MASTER

Determining a possible new hub location in Belgium
application to the distribution of GVT

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Determining a possible new hub location in Belgium: Application to the distribution network of GVT

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Abstract

Gebroeders Versteijnen B.V. (GVT) Transport is a distribution company that delivers and picks up goods throughout the Benelux countries. Due to newly introduced kilometer-based charge legislation in Belgium, the price per kilometer driven in Belgium has increased. In this thesis, the goal is to improve the density of the current network design of GVT Transport, and the possibility of a new hub location in Belgium is investigated. By applying strategies such as cross-docking, warehousing, and use of Long Heavy Vehicles (LHV), economies of scale can be realized with a new hub.

GVT Transport requires an economy of scale factor of at least 20% between Tilburg and a new hub to establish a new hub in Belgium, otherwise no new hub should be established. The sensitivity analysis of the model showed that Antwerp remains a desirable location, with an economy of scale factor between 25% and 50%. Since Antwerp is accessible by LHVs, in the current LHV trial in Belgium a discount of approximately 40% can be achieved between hubs with LHVs.

Results of one week plan show that transportation costs are reduced by €3,156 euro per week by adding a hub location in Antwerp. In addition, total cost reduction could be even higher when the routes from Antwerp to customers are optimized. Furthermore, the company is advised to examine the exact location for a storage space and to investigate the possibility to expand their network by recruiting new customers in the Benelux and France.

Management summary

This thesis provides results for the hub location problem applied to the network design of Gebroeders Versteijnen B.V. (GVT) Transport. The hub location problem is a strategic, long-term decision-making level within the network design. In the current network design, the average distance from the hub in Tilburg to customers in Belgium and Luxemburg is approximately 150 km. Density is defined as the average distance in kilometers from a hub to all customers. In combination with drivers' working hours and working hour regulations, the current density leads to suboptimal planning situations. Furthermore, the new kilometer-based charge legislation in Belgium, which was introduced in April 2016, results in an increase in transportation costs. To address this network design problem the following research objective was set:

Improving the density of the current network design of GVT Transport.

The research objective was achieved by solving the hub location problem. The time period considered in this thesis ranged from July 2014 to June 2015. During this period, a total of 33,672 load meters (ldm) were driven for pick up, compared to 90,541 ldm for delivery. Approximately 75% of the total load meters were transported to/from Flanders in Belgium. In total, approximately 98% of the goods picked up in Belgium and Luxemburg were transported to the Netherlands, and approximately 96% of the goods delivered to Belgium and Luxemburg originated from the Netherlands.

Currently, GVT Transport employs direct shipment and milk runs as distribution strategies for Belgium and Luxemburg. A new hub would not reduce transportation costs if the current strategy is retained. However, a new location in Belgium could provide advantages for planners in terms of driving and working hour regulations. Economies of scale between hubs can be achieved by applying a different strategy. This strategy could consist of warehousing, cross-docking, using Long Heavy Vehicles (LHVs), and using rigid trucks. LHVs consist mostly of a trailer and dolly combination, and can achieve the highest level of economies of scale.

Zip codes are used to identify demand locations, and the zip codes that were selected for the analysis required at least one pallet per day on average for delivery or pick up. The clustered zip codes include the remaining zip codes that have not yet been selected, but do have demand. Selecting the maximum amount of load meters between pickup and delivery per zip code per day is referred to as combined*.

Distances between all selected demand locations (zip codes) were calculated using Google, and are based on the fastest route from zip code to zip code. The p-median model minimizes the demand-weighted average distance and provides the best geographical location for a facility. The percentage of load meters per zip code was used as demand factor. The current hub location in Tilburg was weighted with five different discount factors consisting of 0, 25, 50, 75, and 100. This factor displays the economies of scale for inter-hub traffic. When the factor decreases, the discount increases. A discount factor 75 means that a discount of 25% is achieved in the inter-hub link. With a reduction in transportation costs between Tilburg and the new hub, it becomes attractive to establish a new hub in Belgium. Calculations show that the discount should be at least 12% or more in order for a new hub to be profitable. This data is given in Table 1.

*Table 1: Discount Tilburg corresponding to hub location for combined**

Hub location	Discount Tilburg per zip code	Discount Tilburg per clustered zip code
1780	≥87.40%	≥85.71%
1851	≥79.24%	≥76.98%
2830	≥69.59%	≥67.35%
2610	≥56.27%	≥52.69%
2000	≥19.70%	≥11.94%
5047TM	<19.70%	<11.94%

The strategy of GVT Transport should be adjusted in order to take advantage of economies of scale between Tilburg and a possible new hub. The most interesting strategy is the use of LHVs, which can reduce transportation between the hubs by approximately 40%. The best strategic location for a hub is Antwerp.

The sensitivity of the p-median model was examined to analyze the location under different scenarios. The results of the different scenarios are provided in Table 2:

- **Delivery**: This situation only considers the delivery orders.
- **Pickup**: This situation only considers the pickup orders.
- **Excluding Full Truck Load (FTL) orders**: This situation only considers orders of less than 12 ldm.
- **+25% Wallonia**: All demand in Wallonia is increased by 25%.
- **+25% East- and West-Flanders**: All demand in East- and West-Flanders is increased by 25%.
- **Duration**: The travel duration between zip codes is considered instead of distance.
- **Duration + congestion levels**: Congestion levels are added to the duration.
- **Combined* normal situation**: This considers the current demand based on the combined* situation. No adjustments are made.

Table 2: Overview of calculations p-median model under different scenarios

Factor Tilburg	Delivery	Pick up	Excluding FTL orders	+25 % Wallonia	+ 25% East-West-Flanders	Duration	Duration + congestion levels	Combined* normal situation
100	1780	9320	1082	1780	1083	1780	1780	1780
75	1851	9200	1851	1851	2830	1780	1830	2830
50	2000	2830	2000	2610	2000	2018	2018	2000
25	2000	2000	2000	2000	2000	2018	2018	2000
0	5047	5047	5047	5047	5047	5047	5047	5047

The results showed that the hub locations remain in the line of Antwerp-Brussels for discount factor 50 and 25, which is most likely to be achieved by an LHV. Belgium has initiated a trial for the usage of LHVs in Flanders. The following locations can be visited in the current trial: Antwerp (2000), Antwerp (2018), Antwerp (2610), Willebroek (2830), and Machelen (1830).

Antwerp remains a possible solution for the location of a hub. However, the use of LHVs in Belgium depends on the outcome of the current trial and remains uncertain. An alternative strategy is to use trailers between hubs, and rigid trucks and city trailers from the new hub to customers. Since using LHVs is the best strategy, the transportation costs of the LHV case were calculated in SHORTREC. The strategy of decoupling LHVs at Antwerp was applied and is shown in Figure 1. Only one additional Belgian driver and space for the storage of an extra truck (tow part) in Antwerp is required. Since an LHV requires both a trailer and rigid truck, the remaining trailers that cannot be coupled with a LHV start and end at Tilburg. The transportation costs of the current network and the new network with a hub in Antwerp, including the kilometer-based charge, are shown in Table 3.

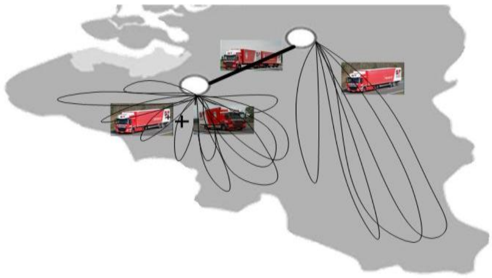

Figure 1: Overview of situation with decoupling LHVs in Antwerp

Table 3: Overview of transportation costs – Tilburg and Antwerp

Date	5047TM	Antwerp	Savings Antwerp
29-2-2016	€ 14,095	€ 13,360	€ 981
1-3-2016	€ 15,225	€ 14,626	€ 826
2-3-2016	€ 15,284	€ 15,036	€ 402
3-3-2016	€ 14,219	€ 13,628	€ 821
4-3-2016	€ 21,040	€ 20,172	€ 1,170
Total:	€ 79,864	€ 76,820	€ 3,156

The results show that GVT Transport already reduces transportation costs by decoupling LHVs in Antwerp. The trailers departing from Antwerp are assumed to be driven by Belgian drivers, which are on average 10% more expensive than Dutch drivers. Allowing all trailers and rigid trucks to depart from Antwerp requires a cross-docking or warehouse facility in Antwerp, resulting in a higher investment cost. Note that the created routes are planned from Tilburg to customers, and that only the beginning and end location of these routes is adjusted to Antwerp. By planning optimal routes from Antwerp to customers, transportation costs can be further reduced. GVT Transport is advised to apply the decoupling LHV strategy in the region of Antwerp within 10 km of a highway.

Finally some recommendations for the future are provided. Among other things, in order to provide insight into the costs when the strategy is adjusted but LHVs are not allowed, GVT Transport is advised to investigate the case study that applies the trailer strategy. This considers using trailers between hubs, and using rigid trucks and city trailers from Antwerp to customers. Furthermore, GVT Transport should conduct detailed research to determine the exact location of the hub, and investigate the effect of a new hub in Belgium on the whole network.

Preface

This master thesis is the result of a research project that was conducted in order to complete my Master Operations, Management and Logistics at the Eindhoven University of Technology. The project was carried out from November to May 2016 at Gebroeders Versteijnen B.V. I want to thank Gebroeders Versteijnen B.V for the opportunity to conduct my research at their company. I would like to thank some people who supported me during my graduation project and Master.

First of all, I would like to thank my mentor, and first supervisor of the TU/e, Luuk Veelenturf. I am very thankful for his available time to support me during my project, to answer my questions, and to provide new insights and advice to help me to successfully finish this graduation project. I would also like to thank Tom van Woensel, my second supervisor, for some critical thoughts and his time to evaluate my project.

Second, I would like to thank my supervisors Stan Hamers and Manon van Baest of Gebroeders Versteijnen B.V. They provided me the opportunity to conduct my research at Gebroeders Versteijnen B.V. Furthermore, they supported me in finding the right source for information and data, and they gave critical and useful comments during the project . Next to them, I also would like to thank some employees of Gebroeders Versteijnen B.V who answered all my questions or provided me with the required data. Thanks to Eric-Jan Pasveer (planner), Vincent Weller (planner), Joeri Stok (IT manager), Herman Scheele (IT specialist), Rob Embrechts (fleet manager).

Finally, I would like to thank my family for their support. Special thanks to my parents for the support and advice during these years. Next to them, also special thanks to my cousin who helped me to improve my report. Furthermore, I would like to thank my girlfriend for her support. Thank you!

Ian Ross
May 2016

Table of contents

List of Figures

List of Tables

List of abbreviations

AED	Apollo Express Delivery
Benelux	Belgium, Netherlands, and Luxemburg
CMR	Convention on the contract for the international carriage of goods by road
EOQ	Economic Order Quantity
EU	European Union
FLP	Facility Location Problem
FTL	Full Truck Load
GVT	Gebroeders Versteijnen B.V.
HLP	Hub Location Problem
HSL	Huisman & Scheur Logistic
ldm	Load meter
LHV	Long Heavy Vehicle
LP	Linear Programming
LLS	Lean Logistic Solutions
LRP	Location-Routing Problem
LTL	Less-than-Truckload
MIP	Mixed Integer Programming
M-M	Many-to-many
NP	Nondeterministic Polynomial time
O/D	Origin-Destination
PDP	Pickup and Delivery
SCM	Supply Chain Management
TMS	Transport Management System
VAL	Value Added Logistics
VBA	Visual Basic for Applications
1-1	One-to-one
1-M-1	One-to-many-to-one

List abbreviation countries

In the data of all the orders of last year, several abbreviations are used for countries. For example, the abbreviation B and BE are both used for Belgium. In order to provide standardization in each file the abbreviation of countries, based on the International Organization for Standardization (ISO) 3166 code, are used. These are standard abbreviations of the countries that are considered.

BE	Belgium
LU	Luxemburg
NL	Netherlands

1. Introduction

This chapter introduces the research conducted at Gebroeders Versteijnen B.V. (GVT) within the Transport department. GVT Transport is a department within GVT Group of Logistics, which is a group of specialized logistics companies, and the group offers services such as inland shipping and rail transport. GVT Group of Logistics is one of the largest actors in logistic distribution within the Netherlands (LLS, 2015). In 2016, GVT Group of Logistics was placed at number 26 out of the top 100 logistic service providers in the Netherlands (Logistic service providers, 2016). GVT Transport is responsible for the transport of goods within the Benelux countries by road. Road transportation includes two types of processes: pickup and delivery.

This chapter describes the development of GVT in recent years, and GVT Transport's current situation. First, the company foundation is described in Section 1.1, followed by the organization of GVT in Section 1.2. The current hubs of GVT are displayed in Section 1.3, and the different types of services are explained in Section 1.4. GVT Transport's current fleet is described in Section 1.5. Finally, an overview of GVT Transport's customers is displayed in Section 1.6.

1.1 Company foundation

The company was founded in 1957 by the Versteijnen brothers. In 1986, GVT began to specialize in road transport, and became known as GVT Transport. During the years that followed, GVT began transport by water and rail. A barge terminal in Tilburg was built in 1998, and the rail terminal in 2004. These modes of transport ensured that goods requiring medium- or long-range distances could be transported faster and more efficiently than would be possible with only road transportation.

In 2009, GVT Global Solutions was formed. GVT Global Solutions offers Supply Chain Management (SCM) services, and enables GVT to distribute goods throughout Europe, from shipment sizes of one pallet to those of Full Truckload (FTL). Thus, GVT distributes goods throughout Europe with Less-than-Truckload (LTL) and FTL. FTL is defined as a truck where the load fills up the entire truck space, whereas LTL is defined as a truck where the load does not fill the entire available space on the truck. FTLs are shipped directly to the customer and are faster than LTLs, as LTL combines shipments from multiple customers and often makes several stops to unpack and repack goods. For LTL, each company pays for the amount of space they use on the truck.

In 2011, GVT Transport expanded by taking over Greuter Logistics, which is located in Alkmaar in the Netherlands. In 2013, GVT Intermodal was created, and it has integrated the transport of goods via road, rail, and inland waterways. GVT Intermodal offers a perfect solution for all "door-to-door" requirements within the corridor of Netherlands-Germany-Austria-Slovakia, as well as transport to the United Kingdom from the Netherlands. In 2014, GVT Transport took over Huisman & Scheur Logistic (HSL). HSL is located in the Netherlands in Apeldoorn, Zwolle, and Veendam.
An overview of the foundation and expansion of GVT Transport can be seen in Figure 2.

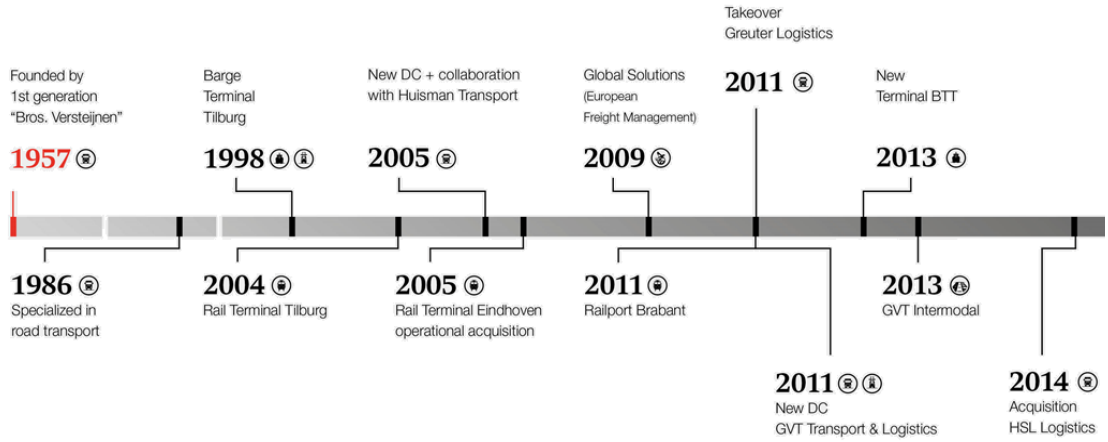

Figure 2: Overview of timeline of GVT Transport (GVT, 2015)

1.2 Organization

GVT Transport, Greuter Logisitics, and HSL are all part of GVT Group of Logistics. This is a group of specialized logistic companies that covers all the departments of GVT and other companies that co-operate with it. For this project, only transportation by road was considered, since the project was executed in the GVT Transport department. An overview of the organization of GVT Group of Logistics is shown in Figure 3.

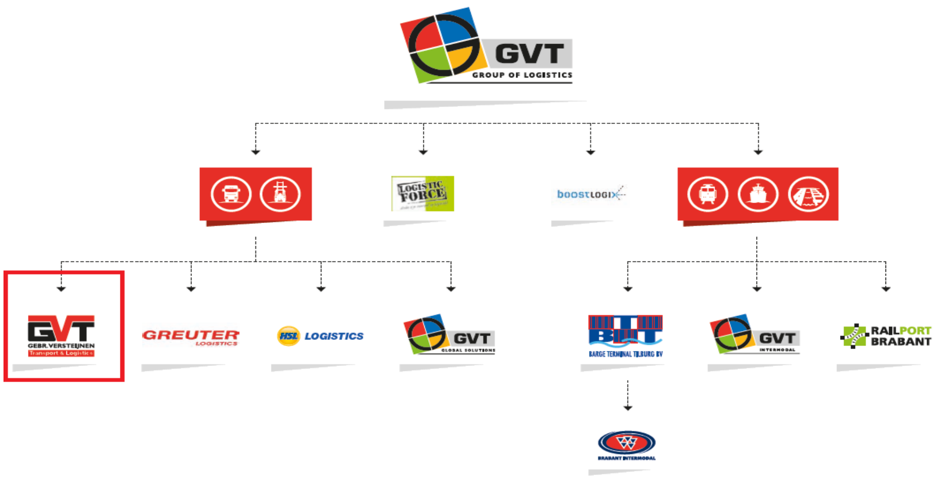

Figure 3: Organization of GVT Group of Logistics (GVT, 2015)

The red box denotes the department where this project was conducted. However, orders from Greuter Logistics and HSL that required delivery or pickup in Belgium or Luxemburg were also considered. Combined, these three companies are known as the Lean Logistic Solutions (LLS) network (LLS, 2015). Greuter Logistics and HSL operate under their own name and logo due to their brand awareness in their respective regions. Greuter Logistics operates mainly in the province of North Holland, and HSL operates mainly in Groningen, Friesland, Drenthe, Gelderland, and Overijssel. LLS has more than 350 trucks on the road daily, and visits approximately 5,000 addresses per day. LLS offers a Transport Management System (TMS) with real-time order tracking. This system has also been implemented at GVT Transport since April 2015.

1.3 Hubs

The LLS is a dense distribution network with several hubs located in, and serving the Benelux region. There are five hubs in Netherlands and one in Belgium. The hubs are located in the following locations:

- Tilburg, NL (GVT Transport);
- Alkmaar, NL (Greuter Logistics);
- Apeldoorn, NL (HSL);
- Zwolle, NL (HSL);
- Veendam, NL (HSL);
- Vilvoorde, BE (Apollo Express Delivery, hereafter “AED”) (This is an external company that delivers goods in Belgium for GVT Transport).

A map of hub locations is presented below in Figure 4.

Figure 4: Overview of current hubs (LLS, 2015)

The first five hubs listed above contain a total storage space of approximately 150,000m^2 (GVT, 2015). Tilburg has the most storage space with a total of 125,000m^2, and also has a cross-docking platform with 6,000m^2 of space. This hub is currently being expanded by 18,000m^2 of warehouse space and 4,000m^2 of cross-docking space, and the expansion is expected to be complete in 2016. Alkmaar has 3,500m^2 of storage space and 2,000m^2 of space for cross-docking. Apeldoorn has no storage space but has 8,000m^2 of space for cross-docking. Zwolle has 12,000m^2 of storage space and has no cross-docking space available. Veendam only has 500m^2 of cross-docking space. The hub in Vilvoorde does not contain any warehouse space, and has only 500m^2 of space for cross-docking. Goods are transported from Tilburg to Vilvoorde by trailers and subsequently transferred to rigid trucks at Vilvoorde. Vilvoorde has two rigid trucks, known as charters, which are used by AED to distribute for GVT Transport throughout the Brussels area. AED is specialized in the Brussels region, and only delivers and picks up goods within this region. GVT Transport determines which orders are delivered by AED and pays a fixed price per day unless AED travels more kilometers than was agreed upon beforehand.

GVT Transport also hires Van Rooijen to service very small-sized requests, defined as orders that are smaller than 0.015 a load meter (ldm). As these orders are not profitable for GVT Transport, they are outsourced to Van Rooijen. GVT Transport pays a fixed price per load.

1.4 Services

As mentioned in Section 1.1, GVT Transport provides different types of services, each of which are denoted by a symbol. An overview of these service symbols is provided in Figure 5.

Figure 5: Overview of GVT Transport service symbols (GVT, 2015)

A description of these services is as follows (GVT, 2015):

Transport: Distribution by trucks over road in the Benelux area. Partial-loads, but also FTLs are delivered within the Benelux region. Orders include both pickup and delivery, and can be combined on one truck.

Rail: Distribution by rail to Rotterdam and Central Europe. The railway network offers solutions for moving large volumes over medium-range distances. From the rail ports, the goods can be shipped to customers by barge or trucks.

Inland shipping: Distribution by waterways to the port of Rotterdam. Goods are shipped in large containers by barge. Transportation by barge is more environmentally friendly than road transport.

Logistics: GVT Transport contains approximately 150,000 m^2 of warehouse space divided over hub locations in Tilburg, Apeldoorn, Alkmaar, Zwolle, and Veendam. From these locations, oriented solutions in the field of warehousing, Value Added Logistics (VAL) and SCM are offered.

As mentioned in Section 1.1, GVT Intermodal integrates transport by road, rail and water, and GVT Global Solutions offers "door-to-door" solutions.

1.5 Fleet

GVT Transport's fleet consists of approximately 106 vehicles. When combined with Greuter Logistics and HSL, this number increases to more than 350 vehicles. There are five different types of vehicles in the fleet of GVT Transport:

- Rigid truck
- Dolly
- Trailer truck
- City trailer
- Long Heavy Vehicle (LHV)

Each vehicle type offers a different amount of space. The space in a truck is defined using ldm. One loading meter is defined as one meter in length of goods on a truck. One euro pallet corresponds to 0.4 ldm. Both a rigid truck and dolly can be filled up to 7.2 ldm, a city trailer up to 10 ldm, a trailer up to 13.6 ldm, and an LHV approximately up to 21.5 ldm. The difference between a rigid truck and dolly is that the dolly can be decoupled from the tow part of the trucks, whereas the rigid truck cannot be decoupled from the tow part. In most cases, an LHV is a combination of a trailer and rigid truck, or a trailer and dolly into one truck. The possible combinations of an LHV are displayed in Figure 6. The combination of a rigid truck with two dollies or three dollies is currently not used at GVT Transport.

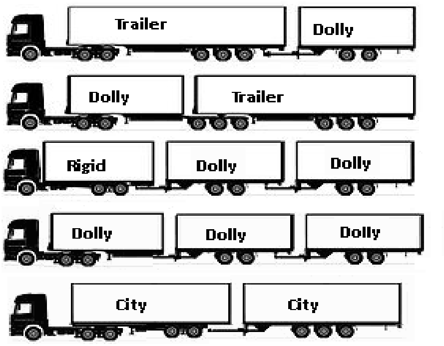

Figure 6: Combinations of LHVs

Each vehicle, independent of type, is labeled with a Euronorm, which is a European emission standard that defines the acceptable limits of exhaust emissions of new vehicles in the EU (Euronorm for vehicles, 2016). The Euronorm scale runs from 1 to 6, where 6 represents the lowest exhaust emissions. In total, approximately 79 vehicles of GVT Transport are labeled with Euronorm 5, nine vehicles are labeled with Euronorm 6, and only one vehicle each is labeled with Euronorm 2 and 4, respectively.

1.6 Customers

GVT Group of Logistics delivers all different types of goods, including clothes, electronics, and white goods. The customers of GVT Transport placing the most orders are Samsung, Syncreon, Sony, and Tristar. A customer overview is provided in Figure 7. The symbol of the type of service offered is noted beside each customer's name.

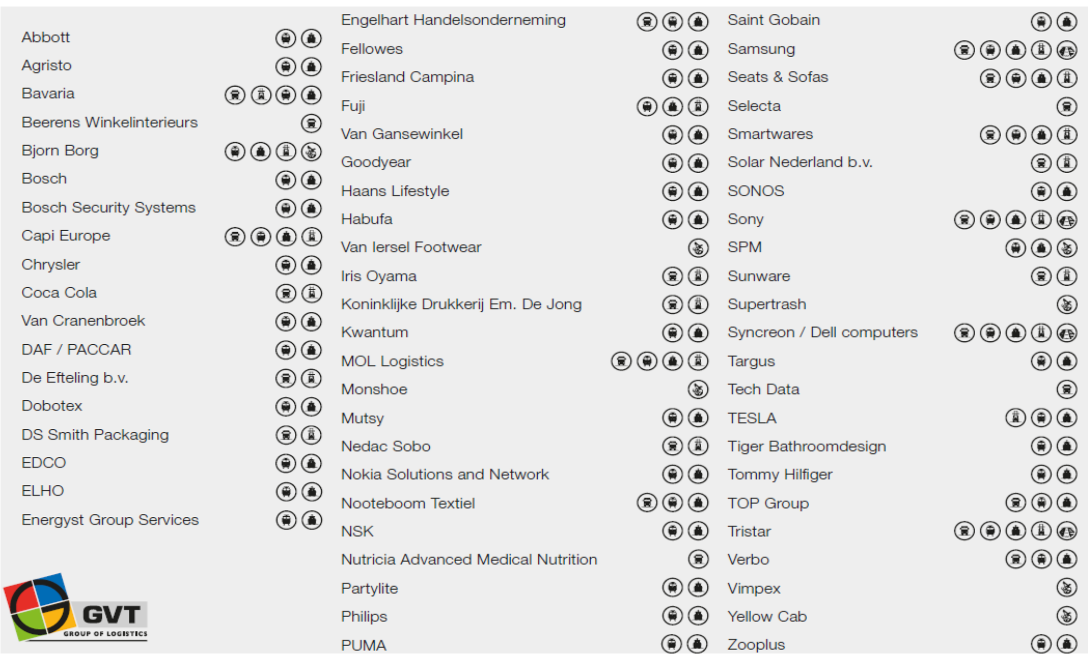

Figure 7: Customers of GVT Group of Logistics (GVT, 2015)

2. Problem description

GVT Transport considers both pickup and delivery processes during transportation. Goods are transported from customer to customer, customer to hub, hub to customer, and hub to hub. In the case of a pickup, there are several origins and few destinations, and the most common destination is Tilburg. In the case of delivery, there are several destinations and several origins, but the most common origin is again Tilburg.

The current network allows goods to be transported from the Netherlands to Belgium and Luxemburg, and vice versa. Since Tilburg is the nearest hub for Belgium and Luxemburg, trucks travel many kilometers and the density can be improved. Density is defined as the average distance in kilometers from a hub to all customers. In the Netherlands, approximately 50 km is the average distance from hub to customer. Currently, however, the average distance from Tilburg to a customer in Belgium or Luxemburg is approximately 150 km, meaning the current density can be improved. In addition, new kilometer-based charge legislation in Belgium was introduced in April 2016. The combination of traveling many kilometers and the higher costs per kilometer in Belgium has lead to an increase in the transportation cost. GVT Transport wishes to improve the current network design by establishing a new hub in Belgium. The location of the hub should both improve the density and decrease the transportation cost. Before any decisions are made, the question of whether a hub in Belgium is required should be discussed. For these reasons, this research considers the location problem applied to a logistics environment.

This chapter provides the background for this thesis. The research objective and the research questions are described in Section 2.1, and the transportation process of GVT Transport is explained in Section 2.2. The discussion regarding whether a new hub is required is described in Section 2.3. Possible distribution strategies are discussed in Section 2.4, and the scope of this thesis is provided in Section 2.5. The methodology of the execution of this research is described in Section 2.6, and the thesis outline is provided in Section 2.7.

2.1 Research objective

In order to address the new kilometer-based charge legislation that came into effect in April 2016, the density of the current network has to be improved to reduce transportation costs. For this reason, GVT Transport wants to investigate whether they should buy or build a new hub in Belgium, and what the most efficient location(s) would be. The main research objective was:

Improving the density of the current network design of GVT Transport.

The general research question was:

How can the density of the current network design of GVT Transport be improved in combination with reducing total transportation costs?

In order to achieve the research objective, multiple sub-questions were formulated:

1. **How are feasible hub locations determined?**

First, all possible locations are identified in Chapter 4. Next, the p-median model is applied to determine locations in Chapter 5. The sensitivity of the model is checked in Chapter 6, and the qualitative aspects are considered in Chapter 7.

2. **How are the network costs calculated?**

   The network cost is calculated based on the routes. The routes of a one-week plan are created in the software program SHORTREC, and are based on the current network. The results of the one-week simulation were used to calculate the transportation costs of the best strategy in Chapter 8, and this was compared with the transportation cost of the current network. Based on these costs, advice is provided to GVT Transport in Chapter 9.

2.2 Processes

As mentioned above, transportation by GVT Transport involves both pickup and delivery. Currently, pickup and delivery are combined on a single truck where possible. Both pickup and delivery can be take place simultaneously for a customer, as a truck can load goods even when it still contains goods that require delivery. Note that the pickup load meters should be less or equal to the remaining space on the truck. In total, 90,451 ldm and 33,672 ldm were delivered and picked up respectively in the period from July 2014 to June 2015. From these numbers, it can be inferred that several trucks return to Tilburg empty.

One example of a route used by GVT Transport that involves both delivery and pickups is displayed in Figure 8.

Figure 8: Example route used by GVT Transport that combines pickups and deliveries

The green line displays the route and the arrows indicate the direction. The white blocks show where goods are unloaded, and the blue blocks denote goods that require pickup. The size of the block displays the demand size, where smaller blocks equal less demand. The route starts at a block and ends at a block, however, the true origin and end location is the hub in Tilburg. In SHORTREC (a software program by ORTEC) the routes to and from the hub location are not displayed, in order to maintain an orderly view (ORTEC, 2015).

Demir et al. (2014) stated that SHORTREC allows the user to minimize the total costs and gain insights into routing decisions. The duration and distance to and from the hub location are included in the route planning. Furthermore, the required rest/break time of the driver, the pickup, and the delivery durations are also included in the route calculations. SHORTREC has a route optimization option, which takes the time windows into account. These time windows are specified by customers, and provide the timeframe in which the good should be delivered or picked up. If this time window is exceeded, the result could be a penalty cost for GVT Transport. However, not all customers have restricted time windows, and in consultation with the customer a time window can be adjusted. Customers' most common time window for delivery is between 08:00 and 17:00 hours.

At present, goods are transported by LHVs from hub to hub overnight, and stored at the hub nearest to their final destination. These goods are transported to the customer the following day.

2.3 Discussion

Both density and transportation cost should be optimized. Establishing a hub in Belgium will improve density, however, it may not necessarily lead to a decrease in transportation costs. Orders placed in the Netherlands with destination Belgium or Luxemburg are commonly collected and stored at the hub in Tilburg before transporting these to those countries. Therefore, during the creation of the routes, SHORTREC assumes that almost all orders with destinations in Belgium and Luxemburg are located at the hub in Tilburg. Similarly, SHORTREC assumes that all orders in Belgium and Luxemburg with destinations in the Netherlands are transported to the hub in Tilburg since these orders are commonly first transported to the hub. All trucks depart and end at the hub in Tilburg, and do not require any stops in the Netherlands. Furthermore, data shows that almost all the goods are transported from Belgium and Luxemburg to the Netherlands and vice versa. These results are displayed in Table 4.

Table 4: Distribution of load meters transported within countries

Pickup			Delivery		
From	To	% ldm	From	To	% ldm
Belgium	Belgium	1.08%	Belgium	Belgium	0.40%
Belgium	Luxemburg	0.01%	Netherlands	Belgium	96.21%
Belgium	Netherlands	98.48%	Netherlands	Luxemburg	3.39%
Luxemburg	Netherlands	0.43%			
		100%			100%

By simply placing a new hub in Belgium, the transportation costs can increase. In the Netherlands, the transportation between two hubs is executed by LHVs, however in Belgium and Luxemburg LHVs are currently prohibited. Trucks are, therefore, required to travel first from hub to hub, and then to the customer. As a result, the number of kilometers driven increases, compared to direct transportation from the hub in Tilburg. In this case, a new hub is not required, unless the distribution strategy can be changed.

Furthermore, in the current network of GVT Transport, the planners must account for European driving and rest time regulations, defined in Regulation (EC) No. 561/2006 of the European Union (European Union law, 2006). In addition, drivers should comply with the rules regarding working hours, which are specified in Directive 2002/15/EC (European Union law, 2002). The work time restrictions were introduced next to the EU drivers' hours, as some drivers are expected to work long hours while doing other work in addition to driving. A summary of the driving time and working time regulations is provided in Appendix A.

Currently, these regulations result in problematic situations for the planners of GVT Transport. For example, due to the regulations and multiple stops, two trucks are required to pick up and deliver goods in Luxembourg, even though the number of orders could fit into one truck. The travel time to and from Luxemburg is six hours from Tilburg. This situation commonly applies to orders that are placed in the south-east of Belgium and in Luxembourg. By locating a hub in Belgium, the driving time to the customers in Belgium and Luxemburg can be reduced, and trucks can be used more efficiently thus reducing costs. However, the percentage of goods ordered in Luxemburg is low (4%), and the reduction in cost would probably not allow a new hub to be profitable. Thus, before creating a new hub, GVT Transport should carefully consider types of distribution strategies.

2.4 Strategies

As GVT Transport's nearest hub for Belgium and Luxemburg is currently Tilburg, economies of scale can be realized by establishing an intermediate hub in Belgium (Laporte, 2015). The advantage of economies of scale lies in the transportation between hubs. However, realizing economies of scale highly depends on the type of strategy. There are four common strategies that are used by transportation companies to organize their distribution activities (Buijs et al., 2014). These strategies are: direct shipment, milk runs, cross-docking, and warehousing. In Section 2.4.1, the direct shipment strategy is introduced. The milk run strategy is described in Section 2.4.2, and the cross-docking strategy is discussed in Section 2.4.3. In Section 2.4.4, the option of warehousing is discussed. The use of an LHV is described in Section 2.4.5, and the use of trailers between hubs is discussed in Section 2.4.6.

2.4.1 Direct shipment

Direct shipment is defined as direct transportation from origin to destination (Buijs et al., 2014). Orders from customers that equal an FTL size (12 ldm or more) are transported directly from the hub to the customer and vice versa by GVT Transport. Orders with 12 ldm or more are considered by GVT Transport as sufficient to travel as FTL directly to the customer. In total, approximately 27% of the load meters delivered to Belgium and Luxemburg and 60% of load meters picked up at those locations equal an FTL order. For pickup and delivery, this equals 20,124 ldm and 24,286 ldm, respectively. In the case of an FTL order size for delivery, the truck travels directly to the customer (one stop) and can pick up goods while traveling back to Tilburg (multiple stops). In the case of an FTL order size pickup, the truck can deliver goods en route to customers (multiple stops) until the pickup destination is reached. From the pickup destination the truck travels directly to the hub (one stop). Note that the truck is required to arrive empty at the pickup location. With this in mind, it can be seen that in the case of direct shipments, a new hub in Belgium is not required.

2.4.2 Milk runs

Milk runs involve grouping shipments into routes, and then visiting multiple origins and destinations sequentially (Buijs et al., 2014). The remaining orders (<12 ldm) are combined by GVT Transport onto trucks in order to achieve an FTL. In some cases, orders can be combined at the hub in Tilburg where goods are stored in the warehouse. In other cases, they can be combined at the locations of customers nearby. In the case of combining goods at Tilburg, a new hub in Belgium is not required. This is applicable for approximately 71% of the total amount of load meters delivered, since these originate from Tilburg.

Approximately 60% of the orders picked up in Belgium and Luxemburg are destined for Tilburg. The total amount of ldm to and from countries or locations is displayed in Table 5.

Table 5: Overview of transportation to and from locations

Pickup				Delivery			
From	To	% ldm	ldm	From	To	% ldm	ldm
Belgium/ Luxemburg	Tilburg	59.52%	20039.61	Tilburg	Belgium/ Luxemburg	71.28%	64471.36
Belgium/ Luxemburg	Other NL	38.97%	13120.56	Other NL	Belgium/ Luxemburg	28.32%	25612.66
Belgium/ Luxemburg	Belgium/ Luxemburg	1.52%	511.08	Belgium/ Luxemburg	Belgium/ Luxemburg	0.40%	366.06

2.4.3 Cross-docking

Cross-docking is defined as the transportation process to the final destination by recombining goods that share the same or near destination, without storing products and materials in a distribution center (Apte and Viswanathan, 2000). By applying cross-docking, the goods are picked up at multiple adjacent origins and combined into FTLs, which are then sent to the cross-dock location (new hub) where they are unloaded and recombined into trucks that share the same destinations (Bozer and Carlo, 2008). As a result of cross-docking, transport efficiencies can be realized through reduced handling and storage costs. As mentioned in Section 2.4.2, approximately 71% of the total amount of load meters delivered can already be transported from Tilburg to destinations and do not require cross-docking. In addition, trucks that consist of FTL orders also do not require cross-docking. Cross-docking could be useful for the remaining 29% of the total amount of load meters delivered, since these do not originate from Tilburg. It should be noted, however, that orders along the route to the customers can be picked up that share approximately the same destination. The percentage that could be useful for cross-docking would then decrease even more. With this in mind, it seems that cross-docking in Belgium with their current strategy is probably not useful to reduce the transportation costs significantly.

2.4.4 Warehousing

Warehousing enables the consolidation of shipments to customers by assembling full truckloads from the products that are stored in the warehouse (Buijs et al., 2014). As a result, trucks can originate from this new hub location and do not need to travel back to Tilburg. Sometimes goods cannot be delivered directly to a customer on the same day the truck set out, and thus require storage. This can create a problem when, for example, an order is picked up in Belgium to be delivered in Belgium, but the order cannot be delivered on the same day as pickup. Since Tilburg is the nearest hub location, the goods are then transported there for storage. On another day, these goods are transported from Tilburg back to Belgium, and as a result, extra kilometers are traveled simply because no warehousing is available in Belgium.

Exact data regarding orders that fall under this category is not available, since the data file provided only considers the transportation to and from a location per order. However, the planners of GVT Transport state that this situation only occurs in very few cases. Warehousing at the new hub location can reduce the amount of kilometers required to travel, but it would also increase the warehousing cost. The amount of warehouse space determines the number of goods that can be stored, depending not only on the available square meters, but also on the height of the building. Exact percentages of the reduction of transportation between Tilburg and the potential new hub cannot be provided, because the data is not available. Considering the amount of load meters transported back to the Netherlands, warehousing is probably not feasible for reducing costs. Almost all goods are destined for the Netherlands, so it is more efficient to store goods in Tilburg.

2.4.5 LHVs

Another method to achieve economies of scale is the use of LHVs. An LHV can transport more goods than a normal truck, as the available space on an LHV is approximately 21.5 ldm, compared to 13.6 ldm for a normal truck. There are two methods that can achieve economies of scale:

1. All goods transported from hub to hub by LHVs

All goods can be transported by LHVs between hubs, and at the new hub these goods can be divided between trailers and rigid trucks. The number of trucks that will be required to travel between Tilburg and the potential new hub will be reduced by approximately 40%. However, the division of goods at the new location requires warehousing or cross-docking, and this results in extra warehousing costs.

2. Decoupling the LHV

At the new hub location, LHVs can be decoupled into a trailer truck and a dolly. At the new hub location, an extra truck (the tow) is required to couple with a trailer or dolly. These two trucks visit the customers and return to the new hub location, where the trailer and dolly are coupled back into one LHV. This means that both space for storing trucks and supplying extra drivers is required as part of any potential new hub. This can be seen as a special case of cross-docking applied to the rolling stock. A disadvantage is that the number of LHVs is equal to the amount of rigid trucks planned for the new location, since a combination of two trailers is not possible in an LHV configuration. The remaining trailers should start and end at Tilburg. This disadvantage can be overcome by creating a cross-docking facility at the new location. The discount will be lower with the decoupling strategy compared to transporting all the goods by LHVs between hubs, since with the decoupling strategy vehicles still travel from Tilburg to customers.

2.4.6 Trailers

Another method to achieve economies of scale is to replace the LHVs with trailers between the hubs. This approach is similar to the LHV method; trailers transport goods between hubs and goods are distributed across city trailers and dollies or rigid trucks, which can transport 10 and 7.2 ldm respectively. Compared to a trailer, the weight of the city trailer or rigid truck is less, and they can travel faster and are smaller. The use of a city trailer or rigid truck is, therefore, cheaper than the use of a trailer. However, in cases where the quantity of load meters is between 10 and 13.6 ldm for the same customer, it is more efficient to use one trailer or to execute two trips with one rigid truck than it is to use two rigid trucks. However, executing two trips with one rigid truck results in more kilometers driven than using one trailer, since the rigid truck must travel to the hub twice. Despite this difference in distance traveled, it should be noted that rigid trucks can be used to deliver goods to customers whose locations cannot be serviced easily by trailers. One example of such a location is the region of Brussels, which is currently served by rigid trucks through AED.

2.5 Thesis scope

As mentioned in Section 1.1, only transportation by road is examined in this thesis. The current business of GVT is taken as the starting point. Data from 1 July 2014 to 30 June 2015 was available. Only working days were considered, and weekends and national holidays were not taken in to account as they consisted of less than 1% of all orders. Commonly, these were backorders. Orders that consisted of less than 0.015 load meters are outsourced. Outsourcing these orders is presently cheaper for GVT Transport than handling these orders themselves. The orders with Tech-data or Neele-Vat as commissioners were not considered, since they are no longer customers of GVT Transport.

In this thesis, only GVT Transport was analyzed, including transport within the Benelux region. Most transport outside the Benelux area is executed by partners of GVT Transport and are therefore not within the scope of this thesis. GVT Transport only operates a few FTL line-haul services to Germany, which are mainly executed at night. The most common destinations in Germany are Duisburg or Köln. The number of load meters to Germany constitutes approximately 30% of what is transported to Belgium and Luxemburg. A new hub for these routes to Germany would have little effect on the transportation costs, and may even lead to an increase in these costs. As the new kilometer-based charge was introduced in Belgium, only the hub in Tilburg was examined for the Netherlands, since Tilburg services all the orders to and from Belgium and Luxemburg. The remaining parts of the Netherlands are excluded from analysis.

The focus of this research is on reducing the transportation flow cost. It is assumed that the costs of building or buying a new hub are equal, independent of location. No exact calculations are made for the materials and personnel, since the focus is placed on reducing the transportation flow cost. A fixed cost is set for orders that are outsourced. A fixed cost per load is paid to Van Rooijen, and a fixed cost per kilometer driven is paid to AED. It is assumed that the same orders are outsourced in both the current, and the new network, so these costs remain unchanged.

The parameters of this research can be summarized as follows:

- Data from 1 July 2014 to 30 June 2015 is analyzed.
- Only working days are included in this data, excluding national holidays.
- Only orders that consist of 0.015 ldm or more are included in this study.
- The former customers Tech-data and Neele-Vat are out of the scope of this research.
- Only the department GVT Transport is studied.
- Only Belgium, Luxemburg, and the region surrounding the hub in Tilburg is within the scope of this research.
- No exact calculations for materials or personnel are made.

2.6 Methodology

In location theory, a methodology containing preprocessing, quantitative modeling, and post-processing is applied (van Woensel, 2014). This methodology is divided into four steps:

Step 1: Preparatory work, the region under consideration, possible locations for distribution centers, and the gathering of necessary data.

Before the start of the project, a literature review is performed to gain insight into the topic. This review is the first activity necessary for achieving the research objective. After the literature review was conducted for this project, the data file of GVT Transport was collected and examined. Information within the data file was checked for completeness and correctness, and after the file was completed and corrected an analysis was performed to create an overview of GVT Transport's current situation. Subsequently, possible hub locations were identified by means of demand, and the distances between these possible locations and demand points were calculated.

Step 2: Find the best possible hub location.

This step considers the quantitative model for determining a hub location. The hub location is determined by the p-median model, which minimizes the average demand-weighted distance.

Step 3: Apply qualitative factors to the solutions obtained from the quantitative model.

The qualitative aspects in location decision-making are investigated. These aspects are considered for the results of the p-median model.

Step 4: The selected location, based on both qualitative and quantitative analysis, is used for creating a test planning in SHORTREC.

Test planning consists of the current situation, which is adjusted to the new situation by only changing the hub location. The results are used for calculating the transportation costs and these costs are subsequently compared.

Upon completion of these steps, a recommendation to GVT Transport was provided for the different options/scenarios that are considered within the project.

2.7 Outline

Before the start of the project, a literature review was conducted. The main findings of this review that can be used in this thesis are described in Chapter 3. The next step in the execution of the project is to examine the data. This analysis is provided in Chapter 4. The distances between demand nodes are calculated, and the quantitative location models are described in Chapter 5. In Chapter 6, the sensitivity of the quantitative models is verified, and the qualitative aspects of the hub location are discussed in Chapter 7. Based on the solutions, a simulation for the current and new location is executed by using one week's worth of data. The results of the simulation are used to calculate the transportation costs for the best possible strategy, and the results are discussed in Chapter 8. Finally, based on the simulation, a recommendation is provided to GVT Transport in Chapter 9.

3. Literature review

The research area of this thesis addresses the location problem. This problem can be seen as a special network design problem, which consists of three different decision-making levels: strategic, tactical, and operational (Ghiani et al., 2013). The location problem can be classified as part of the strategic decision level. These are long-term choices that have a long-term effect on the logistics system, and typically involve significant financial investments (Ghiani et al., 2013). The Pickup and Delivery Problem is addressed in Section 3.1. The Facility Location Problem is introduced in Section 3.2, and the Hub Location Problem is discussed in Section 3.3. In Section 3.4, the Location-Routing Problem is discussed. A general conclusion of the literature review is provided in Section 3.5.

3.1 Pickup and Delivery Problem

GVT Transport engages in two types of processes for transporting goods by road, as noted in Section 1.1. These two processes can be seen together as the Pickup and Delivery Problem (PDP). Savelsbergh (1995), defined a PDP as a transportation request that specifies a single origin (pickup) and a single destination (delivery), where all vehicles depart from and return to a central depot. At GVT Transport, pickup mostly has several origins and few destinations, whereas delivery mostly has few origins and several destinations. However, combining both delivery and pickup provides an approximation of Origin-Destination (O/D) pairs. Since these two processes are combined in routes, this automatically results in several origins and destinations. This is considered as the many-to-many (M-M) variant of the PDP, since there are multiple origins and destinations (Berbeglia et al., 2007). Furthermore, GVT Transport also deals with direct line-haul transportation in the case of FTL orders, which can be seen as the one-to-one (1-1) variant containing only one origin and one destination. In the one-to-many-to-one (1-M-1) problem, goods are initially available at the depot and destined for several customers, whereas the many goods that are located with customers are destined for the single depot, as is the case in SHORTREC (Berbeglia et al., 2007).

3.2 Facility Location Problem

The Facility Location Problem (FLP) is a long-term strategic decision to establish a new facility in order to optimize at least one objective function (Farahani et al., 2010). Possible objective functions could be optimizing cost, profit, revenue, travel distance, service, waiting time, etc. Typical FLPs are the p-median, uncapacitated facility location, p-center, and covering problems. One of the earliest models presented was the p-median of the FLP. The p-median minimizes the sum of the shortest demand-weighted distances traveled. Van Woensel (2014) noted the "complexity" of the p-median problem, which corresponds to $\binom{n}{p}$. Where *p* is the number of facilities and *n* the number of customers. In the case of *n*=20 and *p*=5, there are 15,504 solutions possible. Thus, the number of solutions to evaluate could be enormous.

The "minimax criteria" was a concept introduced by O'Kelly and Miller (1991). Campbell (1994), introduced the p-hub center problem and this was the second paper that considered the minimax criteria. This problem is commonly used for emergency services such as fire stations and ambulances, and seeks to achieve a maximum acceptable travel distance or time (Owen & Daskin, 1998). The p-center problem is defined as finding the location of p facilities such that the maximum travel time (or distance) between any O/D pairs is minimized (Campbell et al., 2005). This is also known as the "minimax problem" since the maximum distance is minimized between any demand and its nearest facility/hub. These are both Nondeterministic Polynomial time (NP) hard problems.

This thesis utilizes the network location model, where distances are computed as shortest paths in a graph. In this graph, the demand points are represented by nodes, and potential facility sites correspond to a subset of the nodes and to points on arcs (Klose and Drexl, 2005). In the FLP, service is provided from the facilities, and flows either originate from demand nodes with their destination as facilities, or vice versa (Laporte et al., 2015). Demand nodes are allocated to a facility in the network design. Generally, the FLP executes a single assignment by assigning each demand node to its closest open facility (Laporte et al., 2015).

By establishing a new facility in Belgium, a two-echelon FLP exists for Tilburg and the newly located hub. The **two-echelon FLP** addresses delivery from the first-echelon facility to the second-echelon facility, and from there to customers (Tragantalerngsak et al., 1997). This occurs, for example, when GVT Transport first transports goods between two hubs.

3.3 Hub Location Problem

"The Hub Location Problem is concerned with establishing hub facilities and allocating demand nodes to hubs in order to route the traffic between Origin-Destination pairs" (Alumur and Kara, 2007). Over the years, several types of models of the Hub Location Problem (HLP) have been reviewed according to their objectives, network components, and constraints. One of the first papers that discussed the HLP was that of Goldman (1969). The first mathematical formulation, Mixed Integer Programing (MIP), for a HLP was presented by O'Kelly (1987). The typical FLP models are also studied within the HLP. The p-hub median problem is defined as determining the location of p-hubs so that the sum of the costs of transporting flow between all O/D pairs in the network is minimized (Campbell et al., 2005).

The HLP is closely related to the FLP, and the key difference between FLP and HLP relies on the functions provided by the facilities and the requirements of users on the type of service demand (Laporte et al., 2015). One important difference between HLP and FLP is that HLP has multiple and single allocation models. In a single allocation model, each demand point is allocated to exactly one hub node, whereas in the multiple allocation model demand points can be allocated to more than one hub (Drezner and Hamacher, 2002). The FLP only considers single allocation models. Furthermore, in HLP demand is defined as flows between many origins and destinations, whereas with FLP the demand for service occurs at discrete points (Drezner and Hamacher, 2002).

The HLP has a variety of applications including airline systems, distribution systems, and telecommunication network design, and the determination of the hub location can be challenging (Campbell et al. 2007). The flow between each demand node can be connected directly, which may be highly inefficient (Tan and Kara, 2007). In the case of using a hub, flows with the same origins but different destinations can be consolidated at a hub node on their route. At the hub node, these flows are combined with other flows from different origins that share the same destination (Tan and Kara, 2007). This phenomenon is known as "hubbing" and can achieve economies of scale in routing costs through the consolidation of flows, as well as help reduce setup costs and centralize commodity handling and sorting operations (Laporte et al., 2015). In the event that a hub would serve as a transshipment point, flows are processed and redirected to other hubs or O/D nodes with far fewer links than required for direct connections. The services of a hub are provided in an M-M distribution system (Alumur and Kara, 2007). Hubs allow fewer connections, as well as indirect ones between all nodes, and the use of hubs can result in lower network costs (Campbell et al. 2007). However, routing all trucks through a hub is not always the best option. Direct shipments between supply and delivery points can result in cost efficiency if vehicles are fully loaded and will stop at only one, or a few adjacent destinations (Rieck et al., 2014).

3.4 Location-Routing Problem

The location problem does not consider the problem of acquisition and routing of vehicles. Perl (1983) showed that locating depots and routing vehicles simultaneously improves the distribution system design, a strategy that is known as the Location-Routing Problem (LRP). Srivastava and Benton (1990), defined the LRP as determining the location of depots and routes to customers from a feasible set of potential depot and customer sites in such a way that overall cost is minimized. By not considering the determination of these routes to customers may lead to increased distribution cost (Salhi and Rand, 1989).

Although this thesis focuses on the issue of location, routes for a one-week plan are created to provide insight into the transportation cost. These routes are planned in SHORTREC based on the selected location, and consider the sequential heuristic of the LRP. The sequential heuristic first solves the location issue and then the routing issue (Nagy and Salhi, 2007).

3.5 Conclusion

Some shortcomings have been identified in the literature review. Literature that considers distribution networks of delivery companies commonly assume a predefined set of possible locations or fixed hub locations (Tan and Kara, 2007). However, in this thesis the set of possible locations needs to be determined. The focus of these papers is on the network design aspect, and the actual determination of possible locations is commonly ignored. Furthermore, environmental aspects, such as infrastructure, are usually not considered. Infrastructure is an important topic since it can have influence on the transportation costs.

Since the routing aspect is executed by the planners, locations are determined with the p-median model. The actual allocation of demand nodes to facilities is executed by the planners, and depends on the particular situation of each individual day. Because the distance traveled is considered to be more important than improving the service time, the p-median is preferable. Based on the current network design, the p-median model is used to determine the best geographical location for a hub in Belgium for minimizing the demand-weighted average distance. In addition, the model is adjusted to consider the economies of scale between hubs.

Based on the demand locations in the data set, the model provides multiple options for hub location, depending on different scenarios. Qualitative factors are considered for the resulting locations. The actual function of the facility is determined by GVT Transport, and is based on the recommendation. Then, the sequential heuristic for the LRP problem is used to create routes with SHORTREC, which are based on the location determined by the p-median model. Finally, the network cost is calculated based on the planned routes.

4. Data analysis

The data used in this thesis was retrieved in a Microsoft Excel format. This data set is described in Section 4.1. After retrieval, the data set was examined for missing data and outliers, and this procedure is described in Section 4.2. After the data file was complete the information was examined. Section 4.3 contains the set of possible locations identified based on demand locations. The results of the analysis are provided in Section 4.4.

4.1 Dataset

For this thesis, the period from 1 July 2014 to 30 June 2015 was considered. Information that was not required for the analysis, for determining hub locations, or for determining routes was not analyzed. The information that was included in this analysis is provided in Table 6.

Table 6: Information included in data set

Dossier number	Order number	Order date	Commissioner
Pickup name	Pickup street	Pickup street number	Pickup zip code
Pickup city	Pickup country	Pickup date	Pickup plan area
Delivery name	Delivery street	Delivery zip code	Delivery street number
Delivery zip code	Delivery city	Delivery country	Delivery date
Delivery arrival date agreed	Delivery arrival time agreed	Delivery max. arrival time	Delivery plan area
Transport amount	Transport unit	Amount ldm	Cost/profit

With the help of the dossier and order number, the orders are checked in GVT Transport's system when data is missing or seems incorrect. The exact location of customers, the amount of load meters, and the dates for delivery and pickup are known. Additionally, the time window that is applicable for each order is known, which is necessary information for determining routes.

The data only provides information about the beginning and end location per order, per day. If an order is picked up and stored at a hub on one day (intermediate destination), this information is stored. This raises a problem when the final destination of the order is to a customer while the order requires an intermediate destination before the final destination date, as this cannot be seen in the data file. The transportation from the intermediate destination to the final destination appears as a new order on a new date. As mentioned in Section 2.4.4, the planners state that this situation occurs only in very few cases. Commonly, orders can be delivered to their final destination in a single day.

4.2 Examining data

In total, 33,672 ldm were picked up during the selected time period, corresponding to 18,944 orders. For delivery, 90,451 ldm were delivered, corresponding to 119,696 orders. Many orders are exactly one pallet, however there are orders that comprise less than one pallet. Roughly 42% of all orders constitute one pallet per order for pickup, while for delivery this number is approximately 28%. Approximately 10% and 27% of all orders were less than one pallet for pick up and delivery, respectively.

The distribution of load meters in Belgium and Luxembourg is provided in Figure 9 for delivery, and in Figure 10 for pickup. The maximum order quantity possible is 13.6 ldm, which is a full truck. Comparing both figures, it can be seen that there are more FTLs for delivery than for pickup. As can be seen in Figure 9, the most ordered quantity is between one and two pallets. When the load meters are considered separately, one pallet is the highest ordered quantity, as one pallet almost equals the orders between 0.4 and 0.8 already. As can be seen in Figure 10, one pallet is already the highest ordered amount.

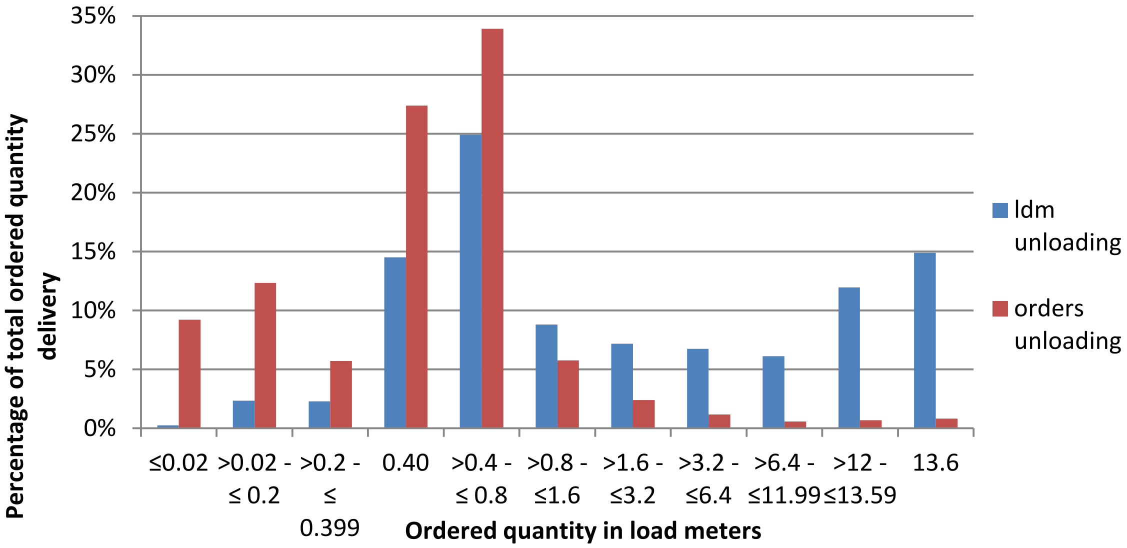

Figure 9: Distribution of load meters for delivery to Belgium and Luxemburg

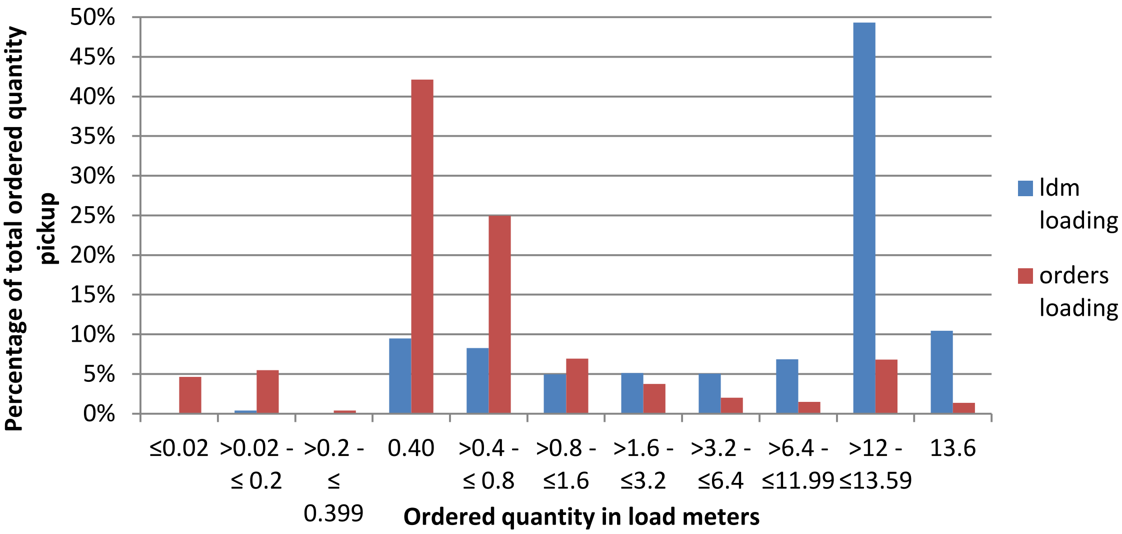

Figure 10: Distribution of load meters for pickup in Belgium and Luxemburg

4.3 Results

The data file is separated by delivery and pickup, since these are two different activities. To provide a reliable approximation of the combination of these two processes, the maximum amount of load meters between delivery and pickup per day, per zip code was selected. Selecting the maximum amount of load meters between pickup and delivery per zip code per day is referred to as combined*. Selecting the maximum per zip code, per day ensures that demand at each zip code can be satisfied almost completely each day, as the two processes can be combined during a route. In practice, however, this many not necessarily work, as the actual routes are dependent on other factors such as the distribution of load meters at locations, duration of the route, and the time windows of customers. Although this method does not display the real situation exactly, it can provide a good approximation of the combination of delivery and pickup.

Belgium is divided into provinces, while Luxembourg is broken into districts. In the remainder of this thesis, the districts of Luxembourg are referred to as “provinces”. Belgium is divided into 11 provinces, and Luxembourg into three. Each province consists of several zip codes, and the different zip codes associated with the various provinces are provided in Appendix B. During the analysis of the data, different methods were applied to provide different types of data overviews. First, an overview of the distributions per month was created and checked for any seasonality. This information is provided in Section 4.3.1. Second, an overview of the results by province in Belgium and Luxemburg was created, which is provided in Section 4.3.2. Finally, an overview of the results by province combined* was created. This overview is discussed in Section 4.3.3.

4.3.1 Results by month

The data spans a one-year period. During such a time span, almost any manufacturer or distributor can expect to have seasonal fluctuations in their demand. Everything from peak holiday sales activity to droughts in sales due to seasonal weather changes can influence demand (Ghiani et al., 2013). The data presented here was investigated to determine whether GVT Transport sees fluctuations in their demand, and if such changes do occur, to determine when and how large these fluctuations are. Both pickup and delivery were considered separately for Belgium and Luxembourg. When pickup was examined, the number of orders was found to fluctuate slightly. In Figure 11, a graph containing the orders and load meters picked up during the period of analysis is provided.

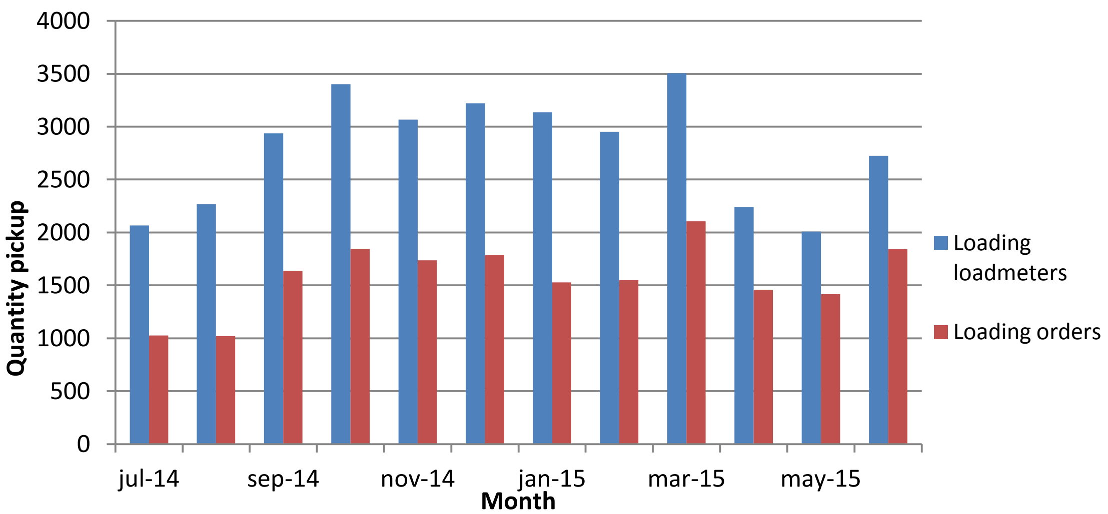

Figure 11: Distribution per month of load meters and orders for pickup

As can be seen in Figure 11, the number of orders is lowest in July and August 2014. A possible explanation for fewer orders in August is that it only consists of 20 working days, while July 2014 consisted of 22 days. Furthermore, these two months are during summer holidays. From

September 2014 to February 2015 the number of orders fluctuates slightly, and these months have at least 500 orders more on average than July and August 2014. A possible explanation for the increase in the number of orders from September to December is the national holidays in December. Saint Nicholas and Christmas are celebrated in December, holidays for which many presents are purchased. In April and May 2015 the number of orders decreased sharply, by approximately 700 orders, compared to March 2015. A possible explanation for this sharp decrease is again the national holidays which fall in these months. In April 2015, King's Day is celebrated in the Netherlands and Easter is celebrated in both the Netherlands and in Belgium and Luxemburg. This means that in April 2015 there were only 20 working days, and in March 2015 there were 22. The same applies for May 2015, which has the national holidays Whitsunday and Ascension Day. The month of May has the fewest number of working days, at only 19 days for the entire month.

The distribution of load meters has a standard deviation of 526 ldm per month. Thus, 68% of the amount of load meters are within one standard deviation from the mean, which is between 2,280 and 3,332 ldm per month. On 8 January 2015, the highest quantity of load meters was ordered for pickup, with 267 ldm. An overview of the detailed specification of pickup per month is provided in Appendix C. For delivery, the fluctuations differ from those for pickup. In Figure 12, a graph displays the distribution of orders and load meters of delivery during the months of the time period analyzed.

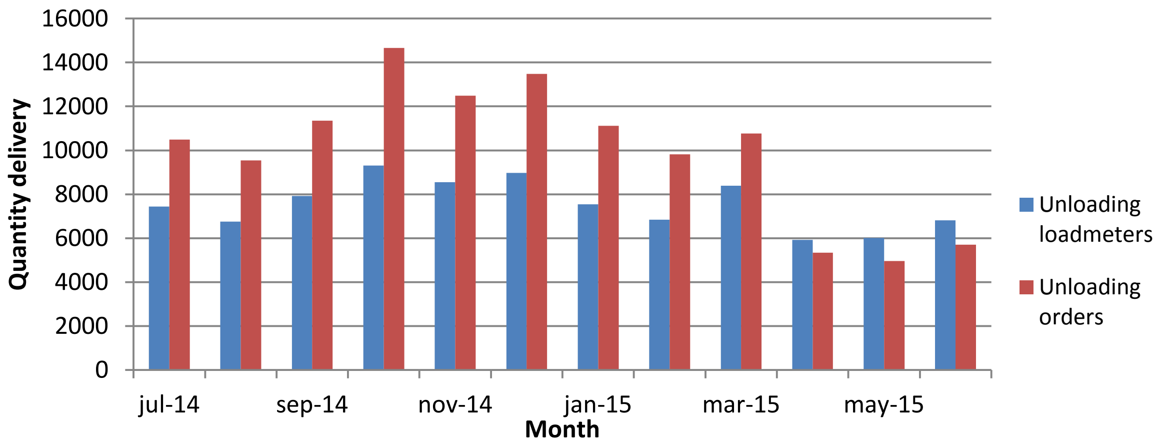

Figure 12: Distribution per month of load meters and orders for delivery

One main difference from pickup that can be seen immediately in Figure 12 is that for almost every month, the total number of orders is higher than the amount of load meters. Only from April to June 2015 is the number of orders somewhat lower than the amount of load meters. With pickup, the average ldm per order is 1.8, whereas with delivery it is 0.81 ldm per order. Furthermore, the fluctuations for delivery are greater than the fluctuations for pickup. The standard deviation of the amount of load meters is 1,114 per month, which is almost twice as much as for pickup. The peak is reached in October 2014. A possible explanation for this peak is the preparation for the national holidays in December. After December 2014, the number of orders slightly decreases. As with pickup, during April and May the number of orders dropped significantly. As explained previously the national holidays could account for this. In June 2015 the number of orders increased marginally, but was still significantly less than the period from July to March 2015. On 12 November 2014, the largest quantity of load meters was ordered for delivery, consisting of 633 ldm. An overview of the detailed specifications of delivery per month is provided in Appendix D.

4.3.2 Results by province

It can be concluded from examining the data that the highest number of load meters (8,896) are picked up in West-Flanders. An overview of the provinces with their respective percentage of orders and the percentage of load meters that were picked up during last year in Belgium and Luxemburg is provided in Figure 13.

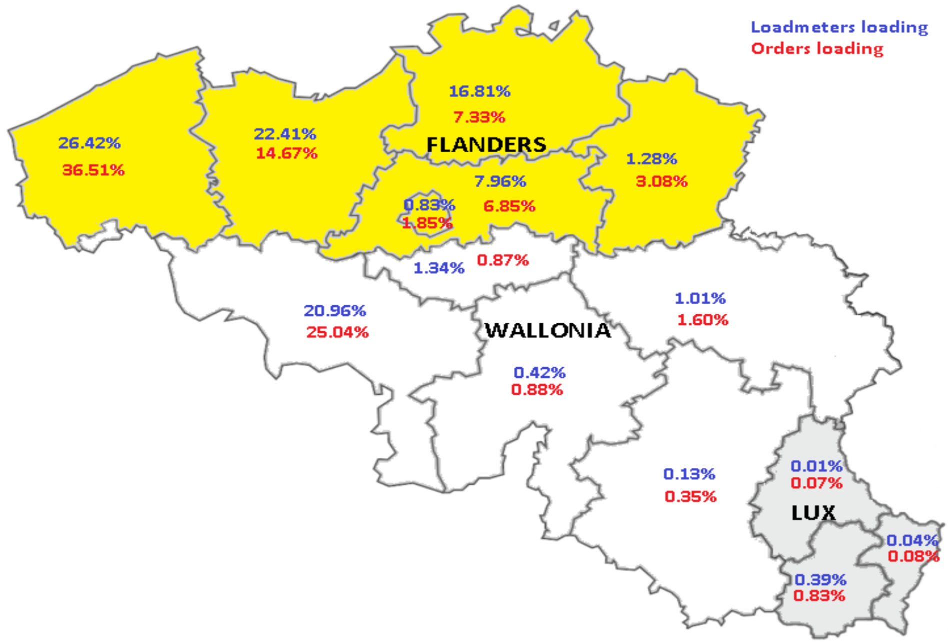

Figure 13: Overview of orders and load meters by province for pickup

For delivery, the largest quantity of load meters (25,190) is delivered to Antwerp. An overview by province in Belgium and Luxemburg containing more details about the number of load meters and orders for both pickup and delivery is provided in Appendix E.

The main transportation activities of GVT Transport in Belgium and Luxemburg are executed in Flanders. As can been seen in Figure 13 and Figure 14, approximately 75% of the load meters for both pickup and delivery are in this region, indicated by yellow in the figures. The remaining orders are delivered/picked up in the Walloon provinces and Luxemburg. Almost all of the goods that are loaded in Belgium are transported to the Netherlands, and goods that are unloaded in Belgium often come from the Netherlands, as mentioned in Chapter 2. An overview of the number of orders and quantity of load meters transported to/from Belgium and Luxembourg is displayed in Appendix F.

The minimum and maximum amount of load meters of an order is examined for each province. For almost every province the minimum quantity is 0.020 ldm, but for some, the minimum is 0.015, 0.017, 0.018, or 0.040. The maximum values vary more between provinces. In Luxemburg, the lowest maximum values of 0.5 and 2 ldm can be found. In the other provinces, the maximum differs from 12.5 ldm in Luxembourg to 13.6 ldm in many other locations. The most common maximum value is 13.6 ldm. In Appendix G, an overview is provided of the minimum and maximum order sizes.

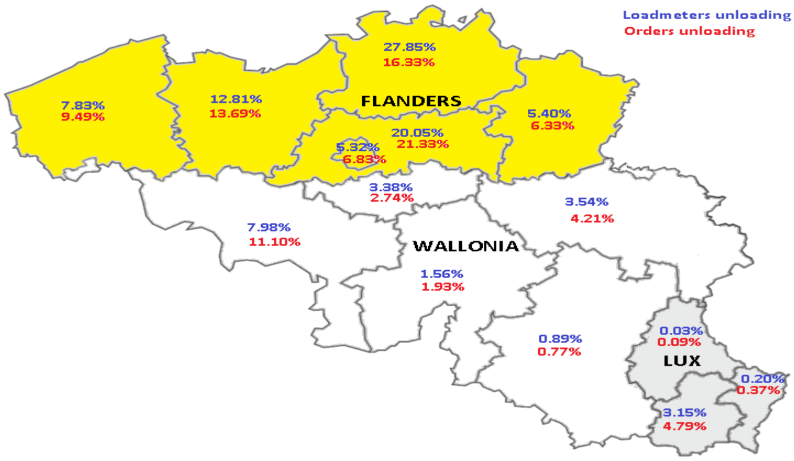

Figure 14: Overview of orders and load meters by province of delivery

4.3.3 Results per province combined*

In previous sections, the processes of pickup and delivery are considered separately. Although these are two different types of operations, these processes will be combined on a route. As mentioned in Section 4.3, the combination of delivery and pickup is an approximation method. In the case of combined* for load meters, the total amount of load meters becomes 97,392ldm, corresponding to a total of 113,501 orders. This is 6,942 ldm more than delivery, but 6,195 orders less. This increase can be explained by the fact that the maximum amount of load meters is selected, and on some days the maximum amount of load meters is higher for pickup at a location than for delivery. The decrease in orders can be explained by larger order sizes. In total, 87% of the orders combined* consist of an order size of 0.8 ldm or less. This indicates that order sizes are commonly small, and explains the decrease in orders for combined*.

In Figure 15 a geographical overview of combined* for load meters is displayed. The highest percentage of load meters and orders remains the same as with delivery. In Antwerp, this percentage is 25.89% of the total load meters. Furthermore, approximately 75% of the total load meters are in Flanders, which is displayed in yellow. The total amount of load meters and the number of orders per province for combined* is provided in Appendix H.

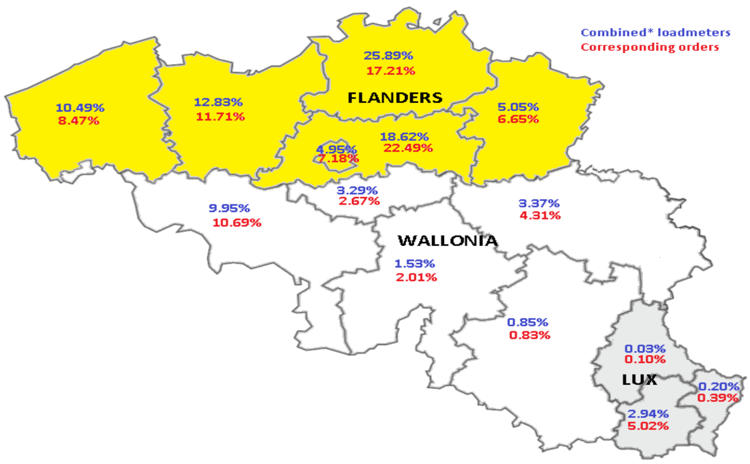

Figure 15: Overview of combined situation by province*

4.4 Set of possible locations

Normally, a set of possible predetermined locations is already provided (Tan and Kara, 2007). For this thesis, however, there is no set of possible locations. There are a few methods available for creating a possible location list. A step in the procedure of developing a hub-and-spoke network can be used for determining a set of possible locations, which selects a node as a hub node (Sule, 2001). Wasner and Zäpfel (2004) used the single-stage warehouse location problem to determine depot locations. All postal zones are considered as potential locations, and the demand of customers corresponds to quantities of shipments in the postal zones. For this thesis the zip codes of customers are considered as potential locations and the demand of customers corresponds to the amount of load meters per zip code.

Quantitative analysis can eventually determine which demand node could be selected as the best hub node in Belgium and Luxemburg. The data file provided by GVT Transport consists of approximately 5,000 different addresses for pickup and delivery. Evaluating each address (demand nodes) as possible locations for a hub could not be executed within the duration of the project. Therefore, the addresses of customers are aggregated to zip codes. Aggregation is a method used to address large-scale location problems in real-world application, which works by assigning several points to a single representative (Gavriliouk, 2009). Van Woensel (2014) showed that by aggregating 18,000 customers into 800 customers based on 3-digit zip codes, the cost difference is only less than 0.05%. The difference between the real and aggregated situation is almost negligible.

For Belgium and Luxemburg combined, the total number of zip codes is 1,169. In order to determine possible locations, the distance between each demand node is required. The distance between each location was calculated by the Google Maps Distance Matrix API using Microsoft Excel, however only 2,500 calculations per day are allowed. This results in 518 days of calculations, when all zip codes in Belgium and Luxemburg are considered, and for this reason locations of the customers with any demand during the year are selected based on the first two digits of the zip code. For example, 1000, 1100, 1200, etc. To improve the accuracy of determining a location, another method was applied that included more zip codes than just the first two digits. It is important to consider the demand nodes that have the highest demand, since these locations are visited more frequently. The zip codes that are considered as fulfilling this requirement are described in Section 4.4.1. The results by selected zip codes are provided in Section 4.4.2. The results by clustered zip codes are described in Section 4.4.3.

4.4.1 Requirement selection zip code

A requirement of an average minimum of one pallet per day, per zip code was set to select more demand nodes, because orders are commonly placed in terms of pallets. If this requirement was fulfilled for either delivery or pickup, the zip code was considered for determining a location. This method resulted in a total of 138 zip codes. This ensures that the most common order locations are selected, and the number of zip codes remains feasible for analysis within the time limit of the project.

The remaining zip codes that were based on the first two digits and do not have any demand were omitted, because these locations were not visited by GVT Transport. The remaining zip codes based on the first two digits but with any amount of demand were retained. For example, if zip code

1400 had only 0.1 ldm ordered within the timeframe studied in this project, it was still considered. If a region did not fulfill the requirement and there was no demand based on the first two digits, the third and fourth digits in that region were examined. The zip code with the highest demand in that region is added to the list of possible locations for this analysis. For example, in region 64, the requirement of an average of 0.4 ldm per day was not fulfilled, and there is no demand at customers in the region of 6400. However, customers at 6440, 6460, 6464, 6470 and 6490 do have demand. The demand of customers in region 6460 was the highest, thus zip code 6460 was taken into account for this analysis. By applying this method, the region with zip code 64 is not lost. It is important to consider as many regions as possible, as this affects the possible location of a hub. In some areas there was no demand within the period analyzed in this thesis and these zip codes were omitted. These begin with the digits: 27, 52, 54, 57, 58, 63, 72, 74, and 81.

This procedure was only applied for Belgium, since Luxemburg had just 0.43% for pickup and 3.39% for delivery of the total load meters. When only the zip codes that fulfilled the average requirement of one pallet per day were considered, these already accounted for 0.21% of 0.43% for pickup, and 2.23% of 3.39% for delivery. By combining the results of the steps above with these zip codes, the total number of zip codes considered was 180 across Belgium and Luxemburg. These 180 zip codes represent 89% for delivery and 95% for pickup of the total load meters. The set of possible hub locations considered can be found in Appendix I. The zip codes that are not selected are displayed in Appendix J.

4.4.2 Results by zip code

The distribution by province provides a good overview of the total situation. For more detailed information about the demand distribution, the zip codes are analyzed. The locations given by zip codes are more specific than those by overall province. In Section 4.4.1, a possible set of locations was determined. For these zip codes, the distribution for pickup and delivery is introduced. Since not all zip codes with any demand fulfilled the requirements in Section 4.4.1, not all of the orders and load meters were taken into account.

Pick up: 95% of the total load meters were considered. The following zip codes in Belgium contribute a large percentage of the total amount of load meters loaded:

- 8700 (32%), 9300 (15%), 7110 (11%), 2800 (10%), 7060 (9%) and 1800 (6%). These zip codes correspond to Tielt, Aalst, La Louvière, Mechelen, Zinnik, and Vilvoorde, respectively.

Delivery: 89% of the total load meters were considered. The locations with the highest percentage of load meters delivered are:

- 2300 (7%), 1600 (4%), 2880(4%), 1800 (4%), 2030 (3%). These zip codes correspond to Turnhout, Sint-Pieters-Leeuw, Bornem, Vilvoorde, and Antwerp, respectively.

An overview by zip code containing the amount of load meters and the number of orders for both pickup and delivery is provided in Appendix K.

Where FTL order quantities were excluded from the data set, demand at some locations decreased by more than 1,000 ldm per year. An overview of these locations including the decrease in ldm and orders is provided in Appendix L.

4.4.3 Results by clustered zip codes

In the previous section, only the zip codes that were identified in Section 4.4.1 were considered. As a result, not all load meters and orders were considered. The percentage of demand that is considered differs by situation. In order to increase the percentages to near 100%, the zip codes in Belgium that were previously excluded were clustered with the selected zip codes. Clustering is executed within regions, to keep distances to a minimum. These regions are based on the first two digits of the zip code. For example, zip codes 1040, 1050, 1060, 1080, 1090, and 1099 were not considered, since the demand in those areas did not fulfill the requirements in Section 4.4.1. These zip codes were added to the approximated most central location in that region, based on the first two digits. These central areas generally have zip codes that contain 00 at the end. For example, in Figure 16 the distribution in the region of Brussels (1000) is displayed.

Figure 16: Overview of distribution of zip codes in region 1000

As can be seen in Figure 16, the zip code 1000 is approximately the most central location for all the zip codes that start with 10. However, in the case that a zip code based on the first two digits is not selected and locations in the region of this zip code do have any demand, as in the case of zip code 64 in Section 4.4.1, the customer location with the highest demand is taken as the central location. In this case, the remaining zip codes are clustered together with the zip code that has any demand in that region.

For Luxemburg, only the selected zip code regions in Section 4.4.1 are taken into account, and for this reason all zip codes that start with 16 are added to 1610. The percentage of load meters and orders are taken into account for pickup becomes 99.83%, and 99.47%, respectively. For delivery, these percentages are 99.09%, and 98.23% respectively. An overview of the selected zip codes with clustered demand can be found in Appendix M.

5. Quantitative hub location analysis

Distances between the identified zip codes were calculated during the data analysis. These were implemented in a matrix form, as is done by Ghiani et al. (2013) for the p-median and p-center problem. With the created matrix, the total demand-weighted distance (p-median) and the maximum distance (p-center) from an origin to all destinations can be calculated. Minimizing the demand-weighted average distance is applied, since the main goal of GVT Transport is to reduce the number of kilometers traveled. The results of the p-center model can be found in Appendix N.

The calculations were executed by zip code and by clustered zip code. The hub location was calculated based on combined*, which was defined in Section 4.3. Furthermore, the distribution of load meters across customers was considered. Finally, an extra constraint was added to the model. This constraint selects the minimum distance between Tilburg or the new hub and the customer. This ensures that customers that are closer to the hub in Tilburg are served by Tilburg, and the customers that are closer to the new hub are served by the new hub location. The following situations were calculated:

- Combined* (based on maximum load meter per zip code, per day)
- By zip code and by clustered zip code
- From hub to customer

The calculation of the distances between the demand nodes is provided in Section 5.1. The p-median was applied and is described in Section 5.2. The minimum distance between Tilburg-customer and the new hub location-customer was selected in addition to the p-median model. This method is applied in Section 5.3. The main results of the three different methods are summarized in Section 5.4.

5.1 Distance calculation

The distances were calculated using the Google Distance Matrix API. As mentioned in Section 4.4, this Google program only allows 2,500 calculations per day; therefore, these calculations were already executed during the data analysis. The calculations were done in Microsoft Excel, using Visual Basic for Applications (VBA). The total VBA code is provided in Appendix O. The pseudo code is displayed in Table 7.

Table 7: Pseudo code for retrieving distances between locations from Google Maps

1. Start algorithm
*2. **Input:** hub and customer (by a 4-integer zip code and country abbreviation according to ISO 1366)*
*3. **Calculate:** distance and duration between hub-customer from Google Maps, based on fastest route by car*
*4. **Output:** distance in kilometers and duration in hours: minutes*
5. End algorithm

In the model, different modes of transport can be chosen. However, none of these transport modes use trucks. Therefore, driving by car is chosen as the travel mode. The distances between origins and destinations are based on the fastest driving route, not on the shortest distance. The shortest distance is not chosen, as it often contains small urban roads and avoids highways, meaning trucks driving this distance will lose a lot of time, incurring extra costs. Additionally, some small roads may be inaccessible for trucks, or trucks may not be permitted to drive on them. It is assumed that the fastest route is accessible and permitted for trucks, so the number of kilometers between locations is equal for both trucks and cars. However, there is a difference of duration, because the driving speed of truck and a car is different. In the distance matrix, the duration using a car is provided. Google provides a "best guess" of the duration based on what is known about both historical traffic conditions and live traffic. This "best guess" does not include departure times and considers a normal scenario outside of peak traffic levels, meaning the duration provided by the matrix does not consider congestion delays.

5.2 P-median

The p-median model is used to calculate the hub location by minimizing the demand-weighted average distance. Consider a directed graph G = (V,A), where V is the set of zip codes, and A represents the arcs. The possible locations of the hubs are provided by the set of zip codes $i \in I$, and the demand nodes are represented by $j \in J$. Since the potential hub can be placed at any demand node, *i* equals *j*. The cost variable was replaced by distance in the model. Usually, the standard cost per unit from location *i* to *j* is proportional to the distance between *i* and *j* (Ghiani et al. 2013). In the remainder of this thesis *i* and *j* are used to index origins and destinations respectively, where *i* is the potential hub location.

The transportation costs are dependent on the routes, which are created in SHORTREC and are currently not yet known. Compared to the normal p-hub median, a demand factor replaces the flow from location *i* to *j*. This demand factor is applied for the amount of load meters, and is the percentage of the total amount. The demand factor is included, as it provides insight into how often a location is visited. Locations that are likely to be visited more frequently than others are weighted more. The demand factor is multiplied by the distance between the potential hub location and the destination. Ghiani et al. (2013) assumed that the potential hub locations have identical facility costs, thus, this is not required in the formulation. Furthermore, since the potential hub locations are both origins and destinations, hubs are specified by *i*. The mathematical Linear Programming (LP) formulation, which corresponds to the p-median problem with *p = 1*, becomes as follows:

$$Minimize \sum_{i\in I}\sum_{j\in J} D_j * c_{ij} * x_{ij} \qquad (1)$$

$Subject\ to$

$$\sum_{i\in I} x_{ij} = 1, \quad \forall j \in J \qquad (1.1)$$

$$x_{ij} - y_i \leq 0, \quad \forall i \in I, \quad j \in J \qquad (1.2)$$

$$\sum_{i\in I} y_i = 1 \quad \forall i \in I \qquad (1.3)$$

$$x_{ij} \in \{0,1\}, \quad \forall i \in I, \quad j \in J \qquad (1.4)$$

$$y_i \in \{0,1\}, \quad \forall j \in J \qquad (1.5)$$

Sets:

I, J: the sets of candidate hub locations and customers, respectively

Parameters:

c_{ij}: the fastest kilometric distance between origin i and destination j
D_j: the demand at location j, expressed as a factor of the percentage demand
Variables:
x_{ij}: the binary decision variable assuming value 1 if the hub is located at location i and serves location j, 0 otherwise
y_i: the binary decision variable assuming value 1 if hub is located at location i, 0 otherwise

The objective function (1) minimizes the sum of distance traveled, multiplied by the demand factor between hub location *i* and destinations *j*. Constraint (1.1) implies that a demand node *j* can only be served by one potential hub location. Constraint (1.2) ensures that demand node *j* can be served by hub location *i* only if there is a hub at *i*. Only one location for *i* is selected as a hub, ensured by constraint (1.3). The last two constraints (1.4) and (1.5) establish that variables x_{ij} and y_i are binary. A value between 0 and 1 is not possible, since a hub must either exist or not. The calculations of this model are discussed in Section 5.2.1.

5.2.1 Calculation

For each potential location, the distances to all possible demand nodes were calculated. These distances were multiplied by the demand factor, and the resulting demand-weighted average distance was compared with all the other potential hub locations. The minimum of the sum of demand-weighted average distance was selected, and defined as the location where the fewest kilometers are driven on average, based on demand. The method of combined* was applied for demand. The LP provided above is not solved, because the number of hubs to locate is one. In the case of locating p-hubs the problem is NP-hard and the LP needs to be solved. In this case, the problem is not NP-hard, and the problem can be solved easily by total enumeration. In Microsoft Excel, a matrix was set up including the calculated distances between demand points. The zip codes within the matrix were multiplied with the corresponding demand factor. The demand-weighted distances can be summed or the average can be taken by row. Each row can be compared, and the lowest value indicates the best location. Since the matrix is 180 by 180, the whole matrix cannot be displayed. However, as an example of the calculation, a smaller part of the matrix is shown in Appendix P. The next step is to multiply the distances between *i* and *j* by the corresponding demand factor.

In Appendix Q, an example of the calculation from *i* to *j* is displayed. The customers were assigned a demand factor, which corresponds to the percentage of load meters. In the case of zip code 1000, the demand factor is 0.9, meaning that 0.9% of the total amount of load meters per year is ordered at that location. In the example of Appendix Q, the new hub should be located at Tilburg, since it has the lowest average demand-weighted distance. In this case, it is not necessary to establish a hub in Belgium. It should be noted that this is an approximation method since the exact routes are not known. The economies of scale factor for Tilburg depends on the situation, as discussed in Section 2.4. Economies of scale are represented by a discount factor, which ranges from 0 to 100, with the discount increasing as the factor decreases. The following five discount factors are applied in the calculation: 0, 25, 50, 75, and 100.

For example, discount factor 75 means that a reduction of 25% is achieved for the flow between Tilburg and the new hub, due to bundling of flows. With these discount factors in mind, the p-hub median is solved for the combined* situation, as described in Section 4.3. The locations are determined based on zip code and clustered zip code, as explained in Sections 4.4.2 and 4.4.3. For both the percentage of load meters and orders as demand factors, the results are displayed in Table 8.

*Table 8: Results for p-median combined**

Discount factor Tilburg	Per zip code (ldm)	Cluster zip code (ldm)	Per zip code (order)	Cluster zip code (order)
0	1780	1780	1082	1780
25	2610	2830	1851	1851
50	2000	2000	2000	2000
75	2000	2000	2000	2000
100	5047	5047	5047	5047

In Table 8, the discount factor for Tilburg is provided in the first column and each discount factor is applied to four different situations. First, the situation by zip code and ldm as the demand factor is considered. In the third column, the situation by clustered zip code and ldm as the demand factor is considered. The fourth and fifth column are the same as the second and third column, respectively, but the demand factor is based on orders in these situations. If no discount can be achieved between Tilburg and a possible new hub, it would not be profitable to buy/build a new hub in Belgium. As the economies of scale between the two hubs increases, a hub should be established in Belgium. In the case of achieving 25% or 50% discount, the best hub location would be Antwerp (2000). This is applicable for both the percentage of load meters, and for orders as the demand factor. When a discount of 75% is achieved (discount factor 25), different locations are possible.

5.3 Minimum distance from Tilburg or new hub location to customer

For the p-median model, the selected hub supplies all destinations in the data set. However, in the case where the current hub location in Tilburg is much closer to the customer, this customer would probably be supplied by Tilburg instead of the newly established hub. In this section therefore, an extra constraint is added to the method in Section 5.2. This constraint selects the shortest distance between a Tilburg-customer and the possible new hub location-customer. This ensures in the calculation that certain customers are served by Tilburg and others by the new hub location. The distance that corresponds to the fastest route is then multiplied by the demand factor of the customer location. This constraint is modeled as follows and is added to the model of Section 5.2:

$$\sum_{i \in I} y_i = 2 \qquad (3.1)$$

$$y_{Til} = 1 \qquad (3.2)$$

Variables:

y_i: the binary decision variable assuming value 1 if hub is located at location i, 0 otherwise

y_{Til}: the hub location in Tilburg, which can always be selected

Constraint (3.1) ensures that two hubs are selected. Constraint (3.2) ensures that one of the hub locations is always Tilburg. The calculations of this model are discussed below, in Section 5.4.1.

5.3.1 Calculation

By applying the constraint of selecting the nearest hub for a customer, some locations are served by Tilburg and others by the potential new hub. As a result, the customers that are closer to Tilburg and are served by Tilburg do not require trucks to travel between the two hubs. The customers that are served by Tilburg, depended on the new location, are provided in Appendix R. The percentage of demand of customers that are closer to Tilburg than the new hub varies between 6% and 9%. By adding this new constraint to the p-hub median model, the following results were obtained, shown in Table 9.

Table 9: Results of p-median combined including minimum Tilburg-j and hub-j*

Discount factor Tilburg	Per zip code (ldm)	Weighted average distance (ldm)	Cluster zip code (ldm)	Weighted average distance (ldm)	Per zip code (order)	Weighted average distance (order)	Cluster zip code (order)	Weighted average distance (order)
0	**1083**	27.24	**1780**	30.85	**1082**	26.64	**1082**	33.23
25	**2830**	42.54	**2830**	46.44	**1851**	42.92	**1851**	49.93
50	**2000**	53.61	**2000**	57.82	**2000**	54.09	**2000**	61.96
75	**2000**	63.55	**2000**	67.77	**2000**	64.04	**2000**	71.90
100	**5047**	65.66	**5047**	72.96	**5047**	64.25	**5047**	77.83

In Table 9, the possible locations are provided and the hub locations are equal for discount factors 50 and 75. However, these locations are based on five assumed discount factors between the hubs. When the demand factor is between the assumed factors, the possible location could change. Therefore, the discount factors are calculated until the point where the location changes via the Solver function in Microsoft Excel. The economies of scale (discount) that should be achieved for a corresponding hub location, with the corresponding density of the location, is provided in Table 10. Note, that the density is calculated based on the zip codes selected in Section 4.4.1.

*Table 10: Discount for Tilburg corresponding to hub location for combined**

Hub location	Discount Tilburg per zip code	Discount Tilburg per clustered zip code	Density hub location
1780	≥87.40%	≥85.71%	74.88 km
1851	≥79.24%	≥76.98%	76.86 km
2830	≥69.59%	≥67.35%	80.68 km
2610	≥56.27%	≥52.69%	84.79 km
2000	≥19.70%	≥11.94%	88.19 km
5047TM	<19.70%	<11.94%	148.76 km

In Table 10, the density of the hub location improves when higher discounts are achieved. A discount value between 20% and 50% is most likely to be achieved.

5.4 Results

In Section 5.2, the p-median model was applied. In Section 5.3 an extra constraint was added to the p-median model, which resulted in the provisions of results for a new hub location. These results provide a good overview of the regions where a hub should be located when considering different activities. Since GVT Transport engages in both pickup and delivery, the combined* version provides the best approximation overview. As mentioned in Section 4.3, combined* is based on the maximum amount of load meters or the maximum number of orders per zip code, per day. The constraint introduced in Section 5.3 improves the approximation. Without it, the new potential hub location serves all customers in Belgium and Luxemburg, even if the distance from Tilburg to that customer is shorter. In addition, kilometers traveled in the Netherlands are cheaper than in Belgium. The results of combined* differ based on the situation that is considered. The actual hub location depends on the discount factor between Tilburg and the new hub, as provided in Table 10. The geographical location of the zip codes in Table 10 are displayed in Figure 17.

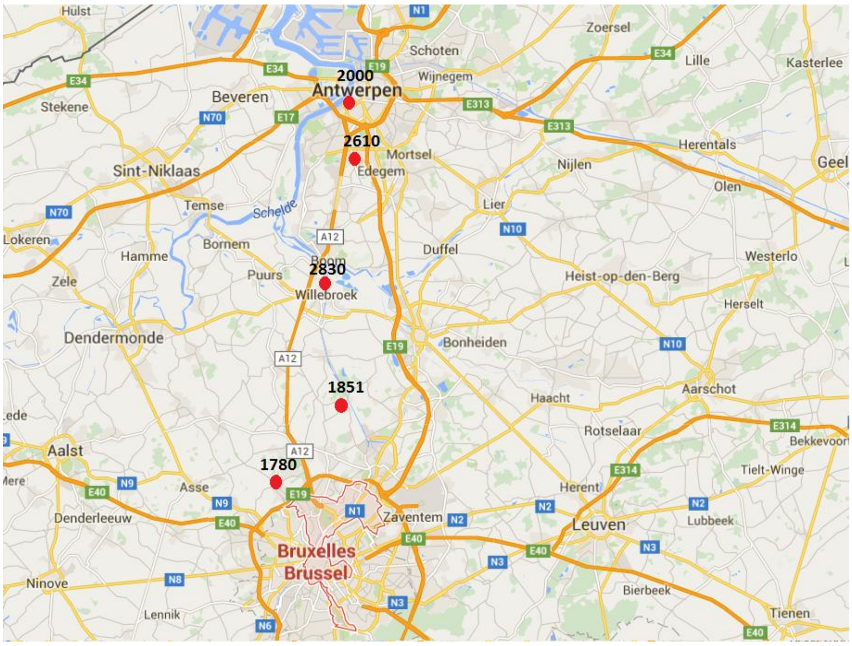

Figure 17: Possible hub locations derived by minimizing the demand-weighted average distance

Compared with orders, the number of load meters provides better insight into the goods that can be transported. The clustered zip codes consider more data, and selecting the minimum distance between Tilburg-customer and hub-customer gives a more realistic situation. Only the demand-weighted average distance combined* by clustered zip codes, including the minimum between Tilburg-customer and hub-customer, with load meters as the demand factor are discussed in the remaining chapters.

The p-median provided more than one option for the hub location. The actual selection of the hub location depends on the strategy, as discussed in Section 2.2. These factors are further investigated in the following sections. It can be concluded that placing a new hub in Belgium is the best option when economies of scale is more than 12% and 20% by clustered zip code and by zip code respectively.

6. Sensitivity analysis

The different models in Chapter 5 provide several results. These results are based on the current situation, and future developments are not considered in these models. Increases or decreases in demand could change the outcome of the model. Since the location of a hub constitutes a long-term decision, as discussed in Chapter 3, the location that is defined as optimal should remain stable regardless of different scenarios over several years. To this end, different scenarios were applied to the model to determine whether the hub location remains in the same region despite the differences in input. As the region of Brussels-Antwerp is commonly the best option for minimizing the demand-weighted average distance, locations outside these regions were considered in the scenarios. The increase in demand in the regions where the hub is located should only strengthen the position of the hub. For all scenarios, the amount of load meters is considered the demand factor. Furthermore, the route duration is also an important factor to consider in regards to travel cost. In Chapter 5, only the distances between origins and destinations were considered. For certain routes, distances could be equal, but travel time could differ significantly. This depends on, for example, congestion levels. For this reason, the effect of travel time is considered in this analysis.

The scenarios were applied to the combined* situation by clustered zip code and selecting the minimum between Tilburg-customer and hub-customer, as mentioned in Section 5.4. First, the locations when considering delivery and pickup separately are discussed in Section 6.1. Second, the situation in which FTL orders are excluded is described in Section 6.2. One scenario considers an increase of 25% demand in Wallonia. The results of this scenario are discussed in Section 6.3. In Section 6.4, a growth of 25% demand in East- and West-Flanders is considered. The effect of duration on the models is considered in Section 6.5. The effect of traffic congestion on duration is considered in Section 6.6. Finally, a summary of the different scenarios is provided in Section 6.7.

6.1 Separate pickup and delivery

In Chapter 5, the combined* method is used to calculate a hub location. Since pickup considers roughly only 1/3 of the total load meters of delivery, it is relevant to investigate the influence of the location of the processes separately. The results of these methods provide insight into the sensitivity of the model, and are displayed in Table 11.

Table 11: Overview of hub locations for delivery and pickup by clustered zip code

Discount factor Tilburg	Delivery	Demand-weighted average distance	Pickup	Demand-weighted average distance
0	**1780**	30.44	**9320**	27.57
25	**1851**	45.67	**9200**	44.76
50	**2000**	56.49	**2830**	59.38
75	**2000**	66.44	**2000**	69.76
100	**5047**	70.07	**5047**	79.76

As can be seen in Table 11, when considering only the delivery process the locations remained approximately equal to those for combined* in Section 5.3. A possible explanation is that delivery accounts for 2/3 of all goods transported. In the case of the pickup process only, the hub should be located at Aalst (9320) or Dendermonde (9200) when the discount factor for Tilburg is 0 or 25 respectively. These two locations are significantly different from those determined when only delivery is considered. The explanation for this difference is that approximately 70% of total load meters are picked up in the Southwest provinces (East- and West- Flanders, and Hainaut) as displayed in Figure 13.

6.2 FTL orders excluded

Currently, when one order equals an FTL size, this order is loaded onto a truck that transports it directly to the customer. A possible new hub would not require visitation by this truck. These orders can be excluded so as to provide an overview of only those trucks that require multiple stops to customers. However, it should be noted that by excluding these FTL order sizes, the trucks that are used to transship these orders can only be used for FTL orders. Using this method, trucks that transport an FTL order to a customer cannot be used to pick up smaller goods when returning to the hub. These trucks can only pick up another FTL order from a customer. If these orders are not available on the same day, the truck will travel empty one way. Furthermore, when small orders are located near a customer that requires an FTL order size, an extra truck will need to travel to this area to pick up the goods even though it is more efficient for the truck that visits the customer with an FTL order to pick up these goods. The results derived from this method are provided in Table 12.

Table 12: Overview of hub locations for combined excluding FTL orders*

Discount factor Tilburg	Combined* excluding FTL orders	Demand-weighted average distance
0	1082	32.42
25	1851	48.51
50	2000	60.59
75	2000	70.54
100	5047	77.22

The possible hub locations are fairly consistent with the normal combined* situation, and the hub location shifts more towards the center of Brussels only when a 100% discount is achieved.

6.3 Increase in demand in Wallonia

The results in Chapter 5 suggest hub locations in Flanders, because demand in Wallonia and Luxemburg is significantly lower than in Flanders. Due to this, the influence of Wallonia and Luxemburg was increased by multiplying the number of load meters by 25%. Wallonia consists of the zip codes from 40 to 79, and encompasses the eastern part of Belgium. Realistically, this type of increase would probably not occur, but this change can be simulated to provide insight into the sensitivity of the model. In this case, the impact of more demand in the eastern part of Belgium was evaluated. The results are provided in Table 13. As can be seen in Table 13, the possible hub location changes to 2610 (Antwerp) with a discount factor of 50 for Tilburg. In the case of a discount factor of 75, the hub location remained at 2000 (Antwerp).

Table 13: Overview of hub locations for combined with 25% demand increase in Wallonia*

Discount factor Tilburg	Combined* + 25% Wallonia	Demand-weighted average distance
0	1780	31.78
25	1851	47.61
50	2610	59.35
75	2000	69.31
100	5047	74.61

6.4 Increase in demand in East- and West-Flanders

In this section for both East- and West-Flanders the demand was increased by 25%. Compared to other provinces, the demand for pickup goods is highest in these two provinces. East- and West-Flanders are located in western Belgium, and by increasing demand in these areas the influence of this region increases. The impact of higher demand in the western part of Belgium was analyzed. The results show that an increase of 25% in East- and West-Flanders influences the hub location slightly. The results are provided in Table 14.

Table 14: Overview of hub locations for combined with 25% demand increase in East- West- Flanders*

Discount factor Tilburg	Combined* + 25% East-West Flanders	Demand-weighted average distance
0	1083	31.18
25	2830	46.84
50	2000	58.09
75	2000	68.03
100	5047	73.68

As can be seen from Table 14, the hub location outcome shifts to Willebroek (2830) and Ganshoren (1083) near Brussels, with 25 and 0 as discount factors for Tilburg.

6.5 Effect of travel time

Time is another cost aspect in transportation. The number of kilometers traveled does not equal the amount of time required for the route. The duration of a route depends on the type of roads used, and other factors such as traffic congestion. The effect of the required travel time is considered here. Note, that the travel time by car is used in this case. However, the differences between the travel times of routes using a car or truck are minimal. The distances were replaced by the travel times (in minutes) in the p-median model. In this case, the demand-weighted average duration was calculated with the p-median model. The results of examining duration instead of distance are provided in Table 15.

Table 15: Overview of hub locations for combined based on duration*

Discount factor Tilburg	Combined* based on duration	Demand-weighted average duration (minutes)
0	1780	22.40
25	1780	33.23
50	2018	41.53
75	2018	49.03
100	5047	49.23

6.6 Effect of congestion levels

Congestion levels also contribute to the time factor. As discussed in Chapter 5, the provided travel times do not include congestion delays. In GVT Transport's current situation, trucks that travel to Belgium depart at approximately 04:30. Other trucks mostly depart around 06:00. Brussels is a central point in Belgium, from which almost every city is accessible. Brussels is surrounded by the ring of Brussels, which is a highway that is about 75 km long. Several highways lead to the ring of Brussels, but since it leads to almost every city in Belgium and is heavily traveled, the disadvantage of this ring is the high congestion level.

Tomtom Traffic Index (2015) measured the congestion levels of cities in Europe in percentages of the average increase in travel time, and Brussels, Antwerp, and Liege are included in this index. Brussels contains the highest congestion level in Belgium with 33%, and is number 32 on the world ranking list for traffic congestion. The morning peak levels are provided for these three cities, which display the increase in morning peak travel times when compared to a free flow situation. Table 16 provides an overview of the congestion levels in Belgium (Tomtom Traffic Index, 2015). These percentages can be used to integrate congestion delays into the travel duration time.

Table 16: Congestion levels of cities in Belgium (Tomtom Traffic Index, 2015)

City	Congestion Level (24 hours)	Morning Peak (06:30 – 09:30)	Evening peak (16:00 – 19:00)
Brussels	33%	67%	71%
Antwerp	28%	48%	60%
Liege	17%	30%	38%

Since the hub location is considered to be a starting point, the morning peak level is taken into account, assuming that the truck departs before or at 06:00 for its destination. This means that the trucks starting in Brussels will avoid the morning peak traffic in the city. The duration of routes between a location outside the Brussels region (zip code 13-14 and higher than 19) and the region of Brussels (zip codes 10-12 and 15-19) were multiplied by factor 1.67. This congestion factor equals the percentage of congestion level identified by Tomtom Traffic Index (2015). Brussels only consists of zip codes 10-12, as displayed in Section 4.3, however, the zip codes 15-19 are adjacent to the ring of Brussels. Originating from these zip codes, trucks can be outside the ring of Brussels within 30 minutes.

The same situation applies to Antwerp. The durations of routes to the region Antwerp (zip codes 20-29) from regions outside the city were multiplied by a congestion factor of 1.48. The route durations from locations outside of Liege to the region of Liege (zip codes 40-49) were multiplied by 1.3. The durations of routes within the same region were not multiplied by any factor, since the morning peak traffic can be avoided. Furthermore, demand within the region can be satisfied with smaller rigid trucks that can use urban roads more easily, thus avoiding traffic congestion on highways. The results shown in Table 17 were obtained applying these congestion factors to the route durations. These results show little difference with the results derived from distance calculations. The hub location remains in Antwerp with a discount factor of 50 or 75, but shifts slightly to another part of Antwerp (2018). This result was expected, since trucks avoid traffic congestion due to their early departures.

Table 17: Overview of hub locations for combined including congestion factor*

Factor Tilburg	Combined* + congestion factor	Demand-weighted average duration (minutes)
0	1780	25.13
25	1830	35.81
50	2018	45.11
75	2018	52.61
100	5047	54.93

6.7 Conclusion

The scenarios in this Chapter were applied in the combined* situation as mentioned in Section 5.4. The results of the scenarios in this section are summarized in Table 18.

Table 18: Overview of results of the different methods/scenarios applied

Discount factor Tilburg	Delivery	Pick up	Excluding FTL orders	+25 % Wallonia	+ 25% East-West-Flanders	Duration	Duration + congestion levels	Combined* normal situation
0	1780	9320	1082	1780	1083	1780	1780	1780
25	1851	9200	1851	1851	2830	1780	1830	2830
50	2000	2830	2000	2610	2000	2018	2018	2000
75	2000	2000	2000	2000	2000	2018	2018	2000
100	5047	5047	5047	5047	5047	5047	5047	5047

As can be seen from this table, when the discount factor of Tilburg is 50 or more, the possible hub locations remain in the region of Antwerp. When the discount factor is 0, the hub location remains in Tilburg. When the discount factor of Tilburg becomes 25, there are more possibilities. In some situations, the location is between Brussels and Antwerp, whereas in other situations the hub location is near the ring of Brussels.

The results indicate that an increase in demand in regions where the current demand is lower does not significantly influence the possible hub location. The same applies when considering route duration instead of distance, explained by the early departure times of the trucks that allows them to avoid traffic congestion in the hub location region. The density and unweighted average duration of the locations found in Table 18 are provided in Table 19.

Table 19: Overview of possible hub locations with density and weighted duration

Location	Density	Demand-weighted duration	Location	Density	Demand-weighted duration
1082	75.87	51.55	2000	88.19	62.00
1083	75.34	52.40	2018	87.48	57.51
1780	74.88	50.40	2610	84.79	57.99
1830	75.44	51.21	2830	80.68	57.78
1851	76.86	56.96	5047	148.76	98.34

All possible hub locations, considering different situations and scenarios, are displayed in Figure 18.

Figure 18: Overview of all possible hub locations

Based on the results, the new location should be located in Antwerp. Zip code 2000 is the most common location. Discount factors between 75 and 50 for Tilburg probably give the most realistic situation. GVT Transport's aim is to use LHV between the two hubs. The use of LHVs between hubs results in economies of scale of approximately 40%.

7. Qualitative location analysis

In Chapter 5 the quantitative models are described and possible hub locations are identified. In Chapter 6, the quantitative models are tested for their sensitivity. The hub locations are determined based on distance, route duration, and demand. However, environmental factors of locations are not considered in Chapter 6, and such factors can influence the exact location of the hub. Therefore, in this chapter, the locations that are selected as potential hubs are further analyzed based on qualitative measures to obtain a holistic view of location decision.

Murthy (2001) suggested that both quantitative and qualitative measures should be included for good performance criteria. Prologis (2013) identified 13 criteria that affect the desirability of a logistics location. Each identified criterion is ranked and grouped into four categories: proximity to customers and suppliers, labor and government, real estate, and most importantly, infrastructure. Infrastructure is considered to be the most important element, and is described in Section 7.1. The current trial with LHVs in Belgium is discussed in Section 7.2, and the three remaining categories, as well as the scores of all categories are discussed in Section 7.3. The main conclusion is provided in Section 7.4.

7.1 Infrastructure

The infrastructure present at the location is considered to be the most important criterion because it can influence the transportation cost. The location should be accessible for trucks and should be near highways. Trucks travel by highways since they are fastest and connect all of the biggest cities to each other. Some hub locations are near the ring of Brussels. This ring surrounds Brussels as well as other smaller towns near the city, and is situated in Brussels, Flanders, and Wallonia. The majority of the ring lies in Flanders, with a length of 51.7km. Starting near the ring ensures that several locations can be visited directly by entering the ring.

One problem is that Brussels is ranked as tenth in the world for traffic congestion, with the highest congestion levels in Europe at 33%, as mentioned in Section 6.6 (Tomtom Traffic Index, 2015). Since the ring leads to several cities, it cannot be avoided. Thus, even if the hub location is further away from the ring, the trucks will probably need to use it. However, the time at which the ring is used determines the influence of congestion. The peak hours in the morning are commonly from 06:30 to 09:30, and in the evening from 16:00 to 19:00. Normally, most trucks depart before the peak hours, as mentioned in Section 6.6. These trucks depart early in the morning to avoid congestion, or to deliver the goods within the time window of customers located at further distances. Furthermore, the customers in Brussels can be supplied using smaller rigid trucks that can travel via urban roads and avoid congestion in the ring of Brussels, as mentioned in Section 6.6.

7.2 LHVs

At present, goods are commonly transported from hub to hub by night using LHVs. Traveling at night ensures that peak congestion hours are avoided. However, LHVs are currently not allowed in Belgium. The Belgian government has set up a trial with LHVs within the Benelux region. Regarding a hub location in Belgium, profitability would increase if LHV use was permitted in Belgium, and LHVs could access the hub location. However, some parts of the ring of Brussels are not eligible for this trial, and neither is the A12 between Antwerp and Brussels. An overview of the roads that are accessible for LHVs during the trial is displayed in Figure 19. Only routes in Flanders are participating in the trial, as cities in Belgium are not obligated to participate. Brussels, Wallonia, and Luxembourg do not yet allow LHVs, although this could change in the future. Based on current information, the hub should be located within Flanders.

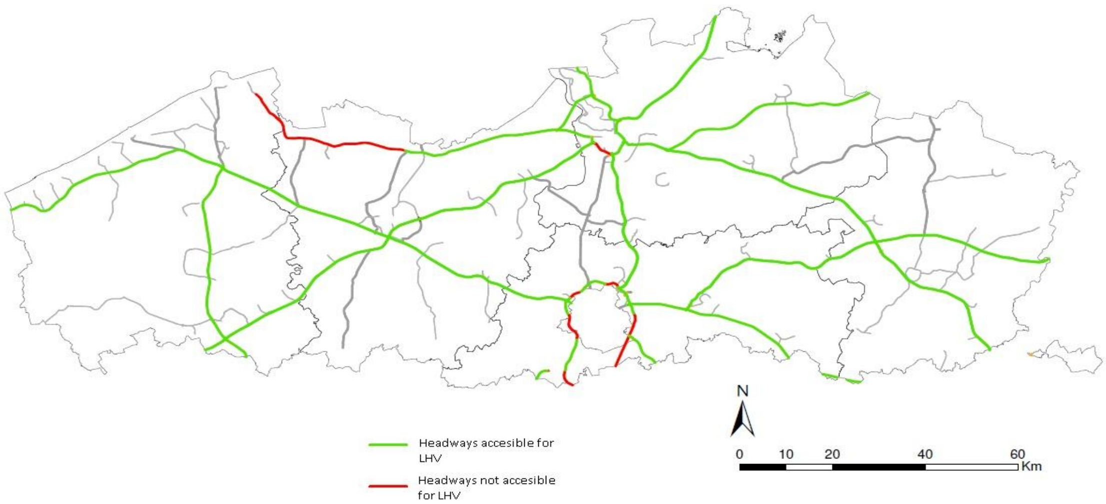

Figure 19: Overview of roads participating in the trial of LHVs (Department mobiliteit and openbare werken, 2014)

Belgium has set strict rules for transportation companies to be allowed to participate in the trial. At the end of 2015, no Dutch transportation company was allowed to participate in the trial due to the requirements of Flanders. Next to the routes in Figure 19, the trucks may not travel through built-up areas, 30-km/hour zones, or pedestrian zones. Furthermore, trucks may not cross railways, the distance from the main highway can be at most 10 km, and such a highway should have a merging lane that is at least 250 meters long and has a width of 3 meters (Transport Joosen, 2015). Based on these requirements, some potential hub locations cannot be accessed by LHVs during the trial. An overview of the locations that are accessible by LHV is displayed in Figure 20. In this figure, the blue line displays a highway that is accessible by LHVs and the gray line displays a route that is not allowed in the LHV trial. Parts of the ring of Brussels are not accessible, as can be seen in Figure 19. One of these sections is from the E19 to the locations Wemmel (1780), Grimbergen (1083), and Sint-Agatha-Berchem (1082). In the case of Willebroek, the distance from the highway is just within the required 10 kilometers. The actual location within Willbroek should be located to the east, as close as possible to the highway E19.

The question remains whether LHVs will be allowed to travel between the Netherlands and Belgium after the trial, on which roads, and when. Since the trial will probably end in 2017, actual implementation of these laws would be in 2018 or 2019, if the trial is successful.

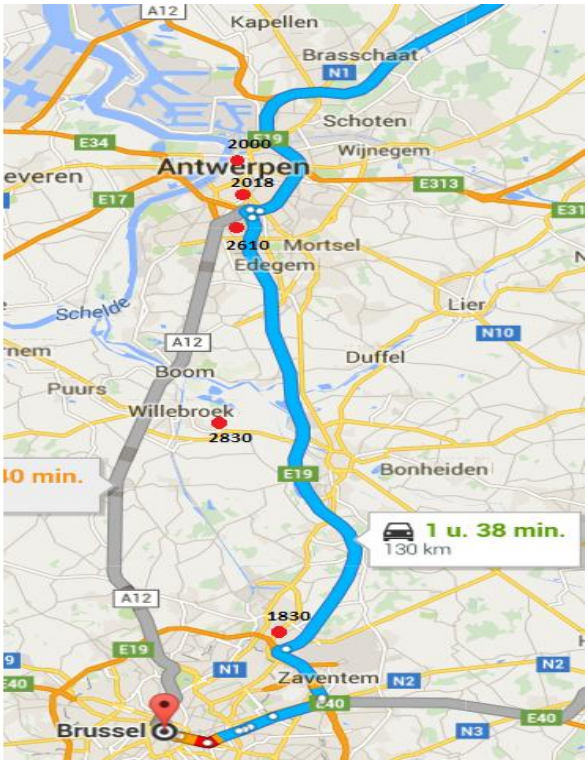

Figure 20: Accessible highways for LHVs between Antwerp and Brussels

Possible hub locations should not be located at the center of the zip code, since this is in the center of a city or town. The actual location should be near a highway. This is only a slight difference in kilometers from the actual zip code, and this difference can be neglected.

7.3 Scores by category

Although the congestion levels are high in Brussels, Antwerp-Brussels is ranked second for Europe's most desirable logistics locations (Prologis, 2013). This considers all the cities between Antwerp and Brussels that are near the A12/E19. The number one location is Venlo. The scores of the four categories for the top five locations in 2013 are provided in Figure 21. These four categories are all important when determining a hub location.

	Infrastructure	Proximity to Cust. & Suppl.	Labor & Government	Real Estate	Total Score
Venlo	105	16	85	42	**249**
Antwerp-Brussels	75	22	41	25	**163**
Rotterdam	93	14	26	23	**156**
Rhein-Ruhr	75	41	22	15	**153**
Madrid	38	14	37	22	**110**

Figure 21: Score by category of the top five logistic hub locations (Prologis, 2013)

As can be seen in Figure 21, the infrastructure of Antwerp-Brussels would bring it to a shared third place with Rhein-Ruhr. The second place ranking of Antwerp-Brussels is mainly due to their score for labor and government.

Labor and government includes labor availability and flexibility, wages and benefits, regulations, and incentives (Prologis, 2013). The third highest score is for real estate, which consists of availability of land, availability of existing modern warehouses, and real estate cost. Antwerp-Brussels has the second highest score in the top five. For real estate costs, Antwerp-Brussels is middle ranked, whereas for the availability of land and modern warehouses Antwerp-Brussels scores the second highest (Prologis, 2013). For the location of a hub, the company should look at industrial zones. The average cost per m^2 of building ground for Antwerp, Willebroek, and Machelen is €335, €299, and €221, respectively (Statistics Belgium, 2014). The investment cost for building a hub in Willebroek and Machelen is thus cheaper than in Antwerp. Building in Willebroek saves €36 on average per m^2 building ground compared to Antwerp.

The lowest score for Antwerp-Brussels is for proximity to customers and suppliers, however, it is the second highest score in the top five. The results are based on the proximity to customers and suppliers considering the location that is best within Europe. The location Antwerp-Brussels can provide the opportunity to serve customers outside the Benelux region, for example in the north of France. Another point worth noting is that French is a commonly spoken language in Brussels. Since the majority of GVT Transport's employees do not speak French, this could result in communication problems.

7.4 Conclusion

This chapter shows the congestion problems in the ring of Brussels but notes that every location has disadvantages. Although there are congestion problems in the ring of Brussels, the region Antwerp-Brussels is ranked second for Europe's most desirable logistic location. From the results in Chapter 5, several possible hub locations are identified across Antwerp-Brussels. Currently, it cannot be concluded whether LHVs will be allowed and able to access the hub location. However, the regulations and restrictions of the trial can be taken into account as a reference point for the actual implementation of LHVs in Belgium. Since the use of an LHV between Tilburg and the newly established hub could reduce the number of trucks that are required for transportation between the two hubs, accessibility is important. The qualitative analysis reduces the possible hub locations to the following locations:

- Antwerp (2000)
- Antwerp (2018)
- Antwerp (2610)
- Willebroek (2830)
- Machelen (1830)

Antwerp remains the best possible location based on the qualitative analysis. However, zip code 2000 is located in the center of Antwerp and is not a feasible location. The actual hub location in Antwerp should within 10 km of a highway and preferably in an industrial complex. The use of LHVs is the best strategy to easily achieve a discount of 40%, and the qualitative analysis shows that Antwerp is accessible for LHVs. The transportation costs of the LHV decoupling strategy at Antwerp is presented in the next chapter, since this is the worst-case of the LHV strategy achieving a lower discount. The possibility that no warehouse or hub is required at Antwerp, but only a storage space for trucks, is considered, since this requires less investment costs.

8. LHV decoupling case

The LHV decoupling case is discussed in this chapter because compared to other strategies, it achieves a feasible discount value with low investment cost. The case where all goods are transported from hub to hub by LHVs achieves an even higher discount value, however, the investment cost would be higher. To provide an approximation of the transportation cost a one-week plan was created in SHORTREC. The one-week plan covered the period from 29 February 2016 to 4 March 2016, excluding weekends. The plan was created by a GVT Transport planner, manually, and was based on the company's current transport needs. The plan cannot be created by SHORTREC simulation, since this provides non-feasible results for GVT Transport. As mentioned in Section 2.3, SHORTREC assumes that all delivery orders in the Netherlands depart from Tilburg, and that all pickup orders with a destination in the Netherlands end at the hub in Tilburg. The problem can be seen as the 1-M-1 PDP. First, the routes were planned from Tilburg to customers for the current network. Next, the hub in Tilburg was adjusted to Antwerp (2000). The start and end location of the routes were changed to Antwerp, but the remainder of the route was equal to the current network. The routes from Antwerp to customers are based on the assumption that they were driven from Tilburg, and are therefore not optimal.

For the calculation of the transportation costs, GVT Transport uses a fixed cost per kilometer driven and a fixed cost for the hourly wage of a driver. The cost per kilometer includes the fuel costs and maintenance. Both fixed costs differ for the type of truck used. An overview of these costs is provided in Table 20.

Table 20: Cost per vehicle

Type of vehicle	Fixed cost per km	Hourly wage
Rigid truck	€0.30	€33.90
Trailer / LHV	€0.43	€43.58

The results of the one-week plan of the current network are described in Section 8.1. The results of the new network, including Antwerp as possible hub location, are provided in Section 8.2. The results of the network with Willebroek as a possible hub location are discussed in Section 8.3. The kilometer-based charge is applied and the transportation costs of the different networks are compared in Section 8.4.

8.1 Current network

This section considers the current network without a new hub in Belgium. The plan provides the amount and types of truck used, the number of kilometers traveled, and the total travel duration (including working and driving time). The start and end location is always Tilburg (5047TM). The results are provided in Table 21. With these results, the cost per day can be calculated by multiplying the distance traveled by the fixed cost per kilometer, and multiplying the duration by the fixed hourly wage per type of truck. The cost by type of vehicle used was provided in Table 20. This results in the following costs, displayed in Table 22. An example of the routes planned in SHORTREC of the current network is shown in Figure 22. Some demand nodes are not included in the routes, as these are the orders that are currently outsourced.

Table 21: Results for current network

Date	Trailers	km	Duration (hour)	Rigid	km	Duration (hour)	Total Distance	Total travel duration	LDM delivery
29-02-16	15	5958	170	7	2389	75	8347	15	237
1-03-16	20	6553	199	7	2026	67	8579	20	303
2-03-16	22	6807	215	5	1547	50	8354	22	315
3-03-16	18	5576	176	7	2457	77	8033	18	276
4-03-16	27	9537	269	9	2811	92	12348	27	400

Table 22: Transportation cost per day

Date	Trailer (km)	Trailer (hours)	Rigid (km)	Rigid (hours)	Total cost
29-2-2016	€ 2,562	€ 7,409	€ 717	€ 2,543	**€ 13,230**
1-03-16	€ 2,818	€ 8,672	€ 608	€ 2,271	**€ 14,369**
2-03-16	€ 2,927	€ 9,370	€ 464	€ 1,695	**€ 14,456**
3-03-16	€ 2,398	€ 7,670	€ 737	€ 2,610	**€ 13,415**
4-03-16	€ 4,101	€ 11,723	€ 843	€ 3,119	**€ 19,786**

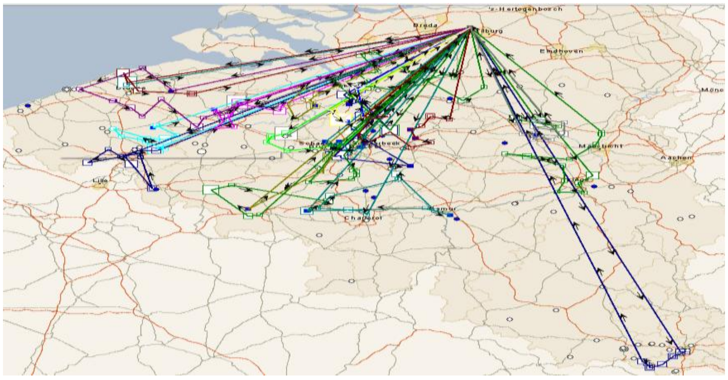

Figure 22: Overview of plan in SHORTREC for current network

8.2 Antwerp

The created plan in SHORTEC of the current network was adjusted by changing the hub in Tilburg to Antwerp. As a result, the trucks all depart from Tilburg to Antwerp, and the routes are driven starting from there. At the end of the route, the trucks return to the newly established hub and from there travel back to Tilburg. With the current strategy, the number of kilometers driven and the total duration increases. For example, the distance increases from 8,345 km to 8,726 km and the duration from 200 to 207 hours when all trucks are required to visit Antwerp (2000) before visiting customers. This results in an increase of approximately €400 for 29 February 2016. The results of adding a new hub in Antwerp with the current strategy are provided in Appendix S.

The new network uses LHVs between Tilburg and Antwerp. No warehousing or cross-docking is considered at Antwerp, only the decoupling on an LHV into a trailer and dolly. The number of trailers and dollies used is the same as the plan for the current network. For 29 February 2016, for example, it was 15 and 7, respectively. Seven trailers and seven dollies in an LHV combination are transported from Tilburg to Antwerp, and these depart from Antwerp separately. The remaining eight trailers depart from Tilburg. These are selected based on the fewest detour kilometers via Antwerp. This situation is displayed in Figure 23 and the results are provided in Table 23.

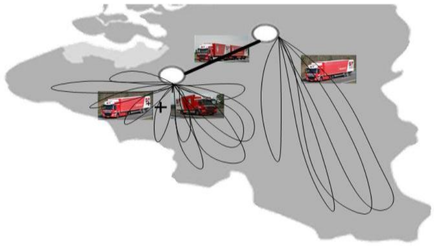

Figure 23: Overview of situation with decoupling LHVs at Antwerp

Table 23: Results of new network considering possibility of LHV decoupling

Date	Trailer (km)	Trailer (hour)	Dolly (km)	Dolly (hour)	LHVs	LHV (km)	LHV (hour)	Total (km)	Total (hour)
29-02-16	4902	152	1399	58	7	1064	17	7365	229
1-03-16	5497	181	1243	52	7	1064	17	7804	252
2-03-16	6054	203	1138	42	5	760	12	7952	259
3-03-16	4553	158	1562	63	7	1064	17	7179	240
4-03-16	8217	247	1688	70	9	1368	21	11273	342

The distance between Tilburg and Antwerp (2000) was set at 152 km and the travel duration was set at two hours and 20 minutes. These values were retrieved from SHORTREC. The outcomes of the new network result in the costs displayed in Table 24, below. With the strategy of decoupling, only a storage space for trucks and a few extra drivers from Belgium are required. The average salary in Belgium is approximately 10% per hour higher than in the Netherlands (Eurostat, 2015). The average salaries for the Netherlands and Belgium are provided in Appendix T. It is assumed that all trailers are driven by Belgian drivers from Antwerp to customers, as it provides the worst-case scenario, since the wage for a trailer driver is higher than for a rigid truck (dolly) driver. Furthermore, trailers generally travel more kilometers than dollies do as dollies are commonly used for short distances with multiple stops and trailers are used for longer distances with few stops. Dutch drivers already require two hours and 20 minutes to travel by LHVs and would probably exceed the driver and working hours when they use trailers from Antwerp. The wage of these Belgian drivers was multiplied by a factor of 1.1, resulting in €47.94 per hour.

Table 24: Transportation costs for new network per day

Date	Trucks (km)	Trucks (hours)	Dolly (km)	Dolly (hours)	LHV (km)	LHV (hours)	Belgian Driver	Total cost
29-2-2016	€ 2,108	€4,372	€ 420	€ 1,966	€ 458	€ 741	€2,477	**€12,593**
1-03-16	€ 2,364	€5,841	€ 373	€ 1,763	€ 458	€ 741	€2,251	**€13,837**
2-03-16	€ 2,603	€7,520	€ 341	€ 1,424	€ 327	€ 523	€1,460	**€14,228**
3-03-16	€ 1,958	€4,768	€ 469	€ 2,136	€ 458	€ 741	€2,330	**€12,907**
4-03-16	€ 3,533	€8,070	€ 506	€ 2,373	€ 588	€ 915	€2,964	**€19,012**

The decision about whether the trailer or dolly is driven by the Dutch LHV driver depends on the driving and working regulations. When possible, the Dutch driver should always use a trailer since this is cheaper than a rigid truck. The total transportations costs for the new network, shown in Table 24, are significantly lower than the transportation cost of the current network shown in Table 22. On average, a reduction of €631 euro is gained by placing a storage space in Antwerp and using the decoupling strategy. These costs do not yet include the new kilometer-based charge in Belgium.

8.3 Willebroek

Before the results of the possible hub locations were known, GVT Transport believed that Willebroek would be the best geographical location. Results show that Willebroek can be the best location if a discount between 69% and 79% is achieved. These discount values are almost impossible to achieve since approximately 95% of the goods in Belgium and Luxemburg are transported back to the Netherlands. However, building a hub in Willebroek is cheaper than building one in Antwerp, since the price per m^2 building ground is, on average, lower (Statistics Belgium, 2014). On average, €36 euro per m^2 of building ground can be saved on the investment cost by choosing Willebroek as location. If a hub is required, depending on the size of the warehouse and the difference in transportation costs between Antwerp and Willebroek, a hub location in Willebroek could become more attractive. Applying the same strategy as in Section 8.2 gave the results provided in Appendix U. Trailers from Willebroek to customers are also assumed to be driven by Belgian drivers.

By comparing the transportation costs of a hub in Antwerp with a hub in Willebroek, it can be concluded that the transportation costs of a hub in Willebroek are higher than those associated with a hub in Antwerp, as expected. A storage space for trucks in Willebroek does reduce the transportation costs by €1,550 compared to the current network, however, a storage space for trucks in Antwerp saves €2,400 euro more on a weekly basis.

8.4 Kilometer-based charge

The introduction of the kilometer-based charge by the Belgian government results in the following increase of cost per kilometer, provided in Table 25.

Table 25: Kilometer-based charge

	Highways Flanders, Wallonia, and Brussels			Urban roads Brussels		
€ / km	3.5-12 ton	12 – 32 ton	>32 ton	3.5-12 ton	12 – 32 ton	>32 ton
EURO 4	€0.095	€0.145	€0.149	€0.132	€0.207	€0.236
EURO 5	€0.074	€0.124	€0.128	€0.109	€0.184	€0.213
EURO 6	€0.074	€0.124	€0.128	€0.099	€0.174	€0.203

The trucks commonly in service for GVT Transport are labeled with Euronorm 5. The maximum mass of a truck is 40 or 50 tons. The price per kilometer does not differ between Euronorm 5 and 6 on the highways of Flanders, Wallonia, or Brussels. However, the price per kilometer on the urban roads within Brussels differs per Euronorm and are higher than using highways. Currently, customers in the region of Brussels are served by rigid trucks, which are lighter and therefore cheaper. GVT Transport's rigid trucks are all Euronorm 5. The maximum mass of the rigid truck is approximately 18 or 19 tons. Thus, for all rigid trucks, €0.124 is added to the current kilometer price, while for LHVs and trailers this cost is €0.128. It is assumed that a rigid truck, trailer, or LHV always remains in the same mass category. The addition of the kilometer-based charge is applied for every kilometer driven in Belgium. In practice, this is not the case, as the charge is only applicable on the main roads (Eurovig) and urban roads in Brussels. The roads for which the kilometer-based charge is applicable are displayed in Appendix V. The calculated cost is therefore higher than it would be in actuality. The kilometer-based charge for the urban roads in Brussels is not applied, since this is too complex to calculate manually.

In the case of the new hub, the distance between Tilburg and the border with Belgium was subtracted from the total distance between Tilburg and the new hub. The remaining distance was multiplied by the kilometer-based charge and the total distances of the rigid trucks and trucks. For the current situation, the assumption was made that the distance is roughly 62 km from Tilburg to the border, since trucks generally travel via Antwerp. This distance is only applicable for the trucks departing from Tilburg. A comparison table of the cost of the driven kilometers between the current and new network is provided in Table 26. This results in the following total transportation costs, which includes the duration, which are compared with those of the current network in Table 27.

Table 26: Transportation costs of driven kilometers in the current, and new network

	Current network				**New network**				
	NL		BE/LUX		NL		BE/LUX		
Date	Trailer	Dolly	Trailer	Dolly	Trailer	LHV	Trailer	Dolly	LHV
29-2-16	€400	€130	€2,806	€829	€213	€187	€2,459	€593	€352
1-03-16	€533	€130	€2,965	€675	€347	€187	€2,618	€527	€352
2-03-16	€587	€93	€3,037	€524	€453	€133	€2,790	€483	€251
3-03-16	€480	€130	€2,489	€858	€293	€187	€2,160	€662	€352
4-03-16	€720	€167	€4,388	€955	€480	€240	€3,962	€716	€452
Total	**€2,719**	**€651**	**€15,684**	**€3,841**	**€ 1,786**	**€ 933**	**€3,988**	**€2,981**	**€1,757**

Table 27: Total transportations costs for the current network and network including Antwerp

Date	5047TM	Antwerp	Savings
29-2-2016	€ 14,116	€ 13,360	**€ 981**
1-3-2016	€ 15,247	€ 14,626	**€ 826**
2-3-2016	€ 15,306	€ 15,036	**€ 402**
3-3-2016	€ 14,237	€ 13,628	**€ 821**
4-3-2016	€ 21,072	€ 20,172	**€ 1,170**
Total:	**€ 79,977**	**€ 76,820**	**€ 3,156**

Antwerp (2000) provides the lowest transportation cost compared to the current network. These costs already include the kilometer-based charge, which was implemented by the Belgian government in April 2016. In total, a savings of €3,156 euro can be achieved for the transportation cost by applying the use of LHVs. On average, GVT Transport can save €631 euro per day. By applying the LHV decoupling case at Willebroek a total saving of only €132 euro is achieved compared to the current network, coming to an average of €131 per day. The situation where all trucks depart from Antwerp is displayed in Appendix W.

8.5 LHV strategy with a hub

The case where all goods are first transported from Tilburg to the new hub, and then transported from there to customers provides different results. This strategy requires a cross-docking or warehouse facility and more Belgian drivers are required that depart from the new hub location. As in Section 8.2, it is assumed that only the rigid trucks from the LHVs are driven by Dutch drivers. The difference in costs between using only Dutch drivers and using both Dutch and Belgian drivers for trailers from both Antwerp and Willebroek is provided in Table 28.

Table 28: Difference in transportation costs using Dutch and Belgian drivers at the new hub

Antwerp		Willebroek	
Only Dutch Drivers	**Dutch and Belgium Drivers**	**Only Dutch Drivers**	**Dutch and Belgium Drivers**
€ 12,852	€ 13,445	€ 13,756	€ 14,366
€ 13,560	€ 14,214	€ 14,553	€ 15,224
€ 14,595	€ 15,332	€ 16,065	€ 16,841
€ 13,525	€ 14,144	€ 13,966	€ 14,594
€ 19,350	€ 20,260	€ 19,805	€ 20,681
€ 73,883	€ 77,395	€ 78,145	€ 81,705

Table 28 shows that the transportation costs are further reduced by only using Dutch drivers from the new hub compared to the LHV decoupling strategy, however, with Belgian drivers the decoupling strategy becomes more profitable than the strategy with a hub. So, only in the case of all Dutch drivers at the new hub is this strategy better than the decoupling strategy, assuming the 10% increase in wages for Belgian drivers. With Dutch drivers the investment cost between Antwerp and Willebroek can be compared, and this is provided in Appendix X.

8.6 Conclusion

The decoupling strategy at Antwerp does not require a facility and there is no increase in handling cost. GVT Transport should only invest in a location in Antwerp that consists of space to store trucks (tow parts), and surround this location with barriers and secure the location. The trucks that are stored at Antwerp are used to tow the decoupled trailers or dolly parts from the LHVs to customers. In the current plan, the maximum amount of LHVs used is nine, thus, at least nine trucks (tow parts) are required at the Antwerp. These trucks can be purchased, but trucks that are already in service can also be stored at the new hub location. In this case the investment cost will be low.

Note that the cost of the new network is based on planning from Tilburg. The routes are planned from Antwerp as if they are executed from Tilburg to customers. As a result, higher savings can be achieved by optimizing the planning of the routes from Antwerp to customers. Furthermore, the kilometer-based charge is currently applied to all the kilometers driven in Belgium, whereas in practice they only apply on the highways of Belgium and urban roads in Brussels. The actual transportation cost will, therefore, be lower.

9. Conclusion

The main findings of this research are described in this chapter. The introduced kilometer-based charge in Belgium increases the transportation cost, and the research focused on investigating the possibility of a new hub in Belgium to improve the density of the current network. Since almost all the goods originate from the hub in Tilburg, a hub does not seem to be required in Belgium. However, by introducing a new distribution strategy a hub location in Belgium becomes feasible. The results of the p-median model, which minimizes the demand-weighted average distance, showed that a hub in Belgium becomes advantageous when a discount of at least 12% can be achieved between hubs. The results showed that the hub should be located in Antwerp when economies of scale is between 12% and 52%. Using the strategy with LHVs between hubs achieves a discount of approximately 40% and, thus, the corresponding hub location is Antwerp. The sensitivity analysis showed that the hub location remained in Antwerp, even under different scenarios. Scenarios with an increase of demand at certain regions and the use of time instead of distance were used.

Currently, LHVs are not allowed in Belgium and a trial is executed to determine whether LHVs will be allowed in the future. Antwerp is accessible by LHVs in the current trial. Since the LHV strategy is considered as the best strategy, this strategy is applied in the case study. In the case of decoupling, LHVs travel between hubs and are decoupled at Antwerp. From Antwerp the decoupled trailer and dolly travel separately to customers. Since the LHV is a combination of a trailer (13.6 ldm) and a dolly (7.2 ldm), and a combination of two trailers is not allowed, the number of LHVs is equal to the number of dollies used. The remaining trailers that are required to fulfill all demand still depart from, and end at Tilburg. With the decoupling strategy only a storage space for trucks (tow parts) is required, and this space should be secured. By calculating the transportation costs of a one-week plan, the results showed that the decoupling strategy in Antwerp already decreases these costs. The plan is created based on the hub location in Tilburg. The start and end location of the route is only adjusted, meaning, the routes are not optimized for the potential situation from Antwerp. By optimally planning the routes from Antwerp, the transportation cost can be reduced even more.

The transportation costs for Willebroek were also calculated, since this was the location expected beforehand by GVT Transport. The calculations showed that the decoupling strategy at Willebroek does reduce costs compared to the current network, however, the costs are higher than decoupling in Antwerp. Based on these results, a recommendation is provided to GVT Transport in Section 9.1. The provided recommendations are discussed in Section 9.2, and recommendations for future research are given in the discussion in Section 9.3.

9.1 Recommendation

The following options are recommended to GVT Transport, based on the results of this research:

1. Decoupling strategy at Antwerp

This concerns the best-case scenario in which LHVs will be allowed in Belgium and GVT Transport uses LHVs between hubs. In Chapter 8, calculations showed that the decoupling LHV strategy already reduced the transportation costs by approximately €631 per day. The investment cost will be low, since only a storage space is required for trucks (tow part). This space should be surrounded by barriers and secured. Furthermore, Belgian drivers are required to drive one part of the decoupled LHV from Antwerp to customers. These Belgian drivers cost on average 10% more than Dutch drivers (Eurostat, 2014). The other decoupled part can be driven by the driver of the LHV when working and driving regulations are not exceeded. The routes are currently based on planning from Tilburg to customers. By optimally planning the routes from Antwerp to customers, an even bigger reduction in the transportation cost can be achieved.

2. Hub in Antwerp including trailer strategy

This concerns the scenario in which LHVs will not be allowed in Belgium and GVT Transport wants to adjust their distribution strategy. In the event that LHVs are not allowed in Belgium, GVT Transport can choose to use trailers between hubs, and city trailers or dollies to deliver goods from Antwerp. This requires a cross-docking facility in Antwerp to transfer goods from the trailer (13.6 ldm) onto city trailers (10 ldm) and dollies/rigid trucks (7.2 ldm). This would also achieve economies of scale between hubs, however, this would be lower than with the LHV strategy.

3. No hub in Belgium

This concerns the scenario in which LHVs are not allowed in Belgium and the distribution strategy is not adjusted or when only an economy of scale below 12% is achieved.

9.2 Discussion recommendation

Based on the results and the possibility of decreasing the transportation costs, the decoupling strategy at Antwerp with LHVs is recommended to GVT Transport (option 1). However, Antwerp-Brussels is known to be one of the most congested cities in Europe and time is an important cost factor. These traffic congestion levels are mainly during the morning and evening peaks. In the Netherlands, LHVs travel between hubs during the night. By applying the same strategy in Antwerp, the congestion in Antwerp is avoided in the morning. LHVs should arrive in Antwerp around 05:00, so the trailers and dollies can depart early to avoid congestion in the region of Brussels. It is highly recommended that the departure times of the LHVs, trailers, and dollies are set such that congestion levels are avoided, otherwise this will result in high costs and loss of time. Furthermore, in the decoupling case it was assumed that all trailers from Antwerp are driven by Belgian drivers as mentioned in Section 8.2. It would be beneficial to reduce the number of required Belgian drivers to a minimum. The driver of the LHV should be fully utilized, without exceeding the working and driving regulations. The company should also look at the possibility of placing two drivers on an LHV between hubs, so that both decoupled parts of the LHV can be driven by Dutch drivers from Antwerp to customers. The trailers that still depart from Tilburg are mainly for customers in Luxemburg and the eastern part of Belgium. These routes are driven mainly through Belgium or the Netherlands. For example, Wanze (4260) can be visited, as well as Turnhout and Maastricht, as shown in Appendix Y. The total duration and distance is approximately equal, except via Turnhout. However, 106 Belgian km in total can be saved via Maastricht, as compared to driving via Antwerp. The trade-off between fewer Belgium kilometers versus duration should be compared for these cases.

Currently, the plan is manually created by the planners of GVT Transport. By importing the correct information for the orders, fleet, and restrictions into SHORTREC, the program can create feasible routes. This provides the planners with extra time to allocate drivers from the LHV to the routes of the trailers and dollies from Antwerp, and the working and driving hours regulations will be adhered to. The trial with LHVs is currently being executed, and it is recommended to focus on the developments of this trial. During the trial, GVT Transport can investigate the possible exact location in the region of Antwerp. The hub location should be within 10 km from a highway, and not in the center of a city. If the trial results are positive, GVT Transport can immediately start building a storage space for trucks (tow part) in Antwerp. If the trial results are negative, GVT Transport can still build a hub in the region of Antwerp and apply the trailer strategy. Warehousing is not required, since approximately 95% of goods originate from and are destined for the Netherlands. When new customers are recruited in Belgium, Luxemburg, or the north of France and the amount of goods increases that is distributed within these countries, warehousing becomes more attractive.

9.2 Future recommendations

Several recommendations can be provided for further research:

- To provide a better approximation of the transportation costs, the routes from Antwerp should be optimally planned and the simulation should cover at least one month.
- Currently, the plan is manually decided by a planner, since simulations by SHORTREC provide infeasible results. SHORTREC is able to provide an optimal planning of routes, but is dependent on the information that is imported. GVT Transport should focus on the importation process of the correct information into SHORTREC considering the orders, time windows of customers, and fleet capacities. When the import data is correct, SHORTREC can provide GVT Transport with an optimal plan in just a few minutes. This saves an enormous amount of time for the planners, which can be used for the allocation of the routes to drivers. Furthermore, the company can easily perform more simulations of possible new networks and evaluate the results, whereas now a planner is required for such simulations.
- The exact location of the storage space or hub location should be examined. This thesis only provides the zip code, but not the exact location. As mentioned in Section 7.2, different categories need to be considered for the hub location decision. So, detailed research for the actual location in the region of Antwerp should be conducted.
- Only the network consisting of Tilburg, Belgium, and Luxembourg was considered. The company should investigate the effect of the new location in Antwerp on the whole network. Currently, small order sizes are outsourced and these orders are commonly located in Luxembourg and near the border with France. In the current network, outsourcing of these orders is cheaper than transportation by GVT Transport. Since the new network reduces the time and distance regarding these orders, it may be cheaper to deliver/pick up these orders themselves. Investigating the difference in costs provides new insight into whether the outsourcing companies should be retained or not.
- Dependent on the outcome of the current LHV trial, a case study including the strategy with trailers between the hubs, and dollies and city trailers from Antwerp to customers should be carried out. This provides more insight into the decision to apply the trailer strategy if LHVs are not allowed by Belgium. This case study should be carried out during the trial.
- GVT Transport should investigate the possibility of expanding their network by recruiting new customers in Belgium, Luxemburg, and France, as a new location in Antwerp provides the opportunity to serve more customers in these regions.
- An investigation should be made into the trade-off between fewer kilometers traveled in Belgium versus duration. This can also be applied in the current situation when beneficial.

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Appendix A Driving and working time regulations

The planners of GVT should fulfill the driving and working time regulations when creating the planning. An overview of the driver and working hours regulation is provided in Table 29.

Table 29; Overview driver and working time regulations

Drivers' hours regulations (EC)561/2006	Working time regulations, Directive 2002/15/EC
9 hour daily driving limit (can be increased to 10 hours twice a week)	Working time must not exceed average of 48 hours a week
Maximum 56 hour weekly driving limit	Maximum working time of 60 hours in one week (provided average not exceeded)
Maximum 90 hour fortnightly driving limit	Maximum working time of 10 hours if night work performed
45 minutes break after 4.5 hours	Cannot work for more than 6 hours without a break. A break should be at least 15 minutes
A break can split into two periods, the first being at least 15 minutes and the second at least 30 minutes (which must be completed after 4.5 hours driving)	30 minute break if working between 6 and 9 hours in total.
11 hour daily rest; which can be reduced to 9 hours no more than three times a week (or split into 3 hours + 9 hours as often as desired)	45 minute break if working more than 9 hours in total
45 hours weekly rest; which can be reduced to 24 hours, provided at least one full rest is taken in any fortnight. There should be no more than six consecutive 24 hour periods between weekly rests.	Same rest requirements as EU drivers' hours regulations

Appendix B Zip codes corresponding to provinces

Each province in Belgium and Luxemburg contains zip codes based on the first two digits. An overview of the zip codes per province is displayed in Table 30.

Table 30; Provinces with corresponding zip codes in Belgium and Luxemburg

Provinces	Zip codes
Brussels	10-12
Walloon Brabant	13-14
Flemish Brabant	15-19, 30-34
Antwerp	20-29
Limburg	35-39
Liege	40-49
Namur	50-59
Hainaut	60-65, 70-79
Luxembourg	66-69
West-Flanders	80-89
East-Flanders	90-99
Luxemburg (LU)	10-49 and 70-84
Grevenmacher (LU)	50-69
Diekirch (LU)	85-99

Appendix C Distribution demand per month for pickup

For each month of the considered period the demand is analyzed. An overview of the demand per month considering pick up is provided in Table 31.

Table 31; Overview distribution per month for pickup

Month	Load meters	Orders	Working Days	ldm/day	order/day	ldm/order	% total ldm	% total orders
jul-14	2071.08	1026	22	94.14	46.64	2.02	6.15%	5.42%
aug-14	2268.76	1019	20	113.44	50.95	2.23	6.74%	5.38%
sep-14	2944.86	1636	22	133.86	74.36	1.80	8.75%	8.64%
okt-14	3408.54	1846	23	148.20	80.26	1.85	10.12%	9.74%
nov-14	3074.39	1736	19	161.81	91.37	1.77	9.13%	9.16%
dec-14	3228.85	1784	21	153.75	84.95	1.81	9.59%	9.42%
jan-15	3141.35	1527	21	149.59	72.71	2.06	9.33%	8.06%
feb-15	2960.58	1548	20	148.03	77.40	1.91	8.79%	8.17%
mrt-15	3545.32	2106	22	161.15	95.73	1.68	10.53%	11.12%
apr-15	2249.61	1458	20	112.48	72.90	1.54	6.68%	7.70%
mei-15	2043.60	1415	19	107.56	74.47	1.44	6.07%	7.47%
jun-15	2734.30	1843	22	124.29	83.77	1.48	8.12%	9.73%
	33671.25	**18944**	**251**	**1608.29**	**905.52**	**21.6**	**100.00%**	**100.00%**

Appendix D Distribution demand per month for delivery

For each month of the considered period the demand is analyzed. An overview of the demand per month considering delivery is provided in Table 32.

Table 32; Overview distribution per month for delivery

Month	Load meter	Orders	Work days	ldm/day	order/ day	ldm/order	% total ldm	% total orders
jul-14	7442.32	10482	22	338.29	476.45	0.71	8.23%	8.76%
aug-14	6757.64	9536	20	337.88	476.80	0.71	7.47%	7.97%
sep-14	7926.65	11353	22	360.30	516.05	0.70	8.76%	9.48%
okt-14	9310.33	14669	23	404.80	637.78	0.63	10.29 %	12.26%
nov-14	8544.67	12487	19	449.72	657.21	0.68	9.45%	10.43%
dec-14	8970.53	13475	22	407.75	612.50	0.67	9.92%	11.26%
jan-15	7539.94	11110	21	359.04	529.05	0.68	8.34%	9.28%
feb-15	6836.19	9811	20	341.81	490.55	0.70	7.56%	8.20%
mrt-15	8380.94	10773	22	380.95	489.68	0.78	9.27%	9.00%
apr-15	5924.14	5337	20	296.21	266.85	1.11	6.55%	4.46%
mei-15	6005.45	4962	18	333.64	275.67	1.21	6.64%	4.15%
jun-15	6811.28	5701	22	309.60	259.14	1.19	7.53%	4.76%
	90450.08	**119696**	**251**	**4319.99**	**5687.7**	**9.77**	**100%**	**100%**

Appendix E Overview pickup and delivery provinces

For each province the demand of pickup and delivery is considered. An overview of the demand of pick up is shown in Table 33.

Table 33; Overview pickup

Pickup	Load meters	Orders	% total ldm	% total orders	Min ldm	Max ldm	Average Ldm
Brussels	278.55	350	0.83%	1.85%	0.020	13.60	0.80
Walloon Brabant	452.48	164	1.34%	0.87%	0.020	13.60	2.76
Flemish Brabant	2681.55	1297	7.96%	6.85%	0.020	13.60	2.07
Antwerp	5658.69	1388	16.81%	7.33%	0.020	13.60	4.08
Limburg	429.98	583	1.28%	3.08%	0.020	13.60	0.74
Liege	340.83	304	1.01%	1.60%	0.020	13.60	1.12
Namur	141.43	167	0.42%	0.88%	0.020	13.20	0.85
Hainaut	7056.17	4743	20.96%	25.04%	0.020	13.60	1.49
Luxembourg	45.36	67	0.13%	0.35%	0.020	13.60	0.68
West-Flanders	8895.76	6916	26.42%	36.51%	0.020	13.60	1.29
East-Flanders	7544.73	2780	22.41%	14.67%	0.020	13.60	2.71
Diekirch (LU)	2.94	13	0.01%	0.07%	0.020	0.50	0.23
Grevenmacher (LU)	12.94	15	0.04%	0.08%	0.040	3.80	0.86
Luxemburg (LU)	129.84	157	0.39%	0.83%	0.020	12.50	0.83
Total	**33671.25**	**18944**	**100%**	**100%**			**1.46**

The amount of load meters and the number of orders per province considering pick up is shown in Figure 24.

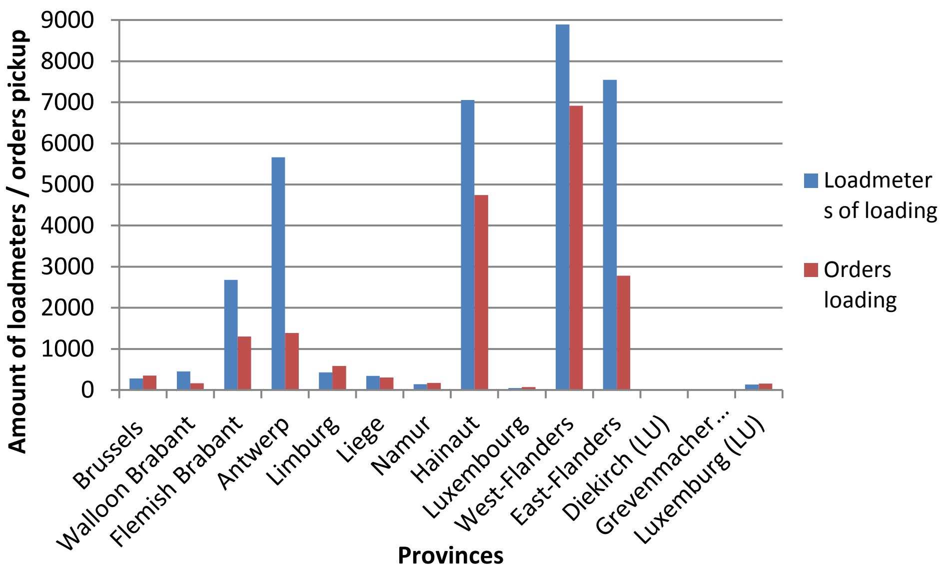

Figure 24; Load meters and orders of pickup

The percentage of load meters and number of orders per province considering pick up is displayed in Figure 25.

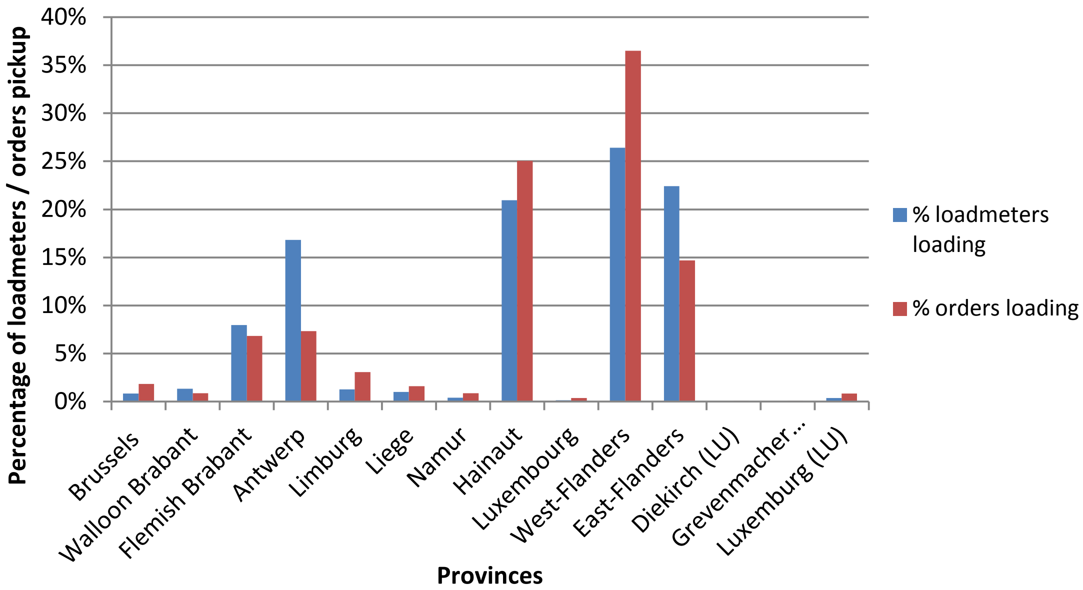

Figure 25; Percentages load meters and orders pickup

An overview of the demand of delivery is shown in Table 34.

Table 34; Overview delivery

Delivery	Load meters	Orders	% total ldm	% total orders	Min ldm	Max ldm	Average Ldm
Brussels	4811.34	8178	5.32%	6.83%	0.015	13.60	0.59
Walloon Brabant	3053.92	3283	3.38%	2.74%	0.020	13.60	0.93
Flemish Brabant	18137.75	25532	20.05%	21.33%	0.015	13.60	0.71
Antwerp	25190.06	19543	27.85%	16.33%	0.020	13.60	1.29
Limburg	4887.14	7579	5.40%	6.33%	0.018	13.60	0.64
Liege	3206.26	5035	3.54%	4.21%	0.020	13.60	0.64
Namur	1412.56	2310	1.56%	1.93%	0.018	13.60	0.61
Hainaut	7220.02	13284	7.98%	11.10%	0.020	13.60	0.54
Luxembourg	806.69	927	0.89%	0.77%	0.020	13.60	0.87
West-Flanders	7077.76	11355	7.83%	9.49%	0.017	13.60	0.62
East-Flanders	11582.66	16382	12.81%	13.69%	0.017	13.60	0.71
Diekirch (LU)	27.57	103	0.03%	0.09%	0.020	2.00	0.27
Grevenmacher (LU)	183.81	448	0.20%	0.37%	0.020	2.44	0.41
Luxemburg (LU)	2852.52	5737	3.15%	4.79%	0.020	12.70	0.50
Total	**90450.08**	**119696**	**100%**	**100%**			**0.67**

The amount of load meters and the number of orders per province considering pick up is provided in Figure 26.

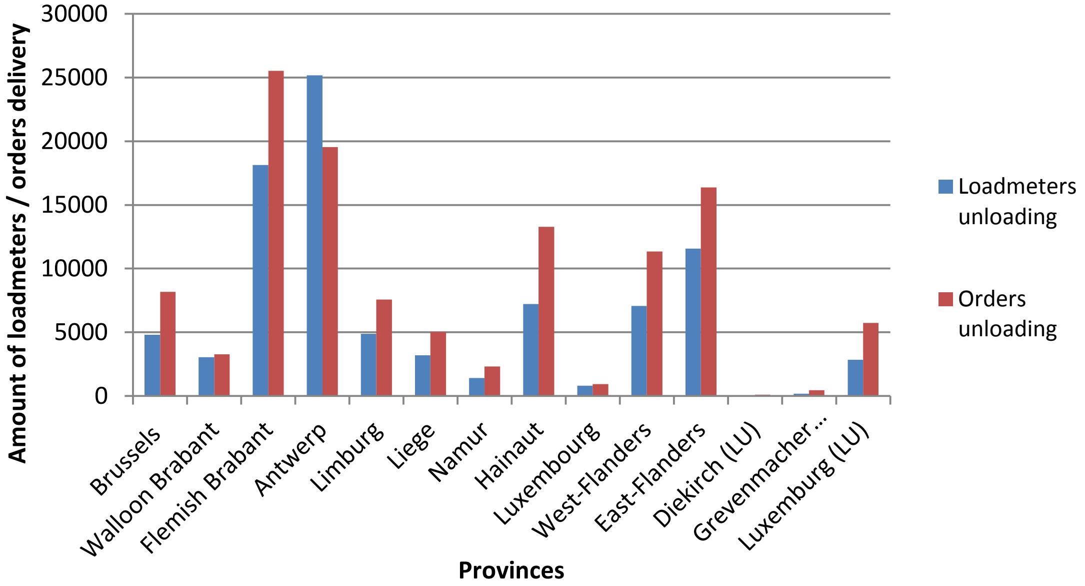

Figure 26; Load meters and orders of delivery

The percentage of load meters and number of orders per province considering delivery is shown in Figure 27.

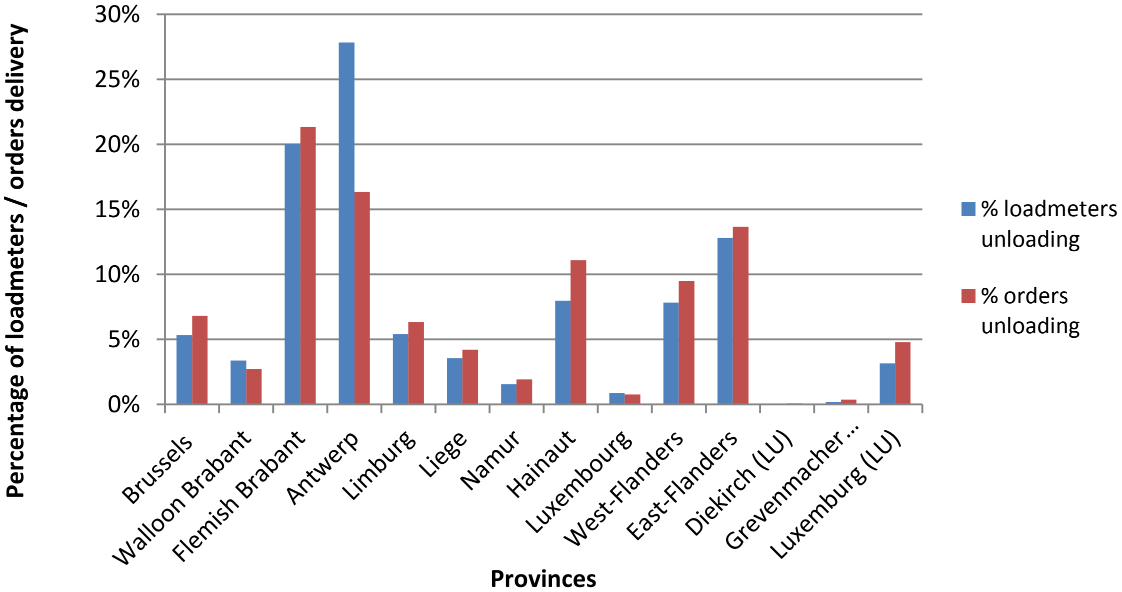

Figure 27; Percentage of load meters and orders delivery

Appendix F Overview pickup and delivery from countries

To consider the option of warehousing at the new hub, the destinations and origins of the goods should be known. An overview of the destinations of the goods that are picked-up in Belgium is provided in Table 35.

Table 35; Overview distribution pickup Belgium

		to: Belgium		to: Netherlands		to: Luxemburg	
Pickup at:	**Zip-code region**	**Load meter**	**Orders**	**Load meter**	**Orders**	**Load meter**	**Orders**
Brussels	**10-12**	15.84	18.00	262.71	332	0.00	0
Walloon Brabant	**13-14**	50.98	8.00	401.50	156	0.00	0
Flemish Brabant	**15-19, 30-34**	63.60	47.00	2617.95	1250	0.00	0
Antwerp	**20-29**	33.29	41.00	5624.60	1345	0.80	2
Limburg	**35-39**	2.28	7.00	427.70	576	0.00	0
Liege	**40-49**	17.70	7.00	323.13	297	0.00	0
Namur	**50-59**	0.02	1.00	141.41	166	0.00	0
Hainaut	**60-65, 70-79**	2.82	6.00	7053.35	4737	0.00	0
Luxembourg	**66-69**	0.04	1.00	45.32	66	0.00	0
West-Flanders	**80-89**	79.45	22.00	8815.91	6893	0.40	1
East-Flanders	**90-99**	97.54	37.00	7446.60	2742	0.60	1
		363.56	**195**	**33160.17**	**18560**	**1.80**	**4**

Table 35 shows that almost all goods that originated from Belgium are delivered in the Netherlands. An overview of the goods that are delivered to Belgium is shown in Table 36.

Table 36; Overview distribution delivery Belgium

		from: Belgium		from: Netherlands		from: Luxemburg	
Delivery	**Zip-code region**	**Load meter**	**Orders**	**Load meter**	**Orders**	**Load meter**	**Orders**
Brussels	**10-12**	18.02	17	4793.32	8161	0.00	0
Walloon Brabant	**13-14**	40.00	4	3013.92	3279	0.00	0
Flemish Brabant	**15-19, 30-34**	51.04	45	18086.72	25486	0.00	0
Antwerp	**20-29**	62.01	38	25127.85	19505	0.20	1
Limburg	**35-39**	1.52	9	4885.62	7570	0.00	0
Liege	**40-49**	4.90	9	3201.36	5026	0.00	0
Namur	**50-59**	0.00	0	1412.56	2310	0.00	0
Hainaut	**60-65, 70-79**	19.47	13	7200.55	13271	0.00	0
Luxembourg	**66-69**	0.24	2	806.45	925	0.00	0
West-Flanders	**80-89**	110.95	22	6966.31	11332	0.50	1
East-Flanders	**90-99**	55.40	36	11527.26	16346	0.00	0
		363.56	**195**	**87021.92**	**113211**	**0.70**	**2**

Table 36 shows that almost all goods that are delivered in Belgium originate from the Netherlands. An overview of the destinations of the goods picked-up in Luxemburg is displayed in Table 37.

Table 37; Overview distribution pickup Luxemburg

		to: Belgium		to: Netherlands		to: Luxemburg	
Pickup	**Zip-code region**	**Load meter**	**Order**	**Load meter**	**Order**	**Load meter**	**Order**
Diekirch (LU)	**85-99**	0.00	0	2.94	13.00	0	0
Grevenmacher (LU)	**50-69**	0.00	0	12.94	15.00	0	0
Luxemburg (LU)	**10-49 en 70-84**	0.70	2	129.14	155.00	0	0
		0.70	**2**	**145.02**	**183**	**0.00**	**0**

Table 37 shows that almost all goods that originated from Luxemburg are delivered in the Netherlands. An overview of the goods that are delivered to Luxemburg is displayed in Table 38.

Table 38; Overview distribution delivery Luxemburg

		from: Belgium		from: Netherlands		from: Luxemburg	
Delivery	**Zip-code region**	**Load meter**	**Order**	**Load meter**	**Order**	**Load meter**	**Order**
Diekirch (LU)	**85-99**	0.00	0	27.57	105	0	0
Grevenmacher (LU)	**50-69**	0.00	0	183.81	448	0	0
Luxemburg (LU)	**10-49 en 70-84**	1.80	4	2850.72	5731	0	0
		1.80	**4**	**3062.10**	**6284**	**0.00**	**0**

Table 38 shows that almost all goods that are delivered in Luxemburg originate from the Netherlands.

Appendix G Maximum and minimum order sizes

The most common maximum order size for both pickup and delivery is 13.6 load meters and the minimum is 0.020 load meters. An overview of the maximum and minimum order size per province of Belgium and Luxemburg, considering pickup, is displayed in Table 39.

Table 39; Overview minimum and maximum order sizes for pickup

Pickup	Zip-code region	Min ldm	Max ldm
Brussels	10-12	0.020	13.60
Walloon Brabant	13-14	0.020	13.60
Flemish Brabant	15-19, 30-34	0.020	13.60
Antwerp	20-29	0.020	13.60
Limburg	35-39	0.020	13.60
Liege	40-49	0.020	13.60
Namur	50-59	0.020	13.20
Hainaut	60-65, 70-79	0.020	13.60
Luxembourg	66-69	0.020	13.60
West-Flanders	80-89	0.020	13.60
East-Flanders	90-99	0.020	13.60
Diekirch (LU)	85-99	0.020	0.50
Grevenmacher (LU)	50-69	0.040	3.80
Luxemburg (LU)	10-49 en 70-84	0.020	12.50

An overview the maximum and minimum order size of delivery is displayed in Table 40.

Table 40; Overview minimum and maximum order sizes for delivery

Delivery	Zip-code region	Min ldm	Max ldm
Brussels	10-12	0.015	13.60
Walloon Brabant	13-14	0.020	13.60
Flemish Brabant	15-19, 30-34	0.015	13.60
Antwerp	20-29	0.020	13.60
Limburg	35-39	0.018	13.60
Liege	40-49	0.020	13.60
Namur	50-59	0.018	13.60
Hainaut	60-65, 70-79	0.020	13.60
Luxembourg	66-69	0.020	13.60
West-Flanders	80-89	0.017	13.60
East-Flanders	90-99	0.017	13.60
Diekirch (LU)	85-99	0.020	2.00
Grevenmacher (LU)	50-69	0.020	2.44
Luxemburg (LU)	10-49 en 70-84	0.020	12.70

Appendix H Combined* per province

An overview of the demand per province of Belgium and Luxemburg is provided in Table 41. This overview considers the situation of combined*.

*Table 41; Overview of combined**

Maximum LDM	Zip-code region	Load meters	Orders	ldm/order	% total ldm	% total orders
Brussels	10-12	4824.99	8147	0.59	4.95%	7.18%
Walloon Brabant	13-14	3207.95	3036	1.06	3.29%	2.67%
Flemish Brabant	15-19, 30-34	18137.75	25532	0.71	18.62%	22.49%
Antwerp	20-29	25213.93	19533	1.29	25.89%	17.21%
Limburg	35-39	4919.44	7544	0.65	5.05%	6.65%
Liege	40-49	3283.58	4894	0.67	3.37%	4.31%
Namur	50-59	1485.96	2286	0.65	1.53%	2.01%
Hainaut	60-65, 70-79	9690.49	12129	0.80	9.95%	10.69%
Luxembourg	66-69	829.51	937	0.89	0.85%	0.83%
West-Flanders	80-89	10218.44	9918	1.03	10.49%	8.74%
East-Flanders	90-99	12495.12	13286	0.94	12.83%	11.71%
Diekirch (LU)	85-99	30.09	114	0.26	0.03%	0.10%
Grevenmacher (LU)	50-69	189.97	446	0.43	0.20%	0.39%
Luxemburg (LU)	10-49 en 70-84	2865.32	5699	0.50	2.94%	5.02%
		97392.55	**113501**	**0.75**	**100%**	**100%**

The results of Table 41 are shown in Figure 28 to provide an orderly view of the differences.

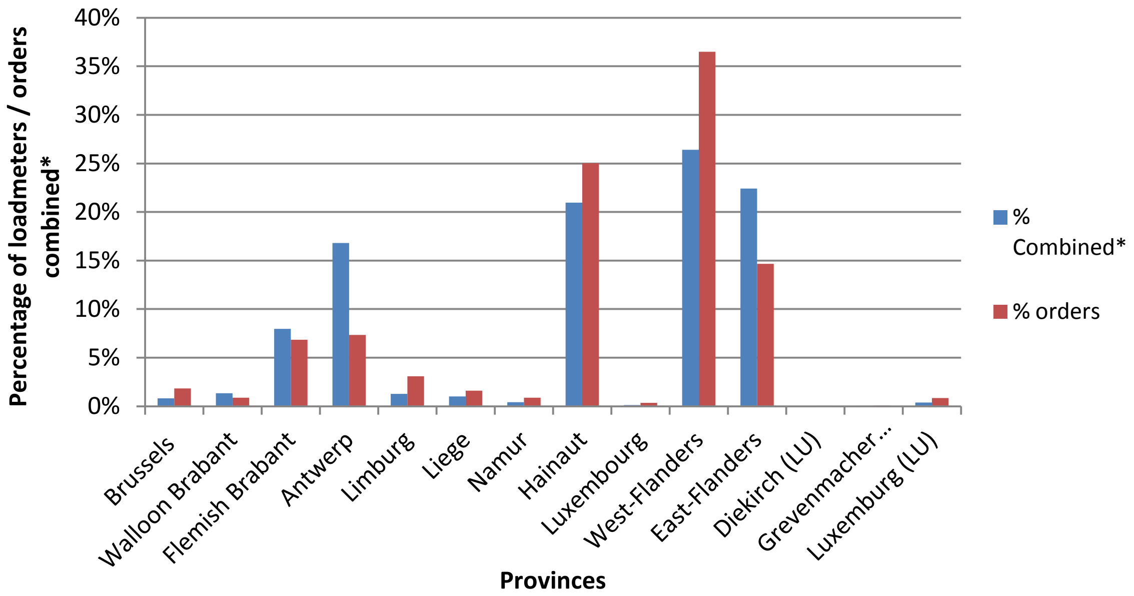

*Figure 28; Overview percentages combined**

Appendix I Selected zip codes

The zip codes that did fulfill the requirements in section 4.4.1. are selected. An overview of these selected zip codes is provided below.

5047TM (NL)	2018	3200	5000	7331	9230
1000	2030	3300	5020	7500	9300
1020	2070	3320	5080	7522	9320
1030	2100	3370	5100	7600	9400
1070	2160	3390	5300	7700	9420
1082	2170	3400	5380	7800	9450
1083	2200	3500	5500	7900	9500
1100	2221	3530	5580	8000	9600
1180	2250	3550	5600	8020	9700
1190	2300	3580	5620	8200	9800
1200	2320	3583	5953	8300	9810
1300	2321	3600	6000	8400	9820
1348	2340	3700	6040	8490	9900
1400	2400	3800	6041	8500	9940
1420	2440	3900	6150	8510	1610 (LU)
1480	2500	3920	6180	8520	3254 (LU)
1500	2520	4000	6200	8560	3364 (LU)
1600	2550	4020	6460	8570	3898 (LU)
1620	2600	4040	6530	8600	4361 (LU)
1651	2610	4041	6600	8700	8399 (LU)
1700	2630	4100	6700	8790	
1702	2640	4280	6780	8800	
1731	2800	4300	6800	8870	
1740	2830	4400	6900	8900	
1780	2870	4432	7000	9000	
1800	2880	4500	7012	9041	
1804	2900	4530	7060	9042	
1830	2950	4600	7100	9080	
1831	2960	4700	7110	9100	
1851	3000	4800	7181	9130	
1930	3001	4801	7300	9140	
2000	3190	4900	7301	9200	

Appendix J Not selected zip codes

The zip codes that did not fulfill the requirements in section 4.4.1 were not selected. An overview of the zip codes that were not selected from Belgium and Luxemburg is shown below.

Belgium

1031	1790	2840	3650	4651	5680	7020	8211	9051
1040	1820	2845	3660	4654	6001	7021	8235	9052
1043	1821	2850	3665	4670	6010	7022	8301	9060
1048	1840	2860	3670	4671	6020	7033	8310	9070
1050	1850	2861	3680	4672	6030	7034	8340	9090
1060	1852	2890	3690	4682	6031	7040	8370	9111
1080	1853	2910	3730	4683	6032	7041	8377	9112
1081	1860	2920	3740	4684	6042	7050	8380	9120
1090	1861	2930	3770	4690	6044	7061	8420	9150
1091	1875	2940	3803	4711	6060	7063	8421	9160
1110	1880	2970	3806	4720	6061	7070	8430	9170
1114	1910	2979	3820	4728	6110	7080	8432	9190
1120	1931	2980	3830	4731	6140	7090	8433	9220
1130	1932	2981	3832	4750	6141	7130	8434	9240
1140	1933	2984	3840	4760	6142	7131	8450	9250
1150	1935	2990	3850	4761	6181	7134	8460	9255
1160	1950	3010	3870	4770	6183	7140	8470	9260
1170	1970	3012	3890	4780	6186	7141	8480	9270
1210	1980	3018	3891	4802	6210	7160	8501	9280
1230	1981	3020	3910	4820	6220	7170	8511	9290
1301	1982	3040	3911	4821	6223	7180	8530	9308
1310	2020	3050	3930	4830	6224	7190	8531	9310
1315	2040	3051	3940	4831	6230	7191	8540	9330
1320	2050	3052	3941	4837	6238	7320	8550	9340
1325	2060	3053	3945	4840	6240	7321	8551	9355
1330	2072	3061	3950	4841	6242	7322	8553	9402
1332	2110	3070	3960	4845	6250	7330	8554	9406
1340	2140	3071	3970	4851	6280	7332	8580	9443
1341	2150	3078	3971	4860	6440	7333	8581	9451
1342	2180	3080	3980	4870	6464	7340	8610	9460
1350	2220	3090	3990	4880	6470	7350	8620	9470
1357	2222	3110	3999	4890	6490	7370	8630	9472
1360	2223	3111	4030	4910	6531	7380	8640	9473
1367	2230	3118	4031	4920	6534	7387	8647	9506
1370	2235	3120	4032	4950	6536	7390	8650	9520
1380	2240	3128	4042	4960	6540	7501	8660	9550
1390	2242	3130	4050	4970	6543	7503	8670	9570
1401	2243	3140	4053	4980	6560	7520	8680	9572
1410	2260	3150	4101	4987	6590	7530	8690	9620
1421	2270	3191	4102	4990	6640	7531	8691	9630
1428	2275	3201	4120	5001	6660	7534	8710	9636

1430	2280	3202	4121	5002	6662	7540	8720	9660
1435	2288	3210	4130	5003	6666	7543	8730	9680
1440	2290	3211	4140	5004	6670	7601	8740	9681
1449	2310	3212	4141	5021	6671	7604	8750	9690
1450	2322	3220	4160	5030	6681	7608	8755	9730
1460	2328	3221	4170	5032	6687	7610	8760	9731
1461	2330	3270	4180	5051	6690	7620	8766	9743
1470	2350	3271	4190	5060	6720	7623	8770	9750
1490	2360	3272	4210	5070	6724	7640	8780	9770
1495	2370	3290	4219	5101	6740	7711	8791	9790
1502	2380	3294	4250	5140	6741	7712	8792	9830
1540	2381	3350	4254	5150	6747	7740	8793	9831
1541	2382	3360	4317	5170	6750	7750	8810	9840
1547	2387	3380	4340	5190	6760	7760	8820	9850
1560	2390	3401	4342	5310	6761	7780	8830	9860
1570	2430	3440	4360	5330	6762	7782	8840	9870
1581	2450	3450	4420	5340	6790	7801	8850	9880
1601	2453	3454	4430	5350	6791	7810	8851	9890
1602	2460	3460	4431	5370	6810	7812	8860	9910
1630	2470	3470	4450	5377	6820	7822	8880	9920
1640	2480	3471	4452	5502	6823	7830	8890	9930
1650	2490	3501	4458	5503	6831	7850	8902	9950
1652	2530	3510	4460	5520	6832	7860	8904	9960
1653	2531	3511	4470	5530	6840	7862	8908	9968
1654	2540	3512	4480	5537	6850	7864	8920	9970
1670	2547	3520	4520	5540	6870	7866	8930	9971
1673	2560	3540	4537	5555	6880	7870	8940	9980
1701	2570	3545	4540	5560	6887	7890	8950	9981
1703	2580	3549	4550	5564	6890	7904	8954	9982
1713	2590	3560	4557	5570	6920	7911	8970	9988
1730	2620	3570	4560	5574	6927	7912	8972	9990
1741	2627	3581	4570	5575	6940	7941	8978	9991
1742	2650	3582	4590	5590	6941	7950	8980	9992
1745	2660	3590	4601	5630	6980	7971	9016	
1750	2801	3620	4608	5640	6983	7972	9030	
1755	2811	3621	4610	5650	6990	7973	9031	
1760	2812	3630	4620	5651	6997	8050	9032	
1770	2820	3631	4630	5660	7010	8051	9040	
1785	2825	3640	4650	5670	7011	8210	9050	

Luxemburg

1013	1611	2380	3358	4365	5404	6832	8038	9230
1025	1618	2410	3370	4366	5411	6868	8041	9233
1123	1648	2420	3372	4367	5460	6911	8050	9254
1129	1660	2440	3378	4380	5480	6921	8051	9361
1150	1724	2442	3394	4384	5481	6970	8060	9501
1212	1736	2449	3401	4385	5542	7201	8069	9559
1220	1740	2450	3475	4394	5544	7220	8070	9638
1221	1818	2453	3510	4437	5591	7240	8079	9668
1225	1820	2529	3515	4463	5612	7327	8080	9706
1233	1852	2538	3590	4490	5690	7333	8212	9749
1246	1855	2540	3598	4556	5691	7380	8235	9764
1248	1858	2546	3670	4562	5826	7390	8279	9779
1253	1881	2549	3754	4671	5887	7440	8287	9809
1273	1882	2550	3801	4702	5888	7450	8301	9836
1274	1899	2557	3841	4832	6118	7452	8302	9905
1313	1911	2560	3852	4930	6131	7502	8303	9956
1331	1940	2610	3890	4940	6150	7525	8308	9964
1351	2013	2632	3895	4946	6212	7526	8331	9990
1354	2016	2633	3961	4950	6401	7542	8359	9991
1359	2144	2637	3980	4959	6412	7545	8374	9999
1445	2163	2668	4002	4963	6440	7619	8437	
1448	2165	2721	4010	4976	6464	7737	8508	
1456	2169	2895	4022	4985	6468	7759	8620	
1458	2179	2984	4149	5218	6477	7763	8706	
1468	2220	2995	4205	5220	6562	7769	8832	
1470	2230	3201	4222	5230	6580	7795	8833	
1471	2249	3220	4260	5231	6630	8001	9051	
1475	2311	3225	4347	5310	6670	8008	9063	
1479	2338	3253	4360	5326	6755	8009	9088	
1490	2339	3284	4362	5365	6773	8010	9099	
1511	2345	3290	4363	5371	6776	8011	9125	
1543	2370	3340	4364	5374	6815	8030	9160	

Appendix K Distribution demand per zip code for pickup and delivery

During the considered period of this thesis the total amount of load meters per zip code for both pickup and delivery is provided in Table 42.

Table 42; Overview distribution demand per zip code for both pickup and delivery

Zip code	Load meters loaded	Orders loaded	% LDM	% Orders	Load meters unloaded	Orders unloaded	% LDM	% Orders
1000	34.00	32	0.10%	0.17%	813.36	1326	0.90%	1.11%
1020	9.24	13	0.03%	0.07%	177.74	335	0.20%	0.28%
1030	22.90	9	0.07%	0.05%	148.87	343	0.16%	0.29%
1070	35.54	61	0.11%	0.32%	602.40	1069	0.67%	0.89%
1082	4.10	7	0.01%	0.04%	314.56	607	0.35%	0.51%
1083	0.90	2	0.00%	0.01%	121.16	136	0.13%	0.11%
1100	0.00	0	0.00%	0.00%	0.10	1	0.00%	0.00%
1180	3.46	9	0.01%	0.05%	103.50	289	0.11%	0.24%
1190	44.20	65	0.13%	0.34%	1203.30	1799	1.33%	1.50%
1200	8.42	22	0.03%	0.12%	704.42	886	0.78%	0.74%
1300	26.39	18	0.08%	0.10%	2048.16	1068	2.26%	0.89%
1348	0.92	2	0.00%	0.01%	147.81	178	0.16%	0.15%
1400	283.70	70	0.84%	0.37%	93.11	122	0.10%	0.10%
1420	10.36	16	0.03%	0.08%	459.60	1228	0.51%	1.03%
1480	94.19	19	0.28%	0.10%	106.62	60	0.12%	0.05%
1500	35.72	32	0.11%	0.17%	417.11	550	0.46%	0.46%
1600	33.55	53	0.10%	0.28%	3764.33	6098	4.16%	5.09%
1620	0.40	1	0.00%	0.01%	222.93	465	0.25%	0.39%
1651	11.60	15	0.03%	0.08%	127.78	140	0.14%	0.12%
1700	39.06	29	0.12%	0.15%	263.28	201	0.29%	0.17%
1702	0.40	1	0.00%	0.01%	296.59	385	0.33%	0.32%
1731	37.95	26	0.11%	0.14%	347.61	384	0.38%	0.32%
1740	108.51	90	0.32%	0.48%	52.57	88	0.06%	0.07%
1780	46.75	12	0.14%	0.06%	1738.72	279	1.92%	0.23%
1800	1982.94	566	5.89%	2.99%	3602.99	5099	3.98%	4.26%
1804	6.84	9	0.02%	0.05%	123.39	206	0.14%	0.17%
1830	12.04	11	0.04%	0.06%	377.67	1074	0.42%	0.90%
1831	6.70	29	0.02%	0.15%	196.51	635	0.22%	0.53%
1851	30.62	57	0.09%	0.30%	2689.83	4328	2.97%	3.62%
1930	47.13	37	0.14%	0.20%	1688.06	1461	1.87%	1.22%
2000	5.98	14	0.02%	0.07%	282.68	489	0.31%	0.41%
2018	14.42	21	0.04%	0.11%	304.12	589	0.34%	0.49%
2030	137.66	53	0.41%	0.28%	2972.53	1296	3.29%	1.08%
2070	6.30	12	0.02%	0.06%	390.86	276	0.43%	0.23%
2100	17.04	29	0.05%	0.15%	273.20	636	0.30%	0.53%

2160	8.30	17	0.02%	0.09%	689.78	440	0.76%	0.37%
2170	13.14	14	0.04%	0.07%	491.78	864	0.54%	0.72%
2200	64.34	29	0.19%	0.15%	2001.81	451	2.21%	0.38%
2221	3.48	9	0.01%	0.05%	137.90	276	0.15%	0.23%
2250	1.46	7	0.00%	0.04%	168.45	258	0.19%	0.22%
2300	87.84	64	0.26%	0.34%	6006.16	1360	6.64%	1.14%
2320	9.30	4	0.03%	0.02%	119.58	55	0.13%	0.05%
2321	29.70	5	0.09%	0.03%	106.88	61	0.12%	0.05%
2340	29.18	11	0.09%	0.06%	106.74	94	0.12%	0.08%
2400	9.30	9	0.03%	0.05%	61.03	158	0.07%	0.13%
2440	11.86	23	0.04%	0.12%	219.49	467	0.24%	0.39%
2500	54.92	11	0.16%	0.06%	69.99	163	0.08%	0.14%
2520	2.90	3	0.01%	0.02%	206.56	166	0.23%	0.14%
2550	40.33	66	0.12%	0.35%	680.95	536	0.75%	0.45%
2600	0.40	1	0.00%	0.01%	21.60	71	0.02%	0.06%
2610	33.07	37	0.10%	0.20%	490.90	893	0.54%	0.75%
2630	7.06	14	0.02%	0.07%	175.02	305	0.19%	0.25%
2640	11.12	16	0.03%	0.08%	443.24	737	0.49%	0.62%
2800	3400.47	336	10.10%	1.77%	851.67	1360	0.94%	1.14%
2830	65.80	17	0.20%	0.09%	561.04	959	0.62%	0.80%
2870	123.80	95	0.37%	0.50%	1191.68	1516	1.32%	1.27%
2880	961.78	102	2.86%	0.54%	3718.87	550	4.11%	0.46%
2900	118.98	28	0.35%	0.15%	294.04	582	0.33%	0.49%
2950	13.00	24	0.04%	0.13%	114.63	212	0.13%	0.18%
2960	45.80	11	0.14%	0.06%	278.99	163	0.31%	0.14%
3000	6.80	10	0.02%	0.05%	71.04	183	0.08%	0.15%
3001	19.55	47	0.06%	0.25%	132.59	478	0.15%	0.40%
3190	0.80	2	0.00%	0.01%	106.37	144	0.12%	0.12%
3200	4.84	9	0.01%	0.05%	73.58	204	0.08%	0.17%
3300	16.67	15	0.05%	0.08%	68.24	188	0.08%	0.16%
3320	4.00	8	0.01%	0.04%	118.70	172	0.13%	0.14%
3370	0.36	1	0.00%	0.01%	153.99	79	0.17%	0.07%
3390	0.00	0	0.00%	0.00%	306.10	47	0.34%	0.04%
3400	1.20	3	0.00%	0.02%	24.16	47	0.03%	0.04%
3500	126.16	209	0.37%	1.10%	422.02	1008	0.47%	0.84%
3530	7.70	14	0.02%	0.07%	246.33	341	0.27%	0.28%
3550	11.95	25	0.04%	0.13%	367.07	272	0.41%	0.23%
3580	26.20	5	0.08%	0.03%	734.30	165	0.81%	0.14%
3583	64.61	29	0.19%	0.15%	149.99	331	0.17%	0.28%
3600	53.55	95	0.16%	0.50%	1375.89	2012	1.52%	1.68%
3700	39.84	35	0.12%	0.18%	393.93	819	0.44%	0.68%
3800	1.84	7	0.01%	0.04%	118.02	241	0.13%	0.20%
3900	3.28	11	0.01%	0.06%	59.63	115	0.07%	0.10%

3920	10.34	20	0.03%	0.11%	114.34	231	0.13%	0.19%
4000	30.26	40	0.09%	0.21%	432.59	773	0.48%	0.65%
4020	5.12	16	0.02%	0.08%	316.80	530	0.35%	0.44%
4040	10.75	29	0.03%	0.15%	797.63	595	0.88%	0.50%
4041	9.38	5	0.03%	0.03%	382.36	460	0.42%	0.38%
4100	1.00	2	0.00%	0.01%	32.45	105	0.04%	0.09%
4280	0.00	0	0.00%	0.00%	21.60	55	0.02%	0.05%
4300	4.92	9	0.01%	0.05%	34.65	66	0.04%	0.06%
4400	1.00	4	0.00%	0.02%	21.20	37	0.02%	0.03%
4432	40.18	68	0.12%	0.36%	136.85	355	0.15%	0.30%
4500	0.92	5	0.00%	0.03%	50.88	162	0.06%	0.14%
4530	52.52	16	0.16%	0.08%	218.16	88	0.24%	0.07%
4600	0.00	0	0.00%	0.00%	5.14	18	0.01%	0.02%
4700	2.66	10	0.01%	0.05%	127.38	211	0.14%	0.18%
4800	10.80	13	0.03%	0.07%	41.81	144	0.05%	0.12%
4801	126.80	10	0.38%	0.05%	1.60	3	0.00%	0.00%
4900	0.10	1	0.00%	0.01%	2.14	8	0.00%	0.01%
5000	0.32	3	0.00%	0.02%	23.22	68	0.03%	0.06%
5020	4.82	24	0.01%	0.13%	326.92	500	0.36%	0.42%
5080	2.14	5	0.01%	0.03%	218.49	438	0.24%	0.37%
5100	0.62	7	0.00%	0.04%	20.36	80	0.02%	0.07%
5300	0.24	3	0.00%	0.02%	31.36	14	0.03%	0.01%
5380	4.00	3	0.01%	0.02%	104.00	108	0.11%	0.09%
5500	0.10	1	0.00%	0.01%	17.35	44	0.02%	0.04%
5580	0.50	2	0.00%	0.01%	120.26	78	0.13%	0.07%
5600	0.12	2	0.00%	0.01%	11.16	49	0.01%	0.04%
5620	14.00	24	0.04%	0.13%	199.78	114	0.22%	0.10%
5953	0.20	1	0.00%	0.01%	0.00	0	0.00%	0.00%
6000	0.92	5	0.00%	0.03%	47.76	78	0.05%	0.07%
6040	3.69	8	0.01%	0.04%	558.43	1370	0.62%	1.14%
6041	8.48	17	0.03%	0.09%	403.56	727	0.45%	0.61%
6150	6.74	6	0.02%	0.03%	537.75	77	0.59%	0.06%
6180	37.26	38	0.11%	0.20%	1199.30	2423	1.33%	2.02%
6200	4.44	15	0.01%	0.08%	267.35	408	0.30%	0.34%
6460	0.00	0	0.00%	0.00%	23.52	10	0.03%	0.01%
6530	0.00	0	0.00%	0.00%	11.20	14	0.01%	0.01%
6600	0.00	0	0.00%	0.00%	19.46	63	0.02%	0.05%
6700	27.52	5	0.08%	0.03%	275.18	108	0.30%	0.09%
6780	1.74	10	0.01%	0.05%	249.26	218	0.28%	0.18%
6800	1.46	6	0.00%	0.03%	19.37	94	0.02%	0.08%
6900	2.84	8	0.01%	0.04%	45.12	112	0.05%	0.09%
7000	3.96	14	0.01%	0.07%	43.54	176	0.05%	0.15%
7012	4.68	15	0.01%	0.08%	267.44	450	0.30%	0.38%

7060	2918.60	2202	8.67%	11.62%	37.16	136	0.04%	0.11%
7100	5.10	16	0.02%	0.08%	154.37	377	0.17%	0.31%
7110	3614.47	2099	10.73%	11.08%	205.73	166	0.23%	0.14%
7181	38.10	16	0.11%	0.08%	243.85	849	0.27%	0.71%
7300	0.12	2	0.00%	0.01%	13.08	52	0.01%	0.04%
7301	7.24	9	0.02%	0.05%	164.95	326	0.18%	0.27%
7331	107.62	20	0.32%	0.11%	145.93	76	0.16%	0.06%
7500	151.28	40	0.45%	0.21%	51.53	139	0.06%	0.12%
7522	2.76	8	0.01%	0.04%	469.55	742	0.52%	0.62%
7600	0.00	0	0.00%	0.00%	6.54	24	0.01%	0.02%
7700	15.47	32	0.05%	0.17%	407.03	726	0.45%	0.61%
7800	0.10	1	0.00%	0.01%	29.10	94	0.03%	0.08%
7900	16.36	45	0.05%	0.24%	971.27	1439	1.07%	1.20%
8000	43.00	38	0.13%	0.20%	1783.77	2978	1.97%	2.49%
8020	2.71	8	0.01%	0.04%	240.28	274	0.27%	0.23%
8200	0.62	4	0.00%	0.02%	44.23	104	0.05%	0.09%
8300	0.42	2	0.00%	0.01%	56.80	116	0.06%	0.10%
8400	8.28	22	0.02%	0.12%	477.02	946	0.53%	0.79%
8490	691.55	136	2.05%	0.72%	123.13	66	0.14%	0.06%
8500	8.84	18	0.03%	0.10%	325.39	723	0.36%	0.60%
8510	1.94	9	0.01%	0.05%	176.67	231	0.20%	0.19%
8520	10.00	11	0.03%	0.06%	146.69	318	0.16%	0.27%
8560	53.48	22	0.16%	0.12%	541.56	665	0.60%	0.56%
8570	31.85	12	0.09%	0.06%	108.94	190	0.12%	0.16%
8600	0.50	2	0.00%	0.01%	7.37	26	0.01%	0.02%
8700	7617.90	6056	22.62%	31.97%	391.43	237	0.43%	0.20%
8790	8.98	20	0.03%	0.11%	167.90	257	0.19%	0.21%
8800	22.08	49	0.07%	0.26%	891.00	958	0.99%	0.80%
8870	13.86	24	0.04%	0.13%	122.80	325	0.14%	0.27%
8900	7.74	13	0.02%	0.07%	70.37	202	0.08%	0.17%
9000	68.80	46	0.20%	0.24%	530.91	1312	0.59%	1.10%
9041	5.45	20	0.02%	0.11%	329.16	617	0.36%	0.52%
9042	852.74	750	2.53%	3.96%	1075.41	1787	1.19%	1.49%
9080	0.92	2	0.00%	0.01%	348.10	61	0.38%	0.05%
9100	59.20	55	0.18%	0.29%	1263.63	1559	1.40%	1.30%
9130	34.26	30	0.10%	0.16%	124.75	222	0.14%	0.19%
9140	9.20	8	0.03%	0.04%	412.32	268	0.46%	0.22%
9200	10.70	11	0.03%	0.06%	77.02	115	0.09%	0.10%
9230	6.32	11	0.02%	0.06%	214.34	256	0.24%	0.21%
9300	5146.15	445	15.28%	2.35%	2630.35	4114	2.91%	3.44%
9320	52.34	20	0.16%	0.11%	167.61	113	0.19%	0.09%
9400	90.42	42	0.27%	0.22%	96.80	125	0.11%	0.10%
9420	84.38	201	0.25%	1.06%	147.32	131	0.16%	0.11%

9450	255.10	374	0.76%	1.97%	10.44	32	0.01%	0.03%
9500	4.02	8	0.01%	0.04%	32.34	88	0.04%	0.07%
9600	21.01	11	0.06%	0.06%	149.94	290	0.17%	0.24%
9700	19.74	26	0.06%	0.14%	87.58	155	0.10%	0.13%
9800	247.00	41	0.73%	0.22%	310.95	447	0.34%	0.37%
9810	9.12	8	0.03%	0.04%	220.90	609	0.24%	0.51%
9820	110.35	15	0.33%	0.08%	2084.10	1088	2.30%	0.91%
9900	0.02	1	0.00%	0.01%	48.57	119	0.05%	0.10%
9940	173.72	344	0.52%	1.82%	93.80	165	0.10%	0.14%
LU	**145.72**	**185**	**0.43%**	**0.98%**	**3063.90**	**6288**	**3.39%**	**5.25%**
1610	4.34	12	0.01%	0.06%	303.14	569	0.34%	0.48%
3254	23.60	21	0.07%	0.11%	763.36	1324	0.84%	1.11%
3364	1.20	3	0.00%	0.02%	286.04	621	0.32%	0.52%
3898	27.00	4	0.08%	0.02%	120.31	237	0.13%	0.20%
4361	11.12	18	0.03%	0.10%	429.77	781	0.48%	0.65%
8399	5.02	15	0.01%	0.08%	110.17	219	0.12%	0.18%
Total	**33671.25**	**18944**	**94.65%**	**89.04%**	**90450.08**	**119696**	**88.59%**	**80.64%**

Appendix L Locations including most FTL orders

At certain zip codes the demand considers FTL orders. The zip codes where the amount of load meters decreased with more than 1000 for pick up are shown in Table 43.

Table 43; Overview locations pickup without FTL orders compared to FTL included

zip code	Location	Decrease in load meters	Decrease in orders
1800	Vilvoorde	1516.60	116
2800	Mechelen	2925.30	219
7060	Zinnik	1616.20	124
7110	La Louvière	1818.00	140
8700	Tielt	3840.40	316
9300	Aalst	5121.60	388

The zip codes where the amount of load meters decreased with more than 1000 for delivery are shown in Table 44.

Table 44; Overview locations delivery without FTL orders compared to FTL included

zip code	Location	Decrease in load meters	Decrease in orders
2200	Herentals	1710.40	126
2300	Turnhout	5434.80	410
2880	Bornem	3560.40	262

Appendix M Distribution demand per clustered zip code

During the considered period of this thesis the total amount of load meters per clustered zip code for both pickup and delivery is provided in Table 45.

Table 45; Overview distribution demand per clustered zip code for both pickup and delivery

Zip code	Load meters picked-up	Orders picked-up	% LDM	% Orders	Load meters delivered	Orders delivered	% LDM	% Orders
1000	68.14	66	0.20%	0.35%	1141.28	1925	1.26%	1.61%
1020	9.24	13	0.03%	0.07%	177.74	335	0.20%	0.28%
1030	22.90	9	0.07%	0.05%	148.87	343	0.16%	0.29%
1070	35.54	61	0.11%	0.32%	602.40	1069	0.67%	0.89%
1082	4.10	7	0.01%	0.04%	314.56	607	0.35%	0.51%
1083	0.90	2	0.00%	0.01%	121.16	136	0.13%	0.11%
1100	81.25	95	0.24%	0.50%	281.04	767	0.31%	0.64%
1180	3.46	9	0.01%	0.05%	103.50	289	0.11%	0.24%
1190	44.20	65	0.13%	0.34%	1203.30	1799	1.33%	1.50%
1200	8.82	23	0.03%	0.12%	717.48	908	0.79%	0.76%
1300	31.89	41	0.09%	0.22%	2139.63	1358	2.37%	1.13%
1348	0.92	2	0.00%	0.01%	147.81	178	0.16%	0.15%
1400	315.12	86	0.94%	0.45%	200.26	459	0.22%	0.38%
1420	10.36	16	0.03%	0.08%	459.60	1228	0.51%	1.03%
1480	94.19	19	0.28%	0.10%	106.62	60	0.12%	0.05%
1500	43.42	35	0.13%	0.18%	478.35	665	0.53%	0.56%
1600	42.79	59	0.13%	0.31%	3840.19	6277	4.25%	5.24%
1620	0.40	1	0.00%	0.01%	222.93	465	0.25%	0.39%
1651	11.60	15	0.03%	0.08%	127.78	140	0.14%	0.12%
1700	132.12	81	0.39%	0.43%	467.98	615	0.52%	0.51%
1702	0.40	1	0.00%	0.01%	296.59	385	0.33%	0.32%
1731	37.95	26	0.11%	0.14%	347.61	384	0.38%	0.32%
1740	108.51	90	0.32%	0.48%	52.57	88	0.06%	0.07%
1780	46.75	12	0.14%	0.06%	1738.72	279	1.92%	0.23%
1800	1989.62	590	5.91%	3.11%	3781.27	5515	4.18%	4.61%
1804	6.84	9	0.02%	0.05%	123.39	206	0.14%	0.17%
1830	12.04	11	0.04%	0.06%	377.67	1074	0.42%	0.90%
1831	6.70	29	0.02%	0.15%	196.51	635	0.22%	0.53%
1851	30.62	57	0.09%	0.30%	2689.83	4328	2.97%	3.62%
1930	85.45	97	0.25%	0.51%	1814.71	1725	2.01%	1.44%
2000	51.79	57	0.15%	0.30%	503.19	1095	0.56%	0.91%
2018	14.42	21	0.04%	0.11%	304.12	589	0.34%	0.49%
2030	137.66	53	0.41%	0.28%	2972.53	1296	3.29%	1.08%
2070	6.30	12	0.02%	0.06%	390.86	276	0.43%	0.23%

2100	24.74	46	0.07%	0.24%	523.86	959	0.58%	0.80%
2160	8.30	17	0.02%	0.09%	689.78	440	0.76%	0.37%
2170	13.14	14	0.04%	0.07%	491.78	864	0.54%	0.72%
2200	90.02	81	0.27%	0.43%	2351.14	1051	2.60%	0.88%
2221	3.48	9	0.01%	0.05%	137.90	276	0.15%	0.23%
2250	1.46	7	0.00%	0.04%	168.45	258	0.19%	0.22%
2300	160.19	99	0.48%	0.52%	6284.23	1779	6.95%	1.49%
2320	9.30	4	0.03%	0.02%	119.58	55	0.13%	0.05%
2321	29.70	5	0.09%	0.03%	106.88	61	0.12%	0.05%
2340	29.18	11	0.09%	0.06%	106.74	94	0.12%	0.08%
2400	22.20	42	0.07%	0.22%	204.44	526	0.23%	0.44%
2440	11.86	23	0.04%	0.12%	219.49	467	0.24%	0.39%
2500	83.34	25	0.25%	0.13%	127.56	315	0.14%	0.26%
2520	2.90	3	0.01%	0.02%	206.56	166	0.23%	0.14%
2550	40.33	66	0.12%	0.35%	680.95	536	0.75%	0.45%
2600	8.02	19	0.02%	0.10%	124.02	416	0.14%	0.35%
2610	33.07	37	0.10%	0.20%	490.90	893	0.54%	0.75%
2630	7.06	14	0.02%	0.07%	175.02	305	0.19%	0.25%
2640	11.12	16	0.03%	0.08%	443.24	737	0.49%	0.62%
2800	3512.69	386	10.43%	2.04%	1005.49	1610	1.11%	1.35%
2830	65.80	17	0.20%	0.09%	561.04	959	0.62%	0.80%
2870	123.80	95	0.37%	0.50%	1191.68	1516	1.32%	1.27%
2880	961.78	102	2.86%	0.54%	3718.87	550	4.11%	0.46%
2900	136.24	72	0.40%	0.38%	496.12	1079	0.55%	0.90%
2950	13.00	24	0.04%	0.13%	114.63	212	0.13%	0.18%
2960	45.80	11	0.14%	0.06%	278.99	163	0.31%	0.14%
3000	18.00	33	0.05%	0.17%	239.95	635	0.27%	0.53%
3001	19.55	47	0.06%	0.25%	132.59	478	0.15%	0.40%
3190	18.12	13	0.05%	0.07%	242.47	454	0.27%	0.38%
3200	15.93	24	0.05%	0.13%	229.83	488	0.25%	0.41%
3300	18.89	22	0.06%	0.12%	108.88	300	0.12%	0.25%
3320	4.00	8	0.01%	0.04%	118.70	172	0.13%	0.14%
3370	0.36	1	0.00%	0.01%	153.99	79	0.17%	0.07%
3390	0.00	0	0.00%	0.00%	306.10	47	0.34%	0.04%
3400	31.48	36	0.09%	0.19%	49.14	98	0.05%	0.08%
3500	149.85	242	0.45%	1.28%	666.82	1527	0.74%	1.28%
3530	7.70	14	0.02%	0.07%	246.33	341	0.27%	0.28%
3550	11.95	25	0.04%	0.13%	367.07	272	0.41%	0.23%
3580	26.20	5	0.08%	0.03%	734.30	165	0.81%	0.14%
3583	64.61	29	0.19%	0.15%	149.99	331	0.17%	0.28%
3600	77.82	139	0.23%	0.73%	1658.86	2664	1.83%	2.23%
3700	42.52	42	0.13%	0.22%	452.41	954	0.50%	0.80%

3800	12.58	16	0.04%	0.08%	156.97	312	0.17%	0.26%
3900	26.41	51	0.08%	0.27%	340.05	782	0.38%	0.65%
3920	10.34	20	0.03%	0.11%	114.34	231	0.13%	0.19%
4000	34.88	46	0.10%	0.24%	470.07	852	0.52%	0.71%
4020	5.12	16	0.02%	0.08%	316.80	530	0.35%	0.44%
4040	10.75	29	0.03%	0.15%	797.63	595	0.88%	0.50%
4041	9.38	5	0.03%	0.03%	382.36	460	0.42%	0.38%
4100	10.00	8	0.03%	0.04%	118.21	235	0.13%	0.20%
4280	0.10	1	0.00%	0.01%	42.82	67	0.05%	0.06%
4300	5.02	10	0.01%	0.05%	56.52	127	0.06%	0.11%
4400	12.04	15	0.04%	0.08%	167.55	427	0.19%	0.36%
4432	40.18	68	0.12%	0.36%	136.85	355	0.15%	0.30%
4500	1.16	7	0.00%	0.04%	78.67	274	0.09%	0.23%
4530	52.52	16	0.16%	0.08%	218.16	88	0.24%	0.07%
4600	4.32	17	0.01%	0.09%	104.92	258	0.12%	0.22%
4700	4.18	16	0.01%	0.08%	158.60	325	0.18%	0.27%
4800	22.03	29	0.07%	0.15%	81.28	263	0.09%	0.22%
4801	126.80	10	0.38%	0.05%	1.60	3	0.00%	0.00%
4900	2.34	11	0.01%	0.06%	74.22	176	0.08%	0.15%
5000	82.33	44	0.24%	0.23%	213.38	443	0.24%	0.37%
5020	4.82	24	0.01%	0.13%	326.92	500	0.36%	0.42%
5080	2.14	5	0.01%	0.03%	218.49	438	0.24%	0.37%
5100	5.62	20	0.02%	0.11%	83.52	225	0.09%	0.19%
5300	0.86	7	0.00%	0.04%	39.04	55	0.04%	0.05%
5380	4.00	3	0.01%	0.02%	104.00	108	0.11%	0.09%
5500	25.14	21	0.07%	0.11%	63.67	254	0.07%	0.21%
5580	0.50	2	0.00%	0.01%	120.26	78	0.13%	0.07%
5600	1.32	13	0.00%	0.07%	43.50	95	0.05%	0.08%
5620	14.00	24	0.04%	0.13%	199.78	114	0.22%	0.10%
5953	0.70	4	0.00%	0.02%	0.00	0	0.00%	0.00%
6000	8.36	25	0.02%	0.13%	262.75	812	0.29%	0.68%
6040	3.69	8	0.01%	0.04%	558.43	1370	0.62%	1.14%
6041	8.48	17	0.03%	0.09%	403.56	727	0.45%	0.61%
6150	11.44	13	0.03%	0.07%	648.93	148	0.72%	0.12%
6180	37.26	38	0.11%	0.20%	1199.30	2423	1.33%	2.02%
6200	7.72	26	0.02%	0.14%	410.51	616	0.45%	0.51%
6460	0.40	4	0.00%	0.02%	37.47	64	0.04%	0.05%
6530	1.70	3	0.01%	0.02%	30.39	67	0.03%	0.06%
6600	8.02	14	0.02%	0.07%	113.95	163	0.13%	0.14%
6700	28.18	12	0.08%	0.06%	310.07	188	0.34%	0.16%
6780	1.74	10	0.01%	0.05%	249.26	218	0.28%	0.18%
6800	2.18	14	0.01%	0.07%	65.67	179	0.07%	0.15%

6900	5.24	17	0.02%	0.09%	67.74	179	0.07%	0.15%
7000	28.56	32	0.08%	0.17%	146.20	450	0.16%	0.38%
7012	4.68	15	0.01%	0.08%	267.44	450	0.30%	0.38%
7060	2918.60	2202	8.67%	11.62%	37.16	136	0.04%	0.11%
7100	10.42	27	0.03%	0.14%	240.52	542	0.27%	0.45%
7110	3614.47	2099	10.73%	11.08%	205.73	166	0.23%	0.14%
7181	38.10	16	0.11%	0.08%	243.85	849	0.27%	0.71%
7300	6.42	15	0.02%	0.08%	77.40	147	0.09%	0.12%
7301	7.24	9	0.02%	0.05%	164.95	326	0.18%	0.27%
7331	107.62	20	0.32%	0.11%	145.93	76	0.16%	0.06%
7500	155.30	52	0.46%	0.27%	83.41	230	0.09%	0.19%
7522	2.76	8	0.01%	0.04%	469.55	742	0.52%	0.62%
7600	0.30	3	0.00%	0.02%	23.36	51	0.03%	0.04%
7700	37.83	46	0.11%	0.24%	471.38	887	0.52%	0.74%
7800	22.60	17	0.07%	0.09%	104.93	523	0.12%	0.44%
7900	22.22	48	0.07%	0.25%	986.89	1482	1.09%	1.24%
8000	43.00	38	0.13%	0.20%	1784.19	2980	1.97%	2.49%
8020	2.71	8	0.01%	0.04%	240.28	274	0.27%	0.23%
8200	3.02	5	0.01%	0.03%	76.28	164	0.08%	0.14%
8300	12.24	15	0.04%	0.08%	168.59	389	0.19%	0.32%
8400	21.60	35	0.06%	0.18%	582.83	1170	0.64%	0.98%
8490	691.55	136	2.05%	0.72%	123.13	66	0.14%	0.06%
8500	126.47	112	0.38%	0.59%	571.68	1060	0.63%	0.89%
8510	1.94	9	0.01%	0.05%	176.67	231	0.20%	0.19%
8520	10.00	11	0.03%	0.06%	146.69	318	0.16%	0.27%
8560	53.48	22	0.16%	0.12%	541.56	665	0.60%	0.56%
8570	31.85	12	0.09%	0.06%	108.94	190	0.12%	0.16%
8600	9.28	17	0.03%	0.09%	118.11	343	0.13%	0.29%
8700	7802.09	6343	23.17%	33.48%	842.27	1099	0.93%	0.92%
8790	8.98	20	0.03%	0.11%	167.90	257	0.19%	0.21%
8800	44.20	76	0.13%	0.40%	1127.52	1350	1.25%	1.13%
8870	13.86	24	0.04%	0.13%	122.80	325	0.14%	0.27%
8900	19.48	33	0.06%	0.17%	178.32	474	0.20%	0.40%
9000	103.12	100	0.31%	0.53%	811.48	2076	0.90%	1.73%
9041	5.45	20	0.02%	0.11%	329.16	617	0.36%	0.52%
9042	852.74	750	2.53%	3.96%	1075.41	1787	1.19%	1.49%
9080	0.92	2	0.00%	0.01%	348.10	61	0.38%	0.05%
9100	112.77	138	0.33%	0.73%	1480.20	1987	1.64%	1.66%
9130	34.26	30	0.10%	0.16%	124.75	222	0.14%	0.19%
9140	9.20	8	0.03%	0.04%	412.32	268	0.46%	0.22%
9200	81.05	41	0.24%	0.22%	244.23	564	0.27%	0.47%
9230	6.32	11	0.02%	0.06%	214.34	256	0.24%	0.21%

9300	5148.15	456	15.29%	2.41%	2697.51	4273	2.98%	3.57%
9320	52.34	20	0.16%	0.11%	167.61	113	0.19%	0.09%
9400	91.22	47	0.27%	0.25%	153.31	248	0.17%	0.21%
9420	84.38	201	0.25%	1.06%	147.32	131	0.16%	0.11%
9450	255.10	374	0.76%	1.97%	10.44	32	0.01%	0.03%
9500	4.08	11	0.01%	0.06%	74.38	151	0.08%	0.13%
9600	24.51	21	0.07%	0.11%	196.48	413	0.22%	0.35%
9700	20.66	30	0.06%	0.16%	139.24	259	0.15%	0.22%
9800	353.74	129	1.05%	0.68%	402.13	697	0.44%	0.58%
9810	9.12	8	0.03%	0.04%	220.90	609	0.24%	0.51%
9820	110.35	15	0.33%	0.08%	2084.10	1088	2.30%	0.91%
9900	11.55	24	0.03%	0.13%	155.46	365	0.17%	0.30%
9940	173.72	344	0.52%	1.82%	93.80	165	0.10%	0.14%
LU	**108.52**	**182**	**0.32%**	**0.96%**	**3063.90**	**6288**	**2.56%**	**6.95%**
1610	4.36	13	0.01%	0.07%	317.92	583	0.35%	0.49%
3254	24.90	24	0.07%	0.13%	787.80	1376	0.87%	1.15%
3364	14.72	8	0.04%	0.04%	410.02	750	0.45%	0.63%
3898	28.60	5	0.08%	0.03%	129.08	257	0.14%	0.21%
4361	11.52	19	0.03%	0.10%	462.59	831	0.51%	0.69%
8399	5.06	16	0.02%	0.08%	135.79	369	0.15%	0.31%
Total	**33671.25**	**18944**	**99.83%**	**99.47%**	**119696**	**90450.08**	**99.09%**	**98.23%**

Appendix N P-center model

Another approach to determine a hub location is the p-center problem. This problem differs from the p-median in the objective. For the p-center the maximum travel time or distance to the customer is minimized (Campbell et al., 2005). If GVT wants to improve the service time to customers, this model becomes interesting. The distance in kilometers that corresponds to the shortest travel time is used for the calculation. The maximum distances between a potential hub location and all customers are obtained. From these values the minimum is selected. This correspond to the following formulation, where the maximum distance from a hub to all customers is minimized:

$$Minimize \ \ z \qquad (2)$$

$$s.t. \qquad \sum_{i} y_i \ = 1 \qquad \forall i \in \ I \qquad (2.1)$$

$$\sum_{i \in I} x_{ij} \ = 1 \qquad \forall j \ \in \ J \qquad (2.2)$$

$$x_{ij} \ \leq \ y_i \qquad \forall i \ \in I, \qquad j \in J \qquad (2.3)$$

$$\sum_{i \in I} D_j * x_{ij} * c_{ij} \ \leq z \qquad \forall j \ \in j \qquad (2.4)$$

$$x_{ij} \ \in \{0{,}1\}, \quad \forall i \in \ I, \qquad j \ \in \ J \qquad (2.5)$$

$$y_i \ \in \{0{,}1\}, \quad \forall j \ \in \ J \qquad (2.6)$$

Sets:

I, J: the sets of candidate hub locations and customer zones respectively

Parameters:

c_{ij}: is the fastest kilometric distance between origin i and destination j

D_j: is the demand at location j, expressed as a factor of the percentage demand

z: is the maximum demand − weighted distance between i and all j's

Variables:

x_{ij}: is the binary decision variable assuming value 1 if the hub is located at location i and serves location j, 0 otherwise

y_i: is the binary decision variable assuming value 1 if hub is located at location i, 0 otherwise

The objective function (2) minimizes the maximum demand-weighted distance between a potential hub location and all customers. Thus for each potential hub, the maximum distance is selected. Constraint (2.1) ensures that exactly one hub is selected. Constraint (2.2) implies that a demand node *j* can only be served by one potential hub location. Constraint (2.3) ensures that demand node *j* can be served by a hub location *i* only if there is a hub at *i*. Constraint (2.4) forces z to be equal to the maximum distance from a potential hub to any customer. The decision variable x_{ij} and y_i can only be 0 or 1, this is ensured respectively by constraint (2.5) and (2.6). These constraints establish whether a location is a hub or not.

Calculation

The same method as with p-median in Section 5.2 is applied. This means that the matrix, containing distances between locations, is used and that the maximum distance between *i* an *j* is selected for each potential hub. Also in this case the distance is multiplied with a demand factor from the percentage of load meters and orders. This results in the maximum demand-weighted distance. A demand factor is also applied in this case, because the demand is not equally spread over customers. The "minimax problem" is used to improve the service time. In the case of no demand factor, the result will always be the most central point between all the demand points. By calculating the maximum distance with the selected zip codes in Section 4.4.1, the location that minimizes the maximum distance is always La Bruyère (5080) in the unweighted situation. This location is situated more to the east in Wallonia. However, the most demand is ordered in the east (Flanders). As a result, the service time to customers with the most demand decreases, while the service time to the customers with less demand improves. Therefore, the demand factor is applied, since service time is more important for customers that have more demand. The demand-weighted maximum distances from the potential hubs are compared and the lowest is selected. In Table 46, the minimum values of the maximum distances are displayed per zip code and per clustered zip code respectively. Both the percentage of load meters and orders as the demand factor is used.

*Table 46; Results p-center combined**

Discount Factor Tilburg	Per zip code (ldm)	Weighted MAX (ldm)	Cluster zip code (ldm)	Weighted MAX (ldm)	Per zip code (order)	Weighted MAX (order)	Cluster zip code (order)	Weighted MAX (order)
0	**9200**	447.96	**9200**	473.85	**9420**	274.65	**9420**	297.87
25	**2321**	870.04	**2321**	936.52	**5047**	745.86	**2321**	840.00
50	**5047**	1046.67	**5047**	1126.64	**5047**	745.86	**5047**	872.89
75	**5047**	1046.67	**5047**	1126.64	**5047**	745.86	**5047**	872.89
100	**5047**	1046.67	**5047**	1126.64	**5047**	745.86	**5047**	872.89

As can be seen in Table 46, only in the cases that the economies of scale factor is high, the possible hub location shifts to Belgium.

Appendix O VBA code Google maps distance matrix

The VBA code that is used to retrieve the distances from Google Maps between zip codes is provided in Table 47.

Table 47; VBA code for retrieving distances from Google maps

```
Public Function get_dis_and_time _
( _origin_zipPostalcode As String, origin_city As String, _
origin_state As String, origin_country As String, _
destination_zipPostalcode As String, destination_city As String, _
destination_state As String, destination_country As String _)

Dim surl            As String
Dim oXH             As Object
Dim bodytxt         As String
Dim tim_e           As String
Dim distanc_e       As String

surl = "http://maps.googleapis.com/maps/api/distancematrix/xml?origins=" & _
Replace(origin_zipPostalcode, " ", "+") & "+" & Replace(origin_city, " ", "+") & "+" &
Replace(origin_state, " ", "+") & "+" & Replace(origin_country, " ", "+") & _
"&destinations=" & _
Replace(destination_zipPostalcode, " ", "+") & "+" & Replace(destination_city, " ", "+") & "+" &
Replace(destination_state, " ", "+") & "+" & Replace(destination_country, " ", "+") & _
"&mode=driving&sensor=false&units=metric"

Set oXH = CreateObject("msxml2.xmlhttp")
  With oXH
    .Open "get", surl, False
    .send
    bodytxt = .responseText
  End With

bodytxt = Right(bodytxt, Len(bodytxt) - InStr(1, bodytxt, "<text>") - 5)
tim_e = Left(bodytxt, InStr(1, bodytxt, "</text>") - 1)
bodytxt = Right(bodytxt, Len(bodytxt) - InStr(1, bodytxt, "<text>") - 5)
distanc_e = Left(bodytxt, InStr(1, bodytxt, "</text>") - 1)
get_dis_and_time = tim_e & " | " & distanc_e
Set oXH = Nothing

End Function
```

Appendix P Example distance matrix

Between each zip code the distance is calculated. Since the matrix is 180 by 180, an example is shown in Table 48.

Table 48; Example distance matrix in kilometers

j i	5047TM (NL)	1000	1020	1030	1070	1082	1083
5047TM (NL)		124	110	121	130	126	123
1000	124		7.1	3.8	5.6	6.2	8
1020	111	6.5		6.1	19.2	13.4	10.5
1030	121	4.1	4.6		9.5	8.4	7.8
1070	131	5.5	18.2	9.7		9.2	12.1
1082	125	5.7	11.6	7.5	8.9		2.4
1083	122	6.5	5.3	7.3	11.8	3	

As can be seen in Table 48, the distance from *i* to *j* does not equal the distance from *j* to *i*; however, the difference between *i* to *j* and *j* to *i* are commonly very small. For example, the difference between zip code 1000 and 1020 is 0.6 km. Therefore, the situation from *i* to *j* is considered, since the starting point is almost always at the hub.

Appendix Q Example distance matrix

The distances between zip codes are retrieved via Google. These distances are set in a matrix and the demand factor per zip code is added. The distance from a location *i* to *j* is then multiplied by the demand factor of *j*. An example of this matrix is shown in Table 49.

Table 49; Example matrix weighted-average distance from i to j

j i	5047TM (NL)	1000	1020	1030	1070	1082	1083	Weighted average
D_j	**100**	**0.90**	**0.20**	**0.16**	**0.67**	**0.35**	**0.13**	
5047TM	0.00	111.51	21.62	19.92	86.58	43.82	16.48	**42.84**
1000	12400.00	0.00	1.40	0.63	3.73	2.16	1.07	**1772.71**
1020	11100.00	5.85	0.00	1.00	12.79	4.66	1.41	**1589.38**
1030	12100.00	3.69	0.90	0.00	6.33	2.92	1.04	**1730.69**
1070	13100.00	4.95	3.58	1.60	0.00	3.20	1.62	**1873.56**
1082	12500.00	5.13	2.28	1.23	5.93	0.00	0.32	**1787.84**
1083	12200.00	5.85	1.04	1.20	7.86	1.04	0.00	**1745.28**

Appendix R Locations served by Tilburg including a new hub

By selecting the minimum distance from Tilburg or the new hub location to all customers, results in some locations that are supplied by Tilburg. An overview of the zip codes that are supplied by Tilburg, considering the location of the new hub, is provided in Table 50.

Table 50; Overview locations that are served by Tilburg with selected hub location known

Hub location	Number of zip codes served by Tilburg	Zip codes served by Tilburg	Total % demand served by Tilburg
1780	14	2200, 2250, 2300, 2320, 2321, 2340, 2400, 2440, 2900, 2960, 3583, 3900, 3920, 5953	**9.72%**
1851	13	2250, 2300, 2320, 2321, 2340, 2400, 2440, 2960, 3580, 3583, 3900, 3920, 5953	**7.77%**
2830	13	2300, 2320, 2321, 2340, 2400, 2440, 3500, 3530, 3580, 3583, 3900, 3920, 5953	**8.23%**
2610	7	2300, 2321, 2340, 2400, 3900, 3920, 5953	**6.26%**
2000	7	2300, 2321, 2340, 2400, 3900, 3920, 5953	**6.26%**

Appendix S Results of hub in Antwerp with current strategy

By applying the current strategy and routing all vehicles from Tilburg via Antwerp to all customers will increase the amount of kilometers driven and, thus, the transportation costs. An overview of the results of the amount of kilometers driven and duration of the trucks is shown in Table 51.

Table 51; Results new network including Antwerp (2000)

Date	Trailer	Trailer (km)	Trailer (hour)	Rigid	Rigid (km)	Rigid (hours)	Total Distance	Total duration	LDM deliver
29-02-16	15	6264	146	7	2463	62	8727	208	237
1-03-16	20	6723	163	7	2307	56	9030	219	303
2-03-16	22	7652	184	5	1898	46	9550	230	315
3-03-16	18	6364	190	7	2626	81	8990	271	276
4-03-16	27	10202	281	9	3056	95	13258	376	400

With the results of Table 51, the transportation costs are calculated in Table 52.

Table 52; Transportation cost per day, including the new hub in Antwerp (2000)

Date	Trailers (km)	Trailers (duration)	Rigid trucks (km)	Rigid trucks (duration)	Total cost
29-2-2016	€ 2,694	€ 7,670	€ 739	€ 2,576	**€ 13,679**
1-03-16	€ 2,891	€ 8,847	€ 692	€ 2,373	**€ 14,803**
2-03-16	€ 3,290	€ 9,936	€ 569	€ 1,898	**€ 15,694**
3-03-16	€ 2,737	€ 8,280	€ 788	€ 2,746	**€ 14,550**
4-03-16	€ 4,387	€ 12,246	€ 917	€ 3,221	**€ 20,770**

The total transportation cost becomes €79,497 in the case that all vehicles are routed from Tilburg via Antwerp to customers. This is an increase of €4,241 euro for the transportation costs of one week. These calculations do not include the kilometer-based charge.

Appendix T Average wage cost Belgium and the Netherlands

The average salary cost in Belgium and the Netherlands is provided in Table 53.

Table 53; Average wages in Belgium and the Netherlands (Eurostat, 2015)

Country	Average Wages and salaries
Belgium	28.20
Netherlands	25.51

Appendix U Results of hub in Willebroek with LHV decoupling

By using the LHV decoupling strategy for the network with a hub in Willebroek, the following results are obtained in Table 54.

Table 54; Results Willebroek considering possibility LHV decoupling

Date	Trailer (km)	Trailer (hour)	Rigid (km)	Rigid (hour)	LHVs	LHV (km)	LHV (hour)	Total (km)	Total (hour)
29-02-16	4769	153	1435	61	7	1337	21	7541	235
1-03-16	5276	180	1337	55	7	1337	21	7950	256
2-03-16	5888	229	1313	46	5	955	15	8156	290
3-03-16	4632	161	1487	56	7	1337	21	7456	238
4-03-16	7873	241	1600	73	9	1719	27	11192	341

With the results of Table 54, the transportation cost is calculated for a hub in Willebroek in Table 55.

Table 55; Transportation cost new network per day

Date	Trailer (km)	Trailer (hours)	Rigid (km)	Rigid (hours)	LHV(km)	LHV (hours)	Total cost
29-2-2016	€ 2,051	€ 6,668	€ 431	€ 2,068	€ 575	€ 915	**€ 12,707**
1-03-16	€ 2,269	€ 7,844	€ 401	€ 1,865	€ 575	€ 915	**€ 13,869**
2-03-16	€ 2,532	€ 9,980	€ 394	€ 1,559	€ 411	€ 654	**€ 15,529**
3-03-16	€ 1,992	€ 7,016	€ 446	€ 1,898	€ 575	€ 915	**€ 12,843**
4-03-16	€ 3,385	€ 10,503	€ 480	€ 2,475	€ 739	€ 1,177	**€ 18,759**

The total transportation cost with the decoupling strategy at Willebroek becomes €78,166 euro. This reduces the transportation cost slightly more than the current situation, however, a hub in Antwerp reduces the transportation cost even more.

Appendix V Kilometer-based charge roads

In Figure 29, an overview of the roads in Flanders that are applicable for the kilometer-based charge are shown.

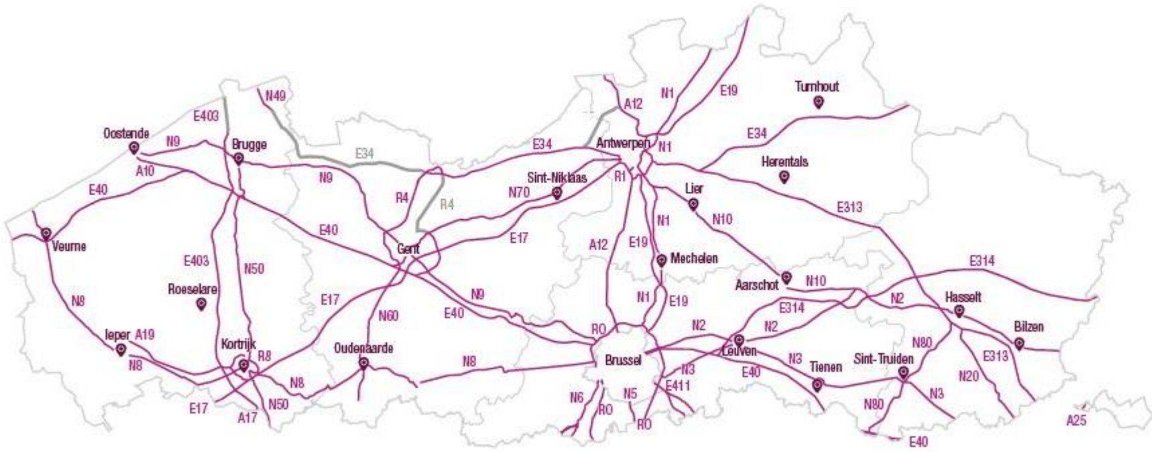

Figure 29; Overview kilometer-based charge roads in Flanders

In Figure 30, an overview of the roads in Brussels that are applicable for the kilometer-based charge are shown.

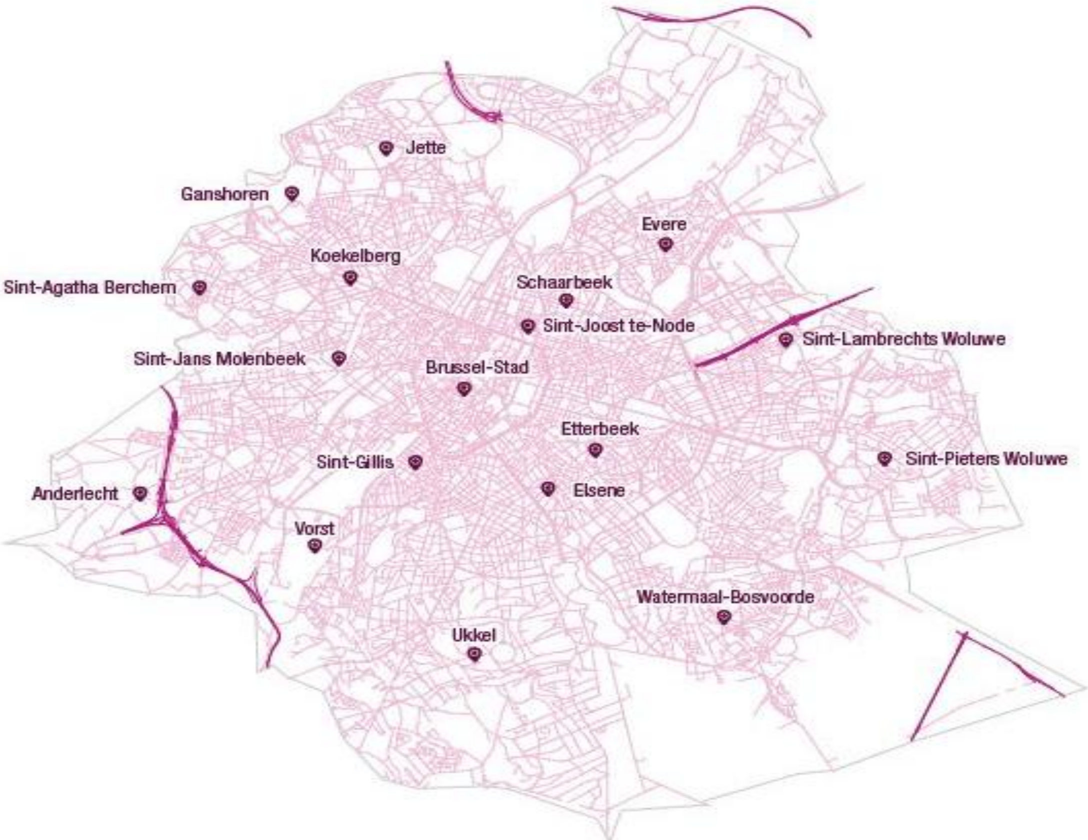

Figure 30; Overview kilometer-based charge roads in Brussels

In Figure 31, an overview of the roads in Wallonia that are applicable for the kilometer-based charge are shown.

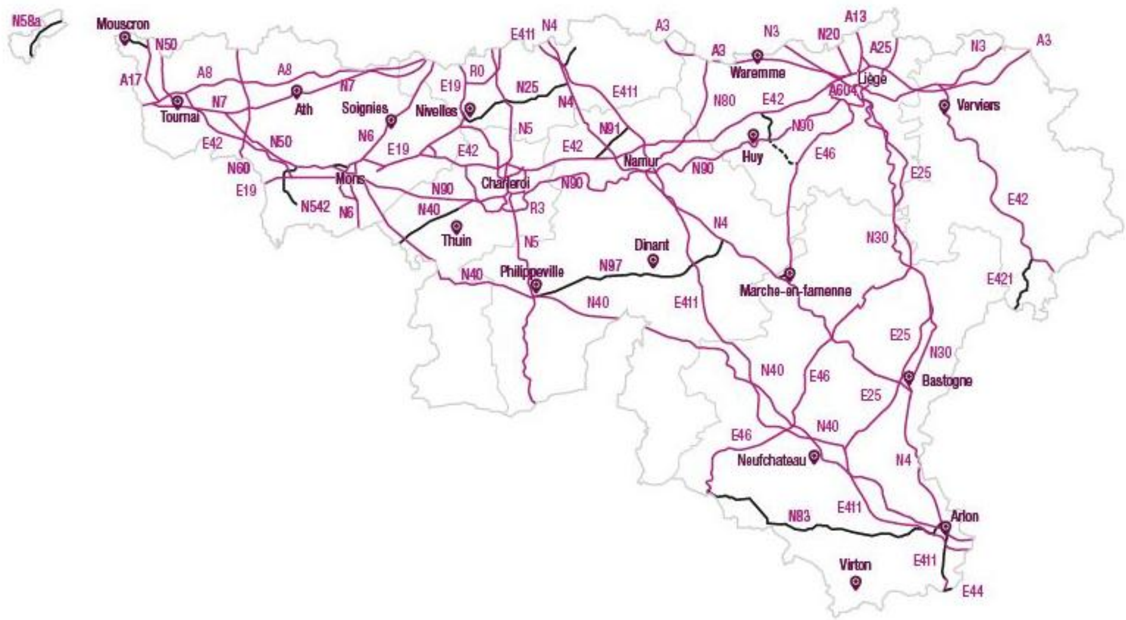

Figure 31; Overview kilometer-based charge roads in Wallonia

Appendix W Overview planning from Antwerp

The planning in Figure 22 is only adjusted by changing the hub location from Tilburg to Antwerp. The result is displayed in Figure 32.

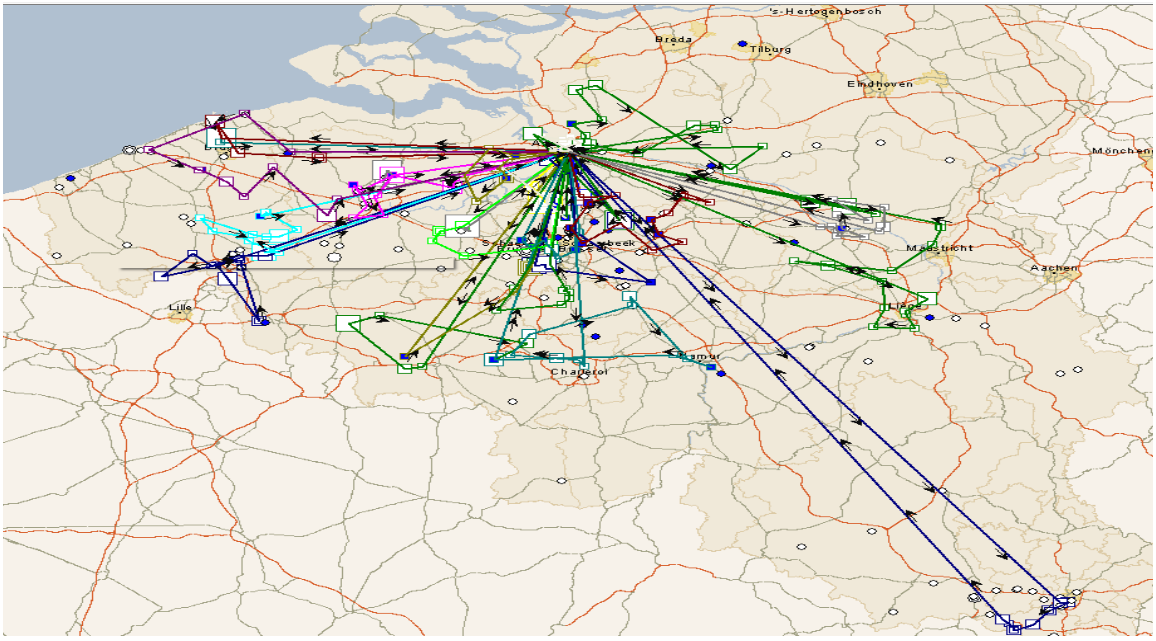

Figure 32; Overview planning routes from Antwerp

Appendix X Comparison cost Antwerp vs Willebroek with Dutch drivers

Assuming that Dutch drivers can drive the trailers and rigid trucks from Antwerp or Willebroek to customers, the location decision depends on the investment cost. By using LHVs between the hubs and letting all trailers and rigid trucks start from Willebroek, the transportation costs are reduced even more compared to the decoupling strategy at Willebroek. All calculations in this appendix are based on Dutch drivers only. The decoupling strategy includes Belgium drivers for the trailers departing from the hub location. An overview of the results of the amount of kilometers driven and duration of the trucks is shown in Table 56.

Table 56; Results new network including hub in Willebroek

Date	Trailer (km)	Trailer (hour)	Trailer (km)	Trailer (hour)	LHVs	LHV (km)	LHV (hour)	Total (km)	Total (hour)
29-02-16	3988	110	1434	46	12	2292	36	7716	237
1-03-16	3530	113	1337	40	15	2865	45	7732	254
2-03-16	4518	133	1313	36	16	3056	48	8888	272
3-03-16	3495	144	1487	56	14	2674	42	7656	242
4-03-16	5511	201	1600	73	21	4011	63	11122	337

With the results of Table 53, the transportation costs, including the kilometer-based charge in Belgium and Luxembourg, are calculated in Table 57.

Table 57; Transportation cost per day, including the new hub in Willebroek

Date	Trailer (km)	Trailer (hours)	Rigid (km)	Rigid (hours)	LHV(km)	LHV (hours)	Total cost
29-2-2016	€ 2,226	€ 6,101	€ 608	€ 2,068	€ 864	€ 1,569	**€ 13,756**
1-03-16	€ 1,970	€ 6,711	€ 567	€ 1,865	€ 1,080	€ 1,961	**€ 14,553**
2-03-16	€ 2,522	€ 7,757	€ 557	€ 1,559	€ 1,152	€ 2,092	**€ 16,065**
3-03-16	€ 1,950	€ 6,276	€ 630	€ 1,898	€ 1,008	€ 1,830	**€ 13,966**
4-03-16	€ 3,075	€ 8,760	€ 678	€ 2,475	€ 1,512	€ 2,746	**€ 19,805**

The total transportation cost becomes €78,145 for this week. This is a decrease of €1,176 euro compared to the decoupling strategy at Willebroek. By using LHVs between the hubs and letting all trailers and rigid trucks start from Antwerp, the transportation costs are reduced even more compared to the decoupling strategy at Antwerp. An overview of the results of the amount of kilometers driven and duration of the trucks is shown in Table 58.

Table 58; Results new network including hub in Antwerp

Date	Trailer (km)	Trailer (hour)	Trailer (km)	Trailer (hour)	LHVs	LHV (km)	LHV (hour)	Total (km)	Total (hour)
29-02-16	3984	136	1399	58	12	1824	28	7207	222
1-03-16	3683	150	1243	52	15	2280	35	7206	237
2-03-16	4308	169	1138	43	16	2432	38	7878	250
3-03-16	3628	142	1562	63	14	2128	33	7318	238
4-03-16	6098	209	1688	70	21	3192	49	10978	328

With the results of Table 58, the transportation costs, including the kilometer-based charge in Belgium and Luxembourg, are calculated in Table 59.

Table 59; Transportation cost per day, including the new hub in Antwerp

Date	Trailer (km)	Trailer (hours)	Rigid (km)	Rigid (hours)	LHV(km)	LHV (hours)	Total cost
29-2-2016	€ 2,223	€ 5,927	€ 593	€ 1,966	€ 598	€ 1,220	**€ 12,852**
1-03-16	€ 2,055	€ 6,537	€ 527	€ 1,763	€ 748	€ 1,525	**€ 13,560**
2-03-16	€ 2,404	€ 7,365	€ 483	€ 1,458	€ 798	€ 1,656	**€ 14,595**
3-03-16	€ 2,024	€ 6,188	€ 662	€ 2,136	€ 698	€ 1,438	**€ 13,525**
4-03-16	€ 3,403	€ 9,108	€ 716	€ 2,373	€ 1,047	€ 2,135	**€ 19,350**

The total transportation cost becomes €73,882 for this week, when all trailers and rigid trucks start, and end at Antwerp, and LHVs are used between the hubs. This is a decrease of €2,938 euro compared to the decoupling strategy at Antwerp. A summary is provided in Table 60.

Table 60; Summary transportation costs decoupling and hub strategy in Antwerp and Willebroek

Date	Antwerp		Willebroek	
	Decoupling	**Hub**	**Decoupling**	**Hub**
29-2-2016	€ 13,360	€ 12,852	€ 13,769	€ 13,756
1-03-16	€ 14,626	€ 13,560	€ 14,984	€ 14,553
2-03-16	€ 15,036	€ 14,595	€ 16,525	€ 16,065
3-03-16	€ 13,628	€ 13,525	€ 13,866	€ 13,966
4-03-16	€ 20,172	€ 19,350	€ 20,174	€ 19,805
Total	**€ 76,820**	**€ 73,882**	**€ 79,321**	**€ 78,145**

Note that in both Antwerp and Willebroek the LHV decoupling strategy costs includes Belgium drivers using the trailers from the hub location to customers. When a hub is required and only Dutch drivers can be used, Willebroek can become more interesting since the price per m^2 building ground is €36 less than in Antwerp. For example, when a hub with 10,000 m^2 storage space is required this results in €360,000 extra investment cost for Antwerp. Antwerp saves on average €4262 euro per day more than Willebroek and this results in 85 days before Antwerp will make more profit than Willebroek. For both locations it is assumed that the handling and materials cost are equal in this example. However, it seems that a hub with storage space is not required since almost all the goods in Belgium and Luxemburg are transported to and from the Netherlands.

Appendix Y Trade-off less Belgium kilometers versus time

Certain customers in Belgium can be visited via different routes through the boreder. In the case of Wanze (4260) the truck can travel via Antwerp, Turnhout and Maastricht as can been seen in Figure 33.

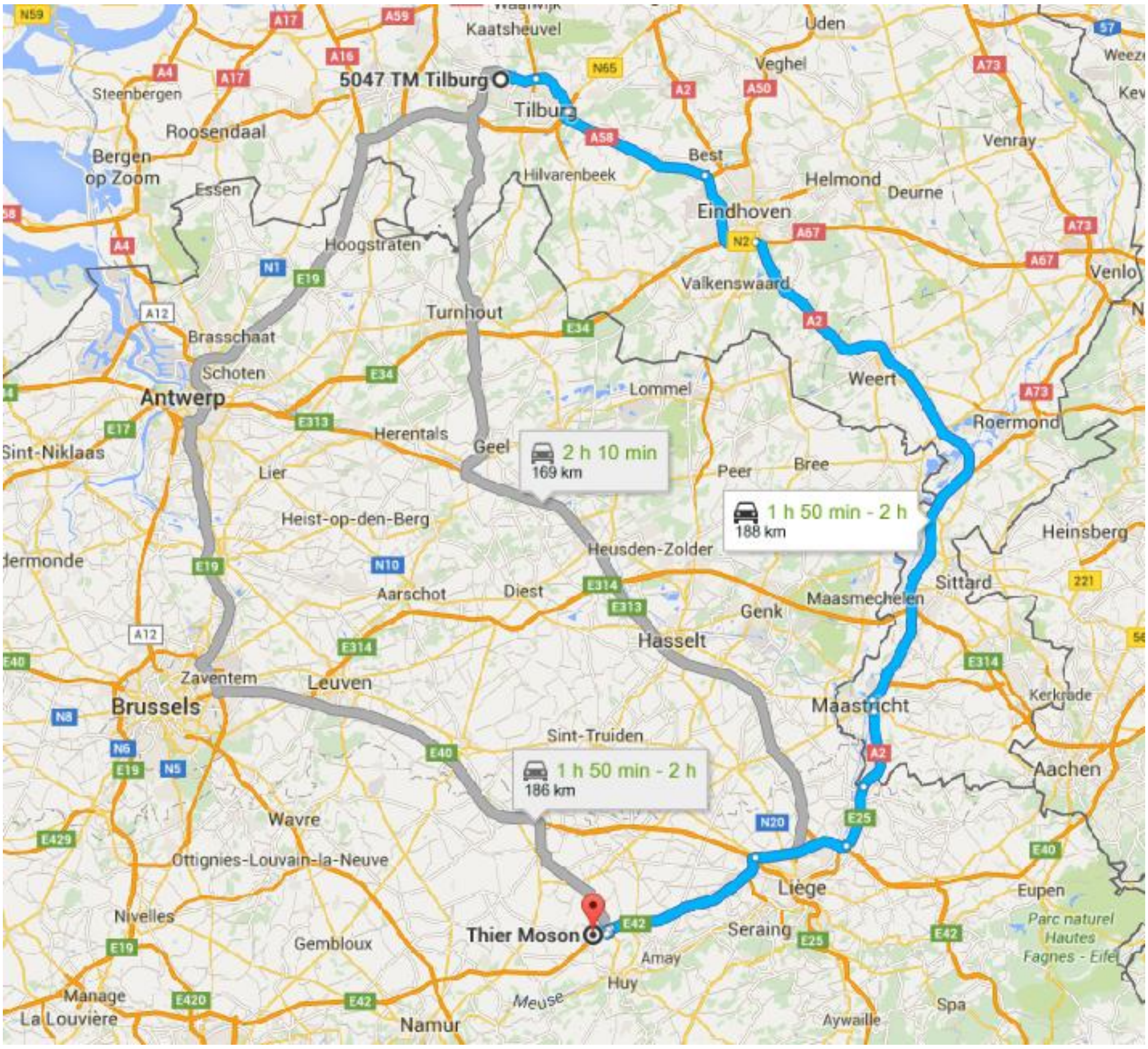

Figure 33; Possibilities routes from Tilburg to Wanze