte/vleeswaren vers | 9 | 3340 | g | 30,06 | 0,032019023 | VB Enschede |
| 12 | 03/01/2020 | SOEPPAKKET | AA45 Groente vers | 16 | 1 | Kg | 16 | 0,022814158 | VB Enschede |
| 13 | 03/01/2020 | GROENTE VERS | AA45 Groente vers | 20 | 5000 | g | 10 | 0,014258849 | VB Enschede |
| 14 | 03/01/2020 | Lasagne | RA11 Rijst/pasta | 50 | 0,19 | Kg | 9,5 | 0,008106849 | VB Enschede |
| 15 | 03/01/2020 | STAMPPOT | MA47 Maaltijd vers | 71 | 5000 | g | 355 | 0,227831013 | VB Midden Twente |
| 16 | 03/01/2020 | HARING | VA49 Vis vers | 163 | 1000 | g | 163 | 0,129839994 | VB Midden Twente |
| 17 | 03/01/2020 | AH VERSPAKKET PASTINAAKSOEP 4/1100GR | AA45 Groente vers | 3 | 44001 | g | 132,003 | 0,18822108 | VB Midden Twente |
| 18 | 03/01/2020 | AH VERS SAP 5/250ML | FA28 Frisdrank | 76 | 1250 | g | 95 | 0,08688816 | VB Midden Twente |
| 19 | 03/01/2020 | VLEESWAREN | VA46 Vlees/gevogelte/vleeswaren vers | 79 | 1000 | g | 79 | 0,084148464 | VB Midden Twente |
| 20 | 03/01/2020 | GROENTE VERS | AA45 Groente vers | 14 | 5000 | g | 70 | 0,099811941 | VB Midden Twente |
| 21 | 03/01/2020 | FRUIT VERPAKT | AA44 Fruit vers | 18 | 3000 | g | 54 | 0,076997783 | VB Midden Twente |
| 22 | 03/01/2020 | GNOCCHI PAKKET | MA47 Maaltijd vers | 13 | 3000 | g | 39 | 0,025029323 | VB Midden Twente |
| 23 | 03/01/2020 | STOEMP | AA45 Groente vers | 6 | 5000 | g | 30 | 0,042776546 | VB Midden Twente |
| 24 | 03/01/2020 | SLA VERPAKT | AA45 Groente vers | 11 | 2000 | g | 22 | 0,031369467 | VB Midden Twente |
| 25 | 03/01/2020 | CHIMICHURRI BURGER 16/215G | VA46 Vlees/gevogelte/vleeswaren vers | 6 | 3340 | g | 20,04 | 0,021346015 | VB Midden Twente |
| 26 | 03/01/2020 | SOEPPAKKET | AA45 Groente vers | 11 | 1 | Kg | 11 | 0,015684734 | VB Midden Twente |
| 27 | 03/01/2020 | Lasagne | RA11 Rijst/pasta | 36 | 0,19 | Kg | 6,84 | 0,005836931 | VB Midden Twente |
| 28 | 03/01/2020 | STAMPPOT | MA47 Maaltijd vers | 28 | 5000 | g | 140 | 0,08984885 | VB Oost Twente |
| 29 | 03/01/2020 | HARING | VA49 Vis vers | 65 | 1000 | g | 65 | 0,051776685 | VB Oost Twente |
| 30 | 03/01/2020 | AH VERSPAKKET PASTINAAKSOEP 4/1100GR | AA45 Groente vers | 1 | 44001 | g | 44,001 | 0,06274036 | VB Oost Twente |
| 31 | 03/01/2020 | AH VERS SAP 5/250ML | FA28 Frisdrank | 30 | 1250 | g | 37,5 | 0,034297958 | VB Oost Twente |
| 32 | 03/01/2020 | VLEESWAREN | VA46 Vlees/gevogelte/vleeswaren vers | 31 | 1000 | g | 31 | 0,033020283 | VB Oost Twente |
| 33 | 03/01/2020 | GROENTE VERS | AA45 Groente vers | 6 | 5000 | g | 30 | 0,042776546 | VB Oost Twente |
| 34 | 03/01/2020 | FRUIT VERPAKT | AA44 Fruit vers | 7 | 3000 | g | 21 | 0,029943582 | VB Oost Twente |
| 35 | 03/01/2020 | GNOCCHI PAKKET | MA47 Maaltijd vers | 5 | 3000 | g | 15 | 0,009626663 | VB Oost Twente |
| 36 | 03/01/2020 | CHIMICHURRI BURGER 16/215G | VA46 Vlees/gevogelte/vleeswaren vers | 3 | 3340 | g | 10,02 | 0,010673008 | VB Oost Twente |
| 37 | 03/01/2020 | STOEMP | AA45 Groente vers | 2 | 5000 | g | 10 | 0,014258849 | VB Oost Twente |
| 38 | 03/01/2020 | SLA VERPAKT | AA45 Groente vers | 4 | 2000 | g | 8 | 0,011407079 | VB Oost Twente |
| 39 | 03/01/2020 | SOEPPAKKET | AA45 Groente vers | 5 | 1 | Kg | 5 | 0,007129424 | VB Oost Twente |
| 40 | 03/01/2020 | Lasagne | RA11 Rijst/pasta | 14 | 0,19 | Kg | 2,66 | 0,002269918 | VB Oost Twente |

Orderrows | Volume | Busses | Buscombinations | DistanceMatrix | PivotTable | Sheet1 | Sheet8 | Overview | Yearvalues | PalletsPerDay | ProportionPalletPerDay

*Figure B-3: Screenshot of order rows sheet with "pallets" column*



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| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **Food bank** | **Amount of busses** | | | **VB Almelo** | | **VB Enschede** | | **VB Hellendoorn** | | **VB Losser** | |
| 2 | VB Almelo | 3 | | | Max pallets | Max weight | Max pallets | Max weight | Max pallets | Max weight | Max pallets | Max weight |
| 3 | VB Enschede | 3 | | Bus 1 | 4 | 1200 | 3 | 1500 | 3 | 1500 | 3 | 1500 |
| 4 | VB Hellendoorn | 1 | | Bus 2 | 4 | 1200 | 4 | 1500 | | | | |
| 5 | VB Losser | 1 | | Bus 3 | 6 | 1500 | 4 | 1500 | | | | |
| 6 | VB Midden Twente | 3 | | Bus 4 | | | | | | | | |
| 7 | VB Oost Twente | 1 | | Bus 5 | | | | | | | | |
| 8 | VB Raalte | 2 | | | | | | | | | | |
| 9 | VB Rijssen Holten | 1 | | | | | | | | | | |
| 10 | VB Vaassen | 2 | | | | | | | | | | |
| 11 | VB Zutphen | 2 | | | | | | | | | | |
| 12 | **Total** | **19** | | | | | | | | | | |

*Figure B-4: Screenshot of busses sheet part 1*

| K | L | M | N | O | P | Q | R | S | T | U | V | W | X |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **VB Losser** | | **VB Midden Twente** | | **VB Oost Twente** | | **VB Raalte** | | **VB Rijssen Holten** | | **VB Vaassen** | | **VB Zutphen** | |
| Max pallets | Max weight | Max pallets | Max weight | Max pallets | Max weight | Max pallets | Max weight | Max pallets | Max weight | Max pallets | Max weight | Max pallets | Max weight |
| 3 | 1500 | 3 | 1256 | 4 | 3500 | 3 | 400 | 4 | 3500 | 5 | 500 | 3 | 1100 |
| | | 4 | 1360 | | | 6 | 2800 | | | 7 | 2500 | 4 | 1400 |
| | | 5 | 1054 | | | | | | | | | | |

*Figure B-5: Screenshot of busses sheet part 2*

| | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | **VB Almelo** | | **VB Enschede** | | **VB Hellendoorn** | | **VB Losser** | | **VB Midden Twente** | |
| 2 | | Max pallets | Max weight | Max pallets | Max weight | Max pallets | Max weight | Max pallets | Max weight | Max pallets | Max weight |
| 3 | 1 bus | 6 | 1500 | 4 | 1500 | 3 | 1500 | 3 | 1500 | 5 | 1256 |
| 4 | 2 busses | 10 | 2700 | 7 | 3000 | 6 | 3000 | 6 | 3000 | 9 | 2414 |
| 5 | 3 busses | 14 | 3900 | 11 | 4500 | 9 | 4500 | 9 | 4500 | 12 | 3670 |
| 6 | 4 busses | 20 | 5400 | 15 | 6000 | 12 | 6000 | 12 | 6000 | 17 | 4724 |
| 7 | 5 busses | 24 | 6600 | 19 | 7500 | 15 | 7500 | 15 | 7500 | 21 | 6084 |
| 8 | 6 busses | 28 | 7800 | 22 | 9000 | 18 | 9000 | 18 | 9000 | 24 | 7340 |
| 9 | 7 busses | 34 | 9300 | 26 | 10500 | 21 | 10500 | 21 | 10500 | 29 | 8394 |
| 10 | 8 busses | 38 | 10500 | 30 | 12000 | 24 | 12000 | 24 | 12000 | 33 | 9754 |
| 11 | 9 busses | 42 | 11700 | 33 | 13500 | 27 | 13500 | 27 | 13500 | 36 | 11010 |
| 12 | 10 busses | 48 | 13200 | 37 | 15000 | 30 | 15000 | 30 | 15000 | 41 | 12064 |
| 13 | Many | 100000000 | 100000000 | 100000000 | 100000000 | 100000000 | 100000000 | 100000000 | 100000000 | 100000000 | 100000000 |

Orderrows | Volume | Busses | **Buscombinations** | Overview | DistanceMatrix | PivotTable | Sheet1 | Sheet8 | Yearvalues

*Figure B-6: Screenshot of bus combinations sheet part 1*



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| J | K | L | M | N | O | P | Q | R | S | T | U |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **VB Midden Twente** | | **VB Oost Twente** | | **VB Raalte** | | **VB Rijssen Holten** | | **VB Vaassen** | | **VB Zutphen** | |
| Max pallets | Max weight | Max pallets | Max weight | Max pallets | Max weight | Max pallets | Max weight | Max pallets | Max weight | Max pallets | Max weight |
| 5 | 1256 | 4 | 3500 | 6 | 2800 | 4 | 3500 | 7 | 2500 | 4 | 1400 |
| 9 | 2414 | 8 | 7000 | 9 | 3200 | 8 | 7000 | 12 | 3000 | 7 | 2500 |
| 12 | 3670 | 12 | 10500 | 15 | 6000 | 12 | 10500 | 19 | 5500 | 11 | 3900 |
| 17 | 4724 | 16 | 14000 | 18 | 6400 | 16 | 14000 | 24 | 6000 | 14 | 5000 |
| 21 | 6084 | 20 | 17500 | 24 | 9200 | 20 | 17500 | 31 | 8500 | 18 | 6400 |
| 24 | 7340 | 24 | 21000 | 27 | 9600 | 24 | 21000 | 36 | 9000 | 21 | 7500 |
| 29 | 8394 | 28 | 24500 | 33 | 12400 | 28 | 24500 | 43 | 11500 | 25 | 8900 |
| 33 | 9754 | 32 | 28000 | 36 | 12800 | 32 | 28000 | 48 | 12000 | 28 | 10000 |
| 36 | 11010 | 36 | 31500 | 42 | 15600 | 36 | 31500 | 55 | 14500 | 32 | 11400 |
| 41 | 12064 | 40 | 35000 | 45 | 16000 | 40 | 35000 | 60 | 15000 | 35 | 12500 |
| 100000000 | 100000000 | 100000000 | 100000000 | 100000000 | 100000000 | 100000000 | 100000000 | 100000000 | 100000000 | 100000000 | 100000000 |

*Figure B-7: Screenshot of bus combination sheet part 2*

```
Sub Buscombi()
Dim Almelo(1 To 11, 1 To 2) As Variant
Dim Enschede(1 To 11, 1 To 2) As Variant
Dim Hellendoorn(1 To 11, 1 To 2) As Variant
Dim Losser(1 To 11, 1 To 2) As Variant
Dim MiddenTwente(1 To 11, 1 To 2) As Variant
Dim OostTwente(1 To 11, 1 To 2) As Variant
Dim Raalte(1 To 11, 1 To 2) As Variant
Dim RijssenHolten(1 To 11, 1 To 2) As Variant
Dim Vaassen(1 To 11, 1 To 2) As Variant
Dim Zutphen(1 To 11, 1 To 2) As Variant
Dim pallets As Integer
Dim weight As Long
Dim LastRow As Integer


For i = 1 To 11 'Loop over all truck combinations of the food banks
Almelo(i, 1) = Sheets("Buscombinations ").Cells(i + 2, 2) 'First dimensions specifies max pallets of truck combination
Almelo(i, 2) = Sheets("Buscombinations ").Cells(i + 2, 3) 'Second dimension specifies max weight of truck combination
Enschede(i, 1) = Sheets("Buscombinations ").Cells(i + 2, 4)
Enschede(i, 2) = Sheets("Buscombinations ").Cells(i + 2, 5)
Hellendoorn(i, 1) = Sheets("Buscombinations ").Cells(i + 2, 6)
Hellendoorn(i, 2) = Sheets("Buscombinations ").Cells(i + 2, 7)
Losser(i, 1) = Sheets("Buscombinations ").Cells(i + 2, 8)
Losser(i, 2) = Sheets("Buscombinations ").Cells(i + 2, 9)
MiddenTwente(i, 1) = Sheets("Buscombinations ").Cells(i + 2, 10)
MiddenTwente(i, 2) = Sheets("Buscombinations ").Cells(i + 2, 11)
OostTwente(i, 1) = Sheets("Buscombinations ").Cells(i + 2, 12)
OostTwente(i, 2) = Sheets("Buscombinations ").Cells(i + 2, 13)
Raalte(i, 1) = Sheets("Buscombinations ").Cells(i + 2, 14)
Raalte(i, 2) = Sheets("Buscombinations ").Cells(i + 2, 15)
RijssenHolten(i, 1) = Sheets("Buscombinations ").Cells(i + 2, 16)
RijssenHolten(i, 2) = Sheets("Buscombinations ").Cells(i + 2, 17)
Vaassen(i, 1) = Sheets("Buscombinations ").Cells(i + 2, 18)
Vaassen(i, 2) = Sheets("Buscombinations ").Cells(i + 2, 19)
Zutphen(i, 1) = Sheets("Buscombinations ").Cells(i + 2, 20)
Zutphen(i, 2) = Sheets("Buscombinations ").Cells(i + 2, 21)
Next i

With Sheets("Overview") 'Find the last row of the overview sheet to know how long the loop should be
        LastRow = .Cells(.Rows.Count, "A").End(xlUp).Row
End With
```

*Figure B-8: Screenshot of VBA code to calculate the correct amount of trucks per order, part 1*

```
For k = 1 To LastRow 'loop over each row in the overview sheet
    weight = Sheets("Overview").Cells(k + 1, 3) 'Take weight of the order
    pallets = Sheets("Overview").Cells(k + 1, 5) 'Take number of pallets of the order
    i = 1 'reset number of trucks to minimum
    If Sheets("Overview").Cells(k + 1, 2) = "VB Almelo" Then 'only execute code if correct food banks is identified
    Do Until weight <= Almelo(i, 2) And pallets <= Almelo(i, 1) 'Weight and pallet of order should be lower than truckcombination
    i = i + 1 'add one to number of trucks that is needed for transport
    Loop 'Loop untill minimal buscombination is found that can transport the order
    ElseIf Sheets("Overview").Cells(k + 1, 2) = "VB Enschede" Then
    Do Until weight <= Enschede(i, 2) And pallets <= Enschede(i, 1)
    i = i + 1
    Loop
    ElseIf Sheets("Overview").Cells(k + 1, 2) = "VB Hellendoorn" Then
    Do Until weight <= Hellendoorn(i, 2) And pallets <= Hellendoorn(i, 1)
    i = i + 1
    Loop
    ElseIf Sheets("Overview").Cells(k + 1, 2) = "VB Losser" Then
    Do Until weight <= Losser(i, 2) And pallets <= Losser(i, 1)
    i = i + 1
    Loop
    ElseIf Sheets("Overview").Cells(k + 1, 2) = "VB Midden Twente" Then
    Do Until weight <= MiddenTwente(i, 2) And pallets <= MiddenTwente(i, 1)
    i = i + 1
    Loop
    ElseIf Sheets("Overview").Cells(k + 1, 2) = "VB Oost Twente" Then
    Do Until weight <= OostTwente(i, 2) And pallets <= OostTwente(i, 1)
    i = i + 1
    Loop
    ElseIf Sheets("Overview").Cells(k + 1, 2) = "VB Raalte" Then
    Do Until weight <= Raalte(i, 2) And pallets <= Raalte(i, 1)
    i = i + 1
    Loop
    ElseIf Sheets("Overview").Cells(k + 1, 2) = "VB Rijssen Holten" Then
    Do Until weight <= RijssenHolten(i, 2) And pallets <= RijssenHolten(i, 1)
    i = i + 1
    Loop
    ElseIf Sheets("Overview").Cells(k + 1, 2) = "VB Vaassen" Then
    Do Until weight <= Vaassen(i, 2) And pallets <= Vaassen(i, 1)
    i = i + 1
    Loop
    ElseIf Sheets("Overview").Cells(k + 1, 2) = "VB Zutphen" Then
    Do Until weight <= Zutphen(i, 2) And pallets <= Zutphen(i, 1)
    i = i + 1
    Loop
    End If
    Cells(k + 1, 6) = i 'list the number of trucks in correct cell
Next k
End Sub
```

*Figure B-9: Screenshot of VBA code to calculate the correct amount of trucks per order, part 2*

| Distance in km | Depot | VB Almelo | VB Enschede | VB Hellendoorn | VB Losser | VB Midden Twente | VB Oost Twente | VB Raalte | VB Rijssen Holten | VB Vaassen | VB Zutphen |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Depot | 0,00 | 46,71 | 60,01 | 31,72 | 64,97 | 47,83 | 58,17 | 19,92 | 29,92 | 25,41 | 12,81 |
| VB Almelo | 45,53 | 0,00 | 28,55 | 17,71 | 33,51 | 16,37 | 26,71 | 30,08 | 17,72 | 67,48 | 55,00 |
| VB Enschede | 59,40 | 27,49 | 0,00 | 38,61 | 11,04 | 9,42 | 12,19 | 50,98 | 38,62 | 81,35 | 68,87 |
| VB Hellendoorn | 33,49 | 18,27 | 39,29 | 0,00 | 44,25 | 27,11 | 37,45 | 12,49 | 9,81 | 55,44 | 42,96 |
| VB Losser | 64,81 | 32,91 | 11,07 | 44,03 | 0,00 | 18,41 | 10,10 | 56,40 | 44,04 | 86,77 | 74,28 |
| VB Midden Twente | 48,61 | 16,71 | 9,37 | 27,83 | 23,07 | 0,00 | 16,27 | 40,20 | 27,83 | 70,56 | 58,08 |
| VB Oost Twente | 58,37 | 26,47 | 12,13 | 37,59 | 10,06 | 11,96 | 0,00 | 49,95 | 37,59 | 80,32 | 67,84 |
| VB Raalte | 19,95 | 30,63 | 51,65 | 12,45 | 56,61 | 39,46 | 49,81 | 0,00 | 24,70 | 47,65 | 32,19 |
| VB Rijssen Holten | 29,97 | 18,13 | 39,15 | 10,73 | 44,11 | 26,96 | 37,31 | 25,69 | 0,00 | 51,93 | 39,44 |
| VB Vaassen | 27,40 | 69,16 | 82,47 | 61,95 | 87,43 | 70,28 | 80,63 | 48,55 | 52,37 | 0,00 | 30,06 |
| VB Zutphen | 12,89 | 55,17 | 68,47 | 47,96 | 73,44 | 56,29 | 66,64 | 34,56 | 38,38 | 30,20 | 0,00 |

| Facility | Distance return trip |
|---|---|
| Depot | 0 |
| VB Almelo | 92,23 |
| VB Enschede | 119,41 |
| VB Hellendoorn | 65,22 |
| VB Losser | 129,79 |
| VB Midden Twente | 96,44 |
| VB Oost Twente | 116,54 |
| VB Raalte | 39,87 |
| VB Rijssen Holten | 59,89 |
| VB Vaassen | 52,81 |
| VB Zutphen | 25,70 |

Orderrows | Volume | Busses | Buscombinations | Overview | DistanceMatrix | PivotTable | Sheet1 | Sheet8 | Yearvalues | Palle ...

*Figure B-10: Screenshot of distance matrix sheet*

| Food bank | Sum of fixed costs | Total amount of busses | Average fixed costs per bus |
|---|---|---|---|
| VB Almelo | € 10.962 | 3 | € 3.654 |
| VB Enschede | € 12.764 | 3 | € 4.255 |
| VB Hellendoorn | € 2.343 | 1 | € 2.343 |
| VB Raalte | € 8.092 | 2 | € 4.046 |
| VB Rijssen Holten | € 2.844 | 1 | € 2.844 |
| Sum | € 37.005 | 10 | € 3.700 |

| Food bank | Sum of fixed costs | Total amount of busses | Average fixed costs per bus |
|---|---|---|---|
| VB Almelo | € 10.962 | 3 | € 3.654 |
| VB Enschede | € 12.764 | 3 | € 4.255 |
| VB Hellendoorn | € 2.343 | 1 | € 2.343 |
| VB Losser | € 3.700 | 1 | € 3.700 |
| VB Midden Twente | € 11.101 | 3 | € 3.700 |
| VB Oost Twente | € 3.700 | 1 | € 3.700 |
| VB Raalte | € 8.092 | 2 | € 4.046 |
| VB Rijssen Holten | € 2.844 | 1 | € 2.844 |
| VB Vaassen | € 7.401 | 2 | € 3.700 |
| VB Zutphen | € 7.401 | 2 | € 3.700 |
| **Total** | **€ 70.309** | **19** | **€ 3.700** |

Orderrows | Volume | Busses | Fixed transport costs | Buscombinations | Dist

*Figure B-11: Screenshot of fixed transport costs sheet*

```
Sub Distance()
Dim Distances(1 To 10, 1 To 2) As Variant
Dim LastRow As Integer


For i = 1 To 10 'fill array with food bank name and corresponding distance of retourtrip to RDC
    For j = 1 To 2
    Distances(i, j) = Sheets("DistanceMatrix").Cells(i + 17, j)
    Next j
Next i

With Sheets("Overview") 'find lastrow of overview sheet
        LastRow = .Cells(.Rows.Count, "A").End(xlUp).Row
End With

For i = 1 To LastRow 'loop over each row in overview sheet
    For j = 1 To 10 'loop over each possible amount of used busses (1 to 10)
    If Sheets("Overview").Cells(i + 1, 2) = Distances(j, 1) Then
        If Sheets("Overview").Cells(i + 1, 6) = 1 Then 'if one bus is used, total distance is distance of retourtrip
            Sheets("Overview").Cells(i + 1, 7) = Distances(j, 2)
        ElseIf Sheets("Overview").Cells(i + 1, 6) = 2 Then 'if two busses are used:
            Sheets("Overview").Cells(i + 1, 7) = Distances(j, 2) * 2 'distance retourtrip is multiplied by 2
        ElseIf Sheets("Overview").Cells(i + 1, 6) = 3 Then 'if three busses are used:
            Sheets("Overview").Cells(i + 1, 7) = Distances(j, 2) * 3 'distance retourtrip is multiplied by 3
        ElseIf Sheets("Overview").Cells(i + 1, 6) = 4 Then
            Sheets("Overview").Cells(i + 1, 7) = Distances(j, 2) * 4
        ElseIf Sheets("Overview").Cells(i + 1, 6) = 5 Then
            Sheets("Overview").Cells(i + 1, 7) = Distances(j, 2) * 5
        ElseIf Sheets("Overview").Cells(i + 1, 6) = 6 Then
            Sheets("Overview").Cells(i + 1, 7) = Distances(j, 2) * 6
        ElseIf Sheets("Overview").Cells(i + 1, 6) = 7 Then
            Sheets("Overview").Cells(i + 1, 7) = Distances(j, 2) * 7
        ElseIf Sheets("Overview").Cells(i + 1, 6) = 8 Then
            Sheets("Overview").Cells(i + 1, 7) = Distances(j, 2) * 8
        ElseIf Sheets("Overview").Cells(i + 1, 6) = 9 Then
            Sheets("Overview").Cells(i + 1, 7) = Distances(j, 2) * 9
        ElseIf Sheets("Overview").Cells(i + 1, 6) = 10 Then
            Sheets("Overview").Cells(i + 1, 7) = Distances(j, 2) * 10
        Else: MsgBox ("this amount of busses is not specified in code") 'only if busses exceed combinations of 10
        End If
    End If
    Next j
Next i
End Sub
```

*Figure B-12: Screenshot of VBA code to calculate the total driving distance to transport an order*



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# Appendix C : Outputs for increases in demand

| *Food bank* | Costs (€) | Weight (kg) | Pallets | Trips | Orders | Distance (km) |
|---|---|---|---|---|---|---|
| *VB Almelo* | € 2.827,26 | 113994 | 511 | 141 | 101 | 13005 |
| *VB Enschede* | € 8.798,43 | 252691 | 1094 | 344 | 113 | 41076 |
| *VB Hellendoorn* | € 1.453,16 | 38607 | 216 | 113 | 104 | 7369 |
| *VB Losser* | € 2.712,18 | 27689 | 172 | 108 | 106 | 14017 |
| *VB Midden Twente* | € 4.195,98 | 153959 | 679 | 202 | 109 | 19480 |
| *VB Oost Twente* | € 3.357,25 | 75564 | 369 | 140 | 112 | 16316 |
| *VB Raalte* | € 996,60 | 84515 | 408 | 117 | 104 | 4664 |
| *VB Rijssen Holten* | € 1.231,94 | 45402 | 233 | 102 | 97 | 6109 |
| *VB Vaassen* | € 1.083,78 | 40103 | 214 | 103 | 103 | 5439 |
| *VB Zutphen* | € 1.076,51 | 129322 | 572 | 199 | 100 | 5113 |
| ***Total*** | **€ 27.733,08** | **961846** | **4468** | **1569** | **1049** | **132589** |

*Table C-1: Output reference model with 10% demand increase*

| *Food bank* | Costs (€) | Weight (kg) | Pallets | Trips | Orders | Distance (km) |
|---|---|---|---|---|---|---|
| *VB Almelo* | € 3.141,68 | 129538 | 571 | 156 | 101 | 14389 |
| *VB Enschede* | € 9.564,61 | 287149 | 1229 | 371 | 113 | 44300 |
| *VB Hellendoorn* | € 1.551,29 | 43872 | 235 | 120 | 104 | 7826 |
| *VB Losser* | € 2.757,07 | 31465 | 188 | 109 | 106 | 14147 |
| *VB Midden Twente* | € 4.705,79 | 174954 | 763 | 226 | 109 | 21795 |
| *VB Oost Twente* | € 3.664,32 | 85868 | 411 | 152 | 112 | 17715 |
| *VB Raalte* | € 1.096,48 | 96040 | 459 | 128 | 104 | 5103 |
| *VB Rijssen Holten* | € 1.302,61 | 51593 | 257 | 107 | 97 | 6408 |
| *VB Vaassen* | € 1.096,28 | 45571 | 244 | 103 | 103 | 5439 |
| *VB Zutphen* | € 1.180,49 | 146956 | 641 | 217 | 100 | 5576 |
| ***Total*** | **€ 30.060,62** | **1093006** | **4998** | **1689** | **1049** | **142696** |

*Table C-2: Output reference model with 25% demand increase*

| *Food bank* | Costs (€) | Weight (kg) | Pallets | Trips | Orders | Distance (km) |
|---|---|---|---|---|---|---|
| *VB Almelo* | € 3.648,89 | 155446 | 678 | 180 | 101 | 16602 |
| *VB Enschede* | € 11.407,84 | 344579 | 1470 | 442 | 113 | 52778 |
| *VB Hellendoorn* | € 1.659,33 | 52647 | 270 | 127 | 104 | 8282 |
| *VB Losser* | € 2.910,79 | 37757 | 217 | 114 | 106 | 14795 |
| *VB Midden Twente* | € 5.379,58 | 209944 | 909 | 256 | 109 | 24688 |
| *VB Oost Twente* | € 4.154,86 | 103041 | 481 | 171 | 112 | 19929 |
| *VB Raalte* | € 1.231,42 | 115248 | 535 | 142 | 104 | 5661 |
| *VB Rijssen Holten* | € 1.449,53 | 61912 | 299 | 118 | 97 | 7067 |
| *VB Vaassen* | € 1.126,75 | 54685 | 276 | 104 | 103 | 5492 |
| *VB Zutphen* | € 1.372,53 | 176348 | 757 | 251 | 100 | 6449 |
| ***Total*** | **€ 34.341,52** | **1311608** | **5892** | **1905** | **1049** | **161744** |

*Table C-3: Output reference model with 50% demand increase*

# Appendix D Outputs scenarios of solution model

| | Mon | Tue | Wed | Thu | Fri | Sat | Total |
|---|---|---|---|---|---|---|---|
| *Trips* | 4 | 7 | 166 | 104 | 18 | 6 | 305 |
| *Distance sum* | 785 | 967 | 20642 | 14840 | 2552 | 775 | 40561 |
| *Distance avg* | 196 | 138 | 124 | 143 | 142 | 129 | 133 |
| *Pallets sum* | 55 | 88 | 2570 | 1435 | 169 | 81 | 4398 |
| *Pallets avg* | 13,8 | 12,6 | 15,5 | 13,8 | 9,4 | 13,5 | 14,4 |
| *Weight sum* | 7895 | 16880 | 594942 | 286196 | 36954 | 18978 | 961846 |
| *Weight avg* | 1974 | 2411 | 3584 | 2752 | 2053 | 3163 | 3154 |
| *Costs* | € 245,63 | € 302,57 | € 6.458,88 | € 4.643,44 | € 798,52 | € 242,50 | € 12.691,54 |

*Table D-1: Results solution model: Single-unit truck, all food banks supplied, demand 10% increase*

| | Mon | Tue | Wed | Thu | Fri | Sat | Total |
|---|---|---|---|---|---|---|---|
| *Trips* | 5 | 7 | 182 | 109 | 19 | 6 | 328 |
| *Distance sum* | 793 | 1002 | 21418 | 15496 | 2627 | 778 | 42114 |
| *Distance avg* | 159 | 143 | 118 | 142 | 138 | 130 | 128 |
| *Pallets sum* | 61 | 99 | 2734 | 1588 | 183 | 88 | 4753 |
| *Pallets avg* | 12,2 | 14,1 | 15,0 | 14,6 | 9,6 | 14,7 | 14,5 |
| *Weight sum* | 8972 | 19182 | 642322 | 325223 | 41993 | 21566 | 1059258 |
| *Weight avg* | 1794 | 2740 | 3529 | 2984 | 2210 | 3594 | 3229 |
| *Costs* | € 248,13 | € 313,53 | € 6.701,69 | € 4.848,70 | € 821,99 | € 243,44 | € 13.177,47 |

*Table D-2: Results solution model: Single-unit truck, all food banks supplied, demand 25% increase*

| | Mon | Tue | Wed | Thu | Fri | Sat | Total |
|---|---|---|---|---|---|---|---|
| *Trips* | 5 | 8 | 198 | 119 | 19 | 7 | 356 |
| *Distance sum* | 871 | 1092 | 22695 | 16057 | 2782 | 846 | 44343 |
| *Distance avg* | 174 | 137 | 115 | 135 | 146 | 121 | 125 |
| *Pallets sum* | 69 | 114 | 3074 | 1730 | 217 | 102 | 5306 |
| *Pallets avg* | 13,8 | 14,3 | 15,5 | 14,5 | 11,4 | 14,6 | 14,9 |
| *Weight sum* | 10766 | 23019 | 735549 | 351903 | 50392 | 25879 | 1197508 |
| *Weight avg* | 2153 | 2877 | 3715 | 2957 | 2652 | 3697 | 3364 |
| *Costs* | € 272,54 | € 341,69 | € 7.101,27 | € 5.024,24 | € 870,49 | € 264,71 | € 13.874,92 |

*Table D-3: Results solution model: Single-unit truck, all food banks supplied, demand 50% increase*

| | Mon | Tue | Wed | Thu | Fri | Sat | Total |
|---|---|---|---|---|---|---|---|
| *Trips* | 4 | 4 | 106 | 67 | 15 | 4 | 200 |
| *Distance sum* | 712 | 780 | 15063 | 12018 | 2373 | 587 | 31533 |
| *Distance avg* | 178 | 195 | 142 | 179 | 158 | 147 | 158 |
| *Pallets sum* | 55 | 88 | 2617 | 1448 | 169 | 83 | 4460 |
| *Pallets avg* | 13,8 | 22,0 | 24,7 | 21,6 | 11,3 | 20,8 | 22,3 |
| *Weight sum* | 7895 | 16880 | 594942 | 286196 | 36954 | 18978 | 961846 |
| *Weight avg* | 1974 | 4220 | 5613 | 4272 | 2464 | 4745 | 4809 |
| *Costs* | € 275,62 | € 301,94 | € 5.830,89 | € 4.652,17 | € 918,59 | € 227,23 | € 12.206,42 |

*Table D-4: Results solution model: Semi-trailer truck, all food banks supplied, demand 10% increase*

| | Mon | Tue | Wed | Thu | Fri | Sat | Total |
|---|---|---|---|---|---|---|---|
| *Trips* | 4 | 4 | 112 | 72 | 15 | 4 | 211 |
| *Distance sum* | 752 | 807 | 15998 | 12343 | 2373 | 627 | 32900 |
| *Distance avg* | 188 | 202 | 143 | 171 | 158 | 157 | 156 |
| *Pallets sum* | 61 | 99 | 2936 | 1613 | 183 | 93 | 4985 |
| *Pallets avg* | 15,3 | 24,8 | 26,2 | 22,4 | 12,2 | 23,3 | 23,6 |
| *Weight sum* | 8972 | 19182 | 676070 | 325223 | 41993 | 21566 | 1093006 |
| *Weight avg* | 2243 | 4796 | 6036 | 4517 | 2800 | 5392 | 5180 |
| *Costs* | € 291,10 | € 312,39 | € 6.192,83 | € 4.777,98 | € 918,59 | € 242,71 | € 12.735,59 |

*Table D-5: Results solution model: Semi-trailer truck, all food banks supplied, demand 25% increase*

| | Mon | Tue | Wed | Thu | Fri | Sat | Total |
|---|---|---|---|---|---|---|---|
| *Trips* | 4 | 5 | 128 | 82 | 17 | 5 | 241 |
| *Distance sum* | 763 | 820 | 17481 | 13041 | 2426 | 686 | 35217 |
| *Distance avg* | 191 | 164 | 137 | 159 | 143 | 137 | 146 |
| *Pallets sum* | 69 | 115 | 3461 | 1889 | 217 | 112 | 5863 |
| *Pallets avg* | 17,3 | 23,0 | 27,0 | 23,0 | 12,8 | 22,4 | 24,3 |
| *Weight sum* | 10766 | 23019 | 811284 | 390267 | 50392 | 25879 | 1311608 |
| *Weight avg* | 2692 | 4604 | 6338 | 4759 | 2964 | 5176 | 5442 |
| *Costs* | € 295,36 | € 317,42 | € 6.766,90 | € 5.048,17 | € 939,10 | € 265,55 | € 13.632,50 |

*Table D-6: Results solution model: Semi-trailer truck, all food banks supplied, demand 50% increase*

| | Mon | Tue | Wed | Thu | Fri | Sat | Total |
|---|---|---|---|---|---|---|---|
| *Trips* | 4 | 4 | 117 | 72 | 14 | 4 | 215 |
| *Distance sum* | 562 | 608 | 15083 | 10116 | 1982 | 547 | 28898 |
| *Distance avg* | 141 | 152 | 129 | 141 | 142 | 137 | 134 |
| *Pallets sum* | 31 | 55 | 1624 | 866 | 121 | 50 | 2747 |
| *Pallets avg* | 7,8 | 13,8 | 13,9 | 12,0 | 8,6 | 12,5 | 12,8 |
| *Weight sum* | 4888 | 11079 | 386327 | 179971 | 25930 | 12484 | 620679 |
| *Weight avg* | 1222 | 2770 | 3302 | 2500 | 1852 | 3121 | 2887 |
| *Costs sum* | € 175,85 | € 190,24 | € 4.719,47 | € 3.165,30 | € 620,17 | € 171,16 | € 9.042,18 |

*Table D-7: Results solution model: Single-unit truck, top five food banks supplied, demand 10% increase*

| | Mon | Tue | Wed | Thu | Fri | Sat | Total |
|---|---|---|---|---|---|---|---|
| *Trips* | 4 | 5 | 124 | 77 | 16 | 4 | 230 |
| *Distance sum* | 562 | 688 | 16048 | 10707 | 2206 | 547 | 30758 |
| *Distance avg* | 141 | 138 | 129 | 139 | 138 | 137 | 134 |
| *Pallets sum* | 35 | 61 | 1794 | 955 | 144 | 54 | 3043 |
| *Pallets avg* | 8,8 | 12,2 | 14,5 | 12,4 | 9,0 | 13,5 | 13,2 |
| *Weight sum* | 5555 | 12590 | 438182 | 204512 | 33122 | 14186 | 708148 |
| *Weight avg* | 1389 | 2518 | 3534 | 2656 | 2070 | 3547 | 3079 |
| *Costs sum* | € 175,85 | € 215,28 | € 5.021,42 | € 3.350,22 | € 690,26 | € 171,16 | € 9.624,18 |

*Table D-8: Results solution model: Single-unit truck, top five food banks supplied, demand 25% increase*

| | Mon | Tue | Wed | Thu | Fri | Sat | Total |
|---|---|---|---|---|---|---|---|
| *Trips* | 4 | 6 | 139 | 88 | 18 | 5 | 260 |
| *Distance sum* | 582 | 793 | 17702 | 11838 | 2419 | 635 | 33969 |
| *Distance avg* | 146 | 132 | 127 | 135 | 134 | 127 | 131 |
| *Pallets sum* | 40 | 71 | 2073 | 1109 | 170 | 62 | 3525 |
| *Pallets avg* | 10,0 | 11,8 | 14,9 | 12,6 | 9,4 | 12,4 | 13,6 |
| *Weight sum* | 6666 | 15108 | 523637 | 243694 | 39746 | 17024 | 845875 |
| *Weight avg* | 1666 | 2518 | 3767 | 2769 | 2208 | 3405 | 3253 |
| *Costs sum* | € 182,11 | € 248,13 | € 5.538,96 | € 3.704,11 | € 756,91 | € 198,69 | € 10.628,90 |

*Table D-9: Results solution model: Single-unit truck, top five food banks supplied, demand 50% increase*

| | Mon | Tue | Wed | Thu | Fri | Sat | Total |
|---|---|---|---|---|---|---|---|
| *Trips* | 3 | 4 | 73 | 54 | 15 | 3 | 152 |
| *Distance sum* | 474 | 562 | 10181 | 8090 | 2080 | 424 | 21811 |
| *Distance avg* | 158 | 141 | 139 | 150 | 139 | 141 | 143 |
| *Pallets sum* | 31 | 55 | 1667 | 879 | 133 | 52 | 2817 |
| *Pallets avg* | 10,3 | 13,8 | 22,8 | 16,3 | 8,9 | 17,3 | 18,5 |
| *Weight sum* | 4888 | 11079 | 386327 | 179971 | 29147 | 12484 | 623896 |
| *Weight avg* | 1629 | 2770 | 5292 | 3333 | 1943 | 4161 | 4105 |
| *Costs sum* | € 183,49 | € 217,55 | € 3.941,07 | € 3.131,64 | € 805,17 | € 164,13 | € 8.443,04 |

*Table D-10: Results solution model: Semi-trailer truck, top five food banks supplied, demand 10% increase*

| | Mon | Tue | Wed | Thu | Fri | Sat | Total |
|---|---|---|---|---|---|---|---|
| *Trips* | 3 | 4 | 82 | 55 | 15 | 3 | 162 |
| *Distance sum* | 474 | 582 | 11157 | 8216 | 2080 | 424 | 22933 |
| *Distance avg* | 158 | 146 | 136 | 149 | 139 | 141 | 142 |
| *Pallets sum* | 35 | 61 | 1870 | 980 | 141 | 59 | 3146 |
| *Pallets avg* | 11,7 | 15,3 | 22,8 | 17,8 | 9,4 | 19,7 | 19,4 |
| *Weight sum* | 5555 | 12590 | 439007 | 204512 | 31467 | 14186 | 707318 |
| *Weight avg* | 1852 | 3148 | 5354 | 3718 | 2098 | 4729 | 4366 |
| *Costs sum* | € 183,49 | € 225,29 | € 4.318,87 | € 3.180,41 | € 805,17 | € 164,13 | € 8.877,36 |

*Table D-11: Results solution model: Semi-trailer truck, top five food banks supplied, demand 25% increase*

| | Mon | Tue | Wed | Thu | Fri | Sat | Total |
|---|---|---|---|---|---|---|---|
| *Trips* | 3 | 4 | 92 | 63 | 15 | 4 | 181 |
| *Distance sum* | 474 | 582 | 12421 | 9033 | 2100 | 530 | 25140 |
| *Distance avg* | 158 | 146 | 135 | 143 | 140 | 133 | 139 |
| *Pallets sum* | 40 | 72 | 2214 | 1158 | 157 | 72 | 3713 |
| *Pallets avg* | 13,3 | 18,0 | 24,1 | 18,4 | 10,5 | 18,0 | 20,5 |
| *Weight sum* | 6666 | 15108 | 526809 | 245415 | 35332 | 17024 | 846354 |
| *Weight avg* | 2222 | 3777 | 5726 | 3895 | 2355 | 4256 | 4676 |
| *Costs sum* | € 183,49 | € 225,29 | € 4.808,17 | € 3.496,67 | € 812,91 | € 205,16 | € 9.731,69 |

*Table D-12: Results solution model: Semi-trailer truck, top five food banks supplied, demand 50% increase*