EINDHOVEN UNIVERSITY OF TECHNOLOGY

Department of Industrial Engineering and Innovation Sciences,

Operations, Planning, Accounting and Control

Identification of Opportunities and Optimization of Longer and Heavier Vehicle Implementation in a Transportation Business

Bachelor End Project

Oisín van Lier

1434055

OPAC Group

Eindhoven,

Friday 24th June, 2022

Supervisors:

First supervisor TU/e:	dr. A. H. Schrotenboer
Daily supervisor TU/e:	M. A. Zamal
Supervisor Van Der Wal:	A. Roosen

Abstract

Transportation business are exercising much effort to make their businesses more efficient and sustainable. Over already a decade ago, longer and heavier vehicles (LHVs) were first permitted in some European countries. In the years following more countries within Europe have allowed them on their roads. LHVs are trucks that exceed the limit specified in the EU Council directive 96/53 established in 1996. LHVs fall into the category of the European Modular System and are allowed a maximum length of up to 25,25 m. These longer trucks provide the opportunity for significant emission and cost savings as less trucks will be needed to transport the same amount of capacity. This thesis focus on how and where LHVs can be implemented in the transportation business of Van Der Wal. First an overview was created of the factors that influence LHV implementation. Next, emission factors were all type of truck configurations that Van Der Wal uses. This factors where then used in calculating the savings for each transportation line if LHVs were to be implemented on these lines. Next to that, for lines that are used regularly, the closest lines for each of these have been found. This will make it possible to combine orders on different lines into one LHV shipment, so that less shipments are needed. Lastly, an optimization model was created such that truck configurations can be assigned to trips, which will lead to the lowest possible total emissions. From this analysis it became clear that CO_2 emissions could be decreased up to 9% on a weekly basis. To achieve these savings additional LHVs will have to be implemented on 15%-20% of the trips. Lastly, a significant difference in the length of LHV lines were found in the current and optimized scenarios. In the scenarios with highest average line length the lines were 40%-80% longer.

Contents

1. Introduction

The freight transportation sector has always been an important sector in Europe. Road freight transport was responsible for over 3 million jobs within the European Union and 123,800 in the Netherlands (Directorate-General for Mobility and Transport (European Commission), 2018). The turnover of road freight transportation in Europe in 2017 was €535 billion compared to 82, 7, 126 and 147 billion for rail, inland water, sea and air transport respectively.

1.1 Longer Heavier Vehicle (LHV)

Because of climate change concerns much interest arises for the question on how to make the transportation sector more sustainable. In 2015 road freight was responsible for 7% of global CO_2 emission (Speirs et al., 2020). Road transportation is the most preferred form of European freight transportation especially on shorter distances. A proposed way to make the transportation industry more sustainable was by legalizing the use of longer and heavier vehicles (LHVs). The first LHV trials started in the Netherlands in 2001 (Aarts & Salet, 2012). On January 1st 2013 LHVs were officially regulated under the European Modular System (EMS) in the Netherlands. In order for a truck to be used as an LHV permission has to be granted by a National Road and Traffic department. Many other countries followed in the years after. Some European countries such as France however, still do not allow the use of LHVs on their roads.

The maximum length of a tractor unit with a semi-trailer in the EU is 16,5 m. For a truck with a short trailer the maximum length is 18,75 m with a maximum weight of 40 ton and 44 ton for intermodal transports. Both these smaller truck combinations can be seen in the top left corner of Figure 1. LHVs are combinations that exceed this length and weight restriction. LHVs can have a maximum length of 25,25 m and a maximum weight of 60 ton (Åkerman & Jonsson, 2007).

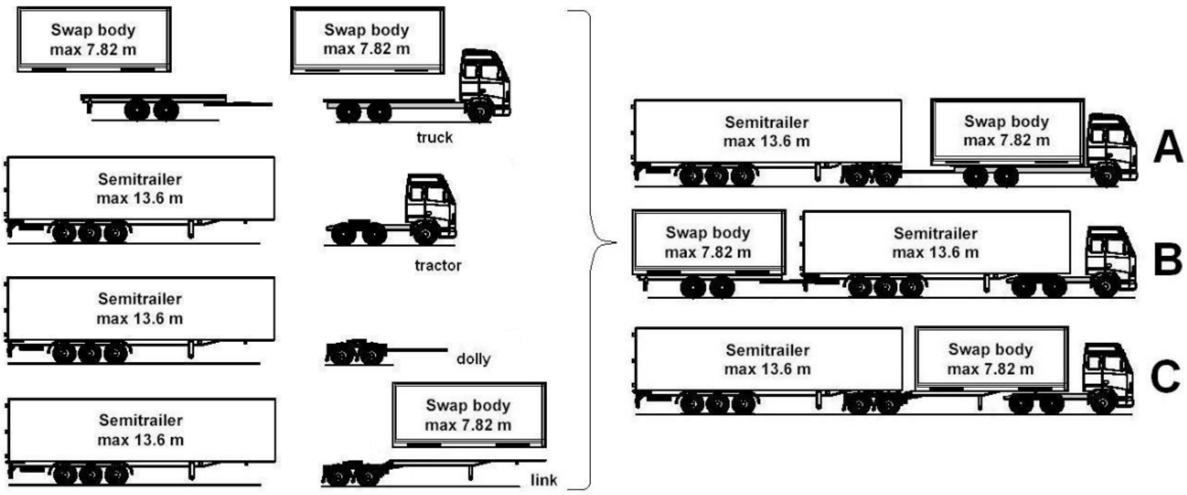

Figure 1. Units used within the European Modular System (Åkerman & Jonsson, 2007)

Figure 1 shows the most popular units from the European Modular System (EMS) and how they are used to make three different LHV configurations. There are two types of pulling units, trucks and tractors. Trucks can carry rigid load or a load carrier such as a swap-body. Trucks can be equipped with towing devices to enable towing or trailer and dollies. A tractor is able to tow semi-trailer and links but is not able to carry rigid loads or load carriers directly. The two main types of load carriers used in LHV configurations are swap bodies and semi-trailers.

Swap bodies have a maximum length of 7,82 m and can be loaded on trucks, links and jiggs (center-axle trailers). Swap bodies are also used for additional storage at suppliers or distribution centers as they can be easily attached to trucks and trailers with the help of forklifts and occupy a relatively small area. Semi-trailers have a maximum length of 13,6 m. The front of these trailers rest on upon a tractor, link or dolly. A link can, as its name suggests, link a semi-trailer with a tractor while having a loading area in between on which a swap body can be placed. A jigg is simply a center-axle trailer on which a swap body can be placed. Dollies are small trailers used as steering axles on which semi-trailers are coupled.

Combination A in Figure 1 consists of a loaded truck with a dolly attached to it. On the dolly a semi-trailer is placed. Combination B consists of a truck with a semi-trailer with a jigg attached to it. On this jigg a swap body is placed. Lastly combination C is extremely similar to B. However the swap body and semi-trailer have switched positions. In order to achieve this a link will have to be used which is attached to the tractor. The semi-trailer is then attached to the back of the link. This configuration is often referred to as a B-double combination in the literature. Combination A and B are considered to have the same fuel consumption. Combination C has an increased fuel consumption of 7,3% (Panteia, 2021). This increased fuel consumption is caused by the additional element of the link that is used in combination C. The reason however why combination C is still used, is that it provides the most stability. On the other hand, it is said to be rather difficult to maneuver this combination in narrow loading and unloading areas, especially when reversing. Configuration B is considered to be the least stable and inflexible of the three and therefore it needs to be loaded more carefully.

1.2 Van Der Wal

This research in this project was conducted at Van Der Wal, a transportation company located in Utrecht, The Netherlands. Van Der Wal is a family owned business established in 1924. Their mission is to offer the best sustainable transport solution based on honesty and respect for people and society. According to their CEO sustainable transport solutions are more important than pure profits. They can take this approach because it is a family owned company that is not dependent on shareholders that strive for profit maximization. They actively pursue to 'Kill empty running', which is a slogan that is visible on many of their trailers. They want to achieve this by active management on less empty driving, active management on higher load rate and by lobbying on less half empty packaging for their customers. Van Der Wal operates in second, third and fourth party logistics (2PL, 3PL, 4PL). In the 2PL side of the business, a company simply puts in a transport request to Van Der Wal. In 3PL, Van Der Wal works as a sort of broker that connects companies in need of transport to transport companies. Lastly, in the 4PL side, Van Der Wal engineers solutions for transportation problems, while also assisting with financing, IT & reporting, freight management etc. 4PL providers can be seen as managers of other logistic service providers (Saglietto, 2013). 4PL is the newest activity in the company. It is the most labour intensive activity, but also the most satisfying.

Van Der Wal uses 4 main types of truck and trailer combinations to deliver services for their clients. The smallest combination is a truck with a single swap unit (7.80 x 2.48 x 3.00). This is the smallest combination and also the least efficient, so the company tries to avoid using this combination as much as possible. However, sometimes the clients requires a small shipment and therefore it is unnecessary to use a larger configuration.

Figure 2. Truck and Swap Unit at Van Der Wal.

The second configuration used are mega trailers or simply mega's. This is an tractor unit followed by a mega trailer, which is a semitrailer (13.60 x 2.48 x 3.00 m). This is the most used combination as it offers much capacity while only using one trailer, which is beneficial for the handling time of the trailer.

Figure 3. Mega trailer at Van Der Wal

Volume combi's are another often used configuration used by the company. This combination usually consists of a truck with a swap unit and then followed by a jigg with another swap unit on top ((7.80+7.80) x 2.48 x 3.00 m). Volume combi's offer slightly more capacity than mega's but are more difficult to load since two the unit have to be loaded separately. Furthermore they also require slightly more driving skill and they are cannot be loaded as easily from behind at a warehouse via a docking station.

Figure 4. Volume Combi at Van Der Wal

Lastly, the company uses LHVs or 'LZV's' as the company itself refers to it. LZV is simply the Dutch translation for LHV. Van der Wal uses all three types described earlier in the introduction but does not differentiate between each type. There are simply all referred to as LHV. Each LHV consists of one mega trailer and a swap body ((13.60+7.80) x 2.48 x 3.00 m). The type of LHV that will be used for a shipment is decided by the planner and the customer requirements.

Figure 5. LHV at Van Der Wal

1.3 Research aim

Van Der Wal sees a great future for LHVs in their business. Currently the company has 87 of their Dutch trucks and tractors certified for LHV usage. However only 20 of them are regularly used as LHV. Van Der Wal is struggling to implement more LHVs on their transportation lines. The aim of this research is to gain transparency in the environmental benefits of using LHVs for Van Der Wal and their customers. Next to that, it will attempt to find customers that use lines which are highly suitable for LHVs. These lines can provide high CO_2 emission savings if LHVs were to be implemented. These savings could either be very high on a trip basis or savings may be a less but since the line is used very often LHV could acquire high total savings over time. From experience with existing customers, Van Der Wal has noticed that is difficult to convince clients to make use of LHVs. Many clients see that the current logistic operations function accordingly and therefore they do not want to take risks by changing up their operations. Van Der Wal has a strong passion for sustainability and therefore wants to convince customers to adopt LHVs by appealing to their clients moral position regarding sustainability. By making use of LHVs, organizations can show that they are actively working on making their business more sustainable. Purely focusing on the financial benefits is often not enough to convince customers to adopt LHVs because the transportation costs are only a marginal amount of the total supply chain costs. Moreover, showing exact figures of how much the savings could be could be an additional trigger for customer to contemplate LHVs.

1.4 Research questions

The main research question this thesis focuses on is:

On which client's transportation lines do LHVs have the most potential to be implemented to reduce CO_2 emissions?

The most potential for implementation refers to the highest emissions savings for Van Der Wal. This will help the sales department of Van Der Wal identify which of the existing customers could switch to LHVs to realize high emission savings.

Sub research questions:

1. *What are the factors that have to be considered when implementing LHVs?*
2. *What are the emission factors of different vehicle configurations?*
3. *How can the existing operations be optimized to reduce CO_2 emissions?*

Sub question 1 will find out which factors are important and how they influence the decision making for LHV implementation. For this question employees in different positions at Van Der Wal will be interviewed. These factors give an overview of which factors have to be taken into account when approaching customers. It can serve as a checklist to see if the customers are matching LHV requirements. Sub question 2 will be answered by combining literature with available data at Van Der Wal. The emission factors will focus on CO_2 only, will be calculated for each of the four truck configurations and will be in the form of g/km. These factors can then be used to answer the main research question.

Sub research question 3 will further critically analyze the current operations at Van Der Wal. Since Van Der Wal is exercising much effort to increase the sustainability of the business by finding new and existing customers that are willing to use (more) LHVs, it would also be appropriate to analyze the current operations and see how vehicle allocation can be optimized.

The research questions will be addressed in the following order. Sub questions 1 and 2 are answered first. They form the base for the main research question of the thesis which will be addressed next. Finally, sub research question 3 will dive deeper into the current processes and is less connected to the main research questions. The aim of this part is to find business implications that are helpful to optimize the current operations.

The scope of this research will be single transports between two locations in the Netherlands and neighboring countries. These are the countries that Van Der Wal first wants to implement extensively. This is because there is a high density of orders appear in these countries and legislation forms not much of a barrier to implement LHVs.

1.5 Content

After this introductory chapter, the existing literature on LHVs will be reviewed in *Chapter 2*. *Chapter 3* will discuss the methodology and datasets that were used to answer both the main and sub research questions. In *Chapter 4,* the findings of the main analysis which include sub questions 1 & 2 and the main research question will be presented. *Chapter 5* will show the further analysis which is done two answer sub research question 3. Finally *Chapter 6* will conclude with a discussion of the findings and limitations, provide further research opportunities and show the practical insights.

1. Literature Review

In this section, the existing literature regarding LHVs will be reviewed on four major aspects. These are transportation costs, emissions, safety and modal shift. These are the main areas which have been investigated in the scientific literature and will provide a good overview of what is currently known about LHV implementation. The last two topics are not directly tied in to the research but they help with understanding the topic of LHVs. Most importantly, the section about 'modal shift' discusses a possible downside of LHVs.

2.1 Transportation Costs

Several studies have investigated the impacts of LHV on transportation costs. In Germany, after trial periods in six different companies driver and fuel costs could be reduced by 33%. Also fuel consumption could be reduced by 30% per ton-km (Sanchez Rodrigues et al., 2015). Knight et al. (2008) performed extensive cost modelling of 8 different types of oversized trucks. According to their research, a B-double will lead to an costs increase of 21% percent per km, but a cost decrease of 25% per ton-km because of the increased capacity that a LHV provides. A rigid truck + semi-trailer combination will increase the costs by 19% per km and decrease the costs by 27% per ton-km. Bâdescu & Purcar (2017) indicated an overall transportation costs reduction of 15% by using LHVs. These savings were caused by lower costs on fuel, driver salaries and vehicle depreciation. Panteia, a Dutch research and consulting company, produces yearly reports with extensive cost calculations. Costs calculations for the three types of LHVs discussed in the introduction are provided in the report. Combination A has a costs of €1,96 per km and €76,42 per hour. Combination B and C have kilometer costs of €1,91 and €2,02 and hourly costs of €74,41 and 78,66 respectively (Panteia, 2021). According to the same report the operating costs for a tractor and semi-trailer combination are €2,13 per km and €75,38 per hour. The total yearly costs for an LHV combination, for example combination A, is slightly higher compared to a single semi-trailer (€225.433 vs €191.306). The lower costs per km for LHVs are acquired because the report assumes LHVs drive a greater amount of kilometers on a yearly basis. The report assumes that regular trucks drive 90.000 km and LHVs 115.000 km per year. Further is was assumed that semi-trailers are used 2538 hours compared to 2950 for LHVs. Table 1 shows an overview of the costs of the different LHV combinations

	Costs per km	*Costs per hour*	*Costs per year*	*Capacity*
LHV combination A	€1,96	€76,42	€225.443	160 m^3
LHV combination B	€1,91	€74,41	€219.516	160 m^3
LHV combination C	€2,02	€78,66	€232.033	160 m^3
Semi-trailer	€2,13	€75,38	€191.306	105 m^3

Table 1. Costs of different LHV types compared to a regular semi-trailer (Panteia, 2021)

Especially in Scandinavian countries, much research has been conducted concerning trucks that exceeds the European Modular System in length and weight. These types of trucks are sometimes referred to as High Capacity Vehicles (HCV) (Lindqvist et al., 2020). These HCVs could have a length of up to 34,5 m. A cost benefit analysis was conducted on DHL's haulage network in Sweden and they found that costs could be reduced by up to 6% when a combination of LHVs and HCVs were used. Implementation of solely HCV would actually lead to a minor increase in costs. Karam & Reinau (2021) performed a similar analysis to Lindqvist et al. (2020), but this time in Denmark. They investigated the cost savings of A-double LHVs compared to LHVs under the European Modular System. These A-double configurations consist of two semi-trailers attached to each other pulled by a tractor. The analysis indicted that in the least beneficial scenario transport costs could be reduced by 9,65%. Besides that the number of empty trucks were significantly reduced. However, the benefits were less in the case of just-in-time deliveries and cargo constrained vehicle weight. Next to that, cost saving is highly sensitive to driver salaries, fuel prices and driving speeds.

2.2 Emissions

The main premise of LHVs is that capacity can be significantly improved while only marginally increasing the fuel consumption and therefore the CO_2 emission. Tunnell & Brewster (2005) were some of the early researchers that investigated the effects of increasing the gross vehicle weight (GVW) in North America. Six different combinations with weights ranging from 100.000 lb (45,4 ton) to 140.000 lb (63,5 ton) were compared to the standard GVW of 80.000 lb (36,3 ton). Decreases in fuel consumption and emissions were 4% to 19% at 100.000 lb, 15% to 22% at 120.000 lb and 27% at 140.000 lb GVW. Trials with LHVs in the Netherlands and Denmark indicated certain CO_2 emission reductions (Aarts & Salet, 2012; The Danish Road Directorate, 2011). Research has also been conducted on the load factor of LHVs. LHVs should be loaded roughly about 65-70% of its maximum carrying capacity to be as energy efficient than a fully-loaded tractor semi-trailer combination (Leduc, 2009). Anything higher than that will lead to emission savings although the magnitude of these savings were not specified. Knight et al. (2008) calculated emission rates for many different truck configurations. A regular tractor semi-trailer have an emission rate of 1081 g/km for CO_2. The two types of LHVs (configuration A & C) had nearly identical emission rates of 1445,3 and 1445,2 g/km of CO_2. A tractor semi-trailer configuration has an emission rate of 1081,3 g/km. All these rates are for Euro 4 vehicles. Nowadays, new vehicles adhere to Euro 6 regulations which are more restrictive and thus less polluting. Leach et al. (2013) used a carbon factor of 0,82 kg of CO_2/km for single semi-trailers and 1,07 kg/km for LHVs in their research. This is an increase of roughly 30%. Pålsson & Sternberg (2018) indicated that CO_2 emissions decreased with using LHVs but could be decreased even further by using A-double combinations (34 m/ 74 ton). They also found that imposing kilometer-based charges LHVs would negatively impact the emission savings. This is because in that case LHVs would not be used in an optimal fashion. By using A-double configurations CO_2 emission savings could be increased with 5,34% to 14,75% compared to LHVs (Karam & Reinau, 2021).

2.3 Safety

The impacts that LHVs have on road traffic safety has been an important concern for politicians and the public. Opponents of LHVs often argue that these larger vehicles are dangerous for other traffic participants. However, some scientists argue that there is a lack of evidence showing that LHVs cause more traffic accidents (Grislis, 2010). The perceived safety of LHVs can also differ per country (Aarts & Salet, 2012). Each country has its own spatial planning characteristics and road network design. In the Netherlands for example the division between urban an non-urban areas is quite clear, since main roads are mostly planned around the urban areas. This makes it easy for LHVs to keep away from local urban roads. In the neighboring country of Belgium however, many main roads go through urban areas.

In Canada it was found that the introduction of longer vehicles reduced the risk of accidents by 58% compared to standard sized trucks (Tunnell & Brewster, 2005). A meta-analysis of the difference in accident risk between long and short truck configurations conducted by (Af Wåhlberg, 2008) found that LHVs caused less accidents. Although, the number of fatal casualties was indifferent for LHVs and standard sized trucks. Another study found similar results. LHVs could significantly decrease the number of road accidents, however when accidents appeared they were more likely to be severe and had a higher probability of being fatal (Castillo-Manzano et al., 2021). Possible reasons for the fewer amount of accidents were given by Sanchez Rodrigues et al. (2015). LHVs could cause fewer accidents since they are restricted to specific roads, they are prepared with safer technological advances, or are operated by more experienced drivers. Furthermore less trucks will be needed because each truck has more capacity. Therefore there could be less trucks on the road, which decreases the likelihood of an accident. In total, accident costs in the EU could be reduced by approximately €1491 million (Klingender et al., 2009).

2.4 Modal Shift

Another often mentioned concern regarding is that it can possibly cause a model shift back to road transport (Sanchez Rodrigues et al., 2015). LHVs make road transport cheaper which will increase the demand for it and therefore decrease the demand for train transport. Since train transport is more environmentally friendly, LHVs can actually increase the global greenhouse gas emissions (Leach et al., 2013). In the UK the introduction of LHVs was estimated to cause a modal shift of 8-18% of total ton-kilometers from rail to road (Knight et al., 2008). In Sweden, the modal shift would be 6.4% from rail to road (Pålsson & Sternberg, 2018). This number would be 8.7% if even longer vehicles (34m) would be used. The researchers suggested implementing a kilometer-based charge for LHVs to avoid the modal shift. Liimatainen et al. (2020) reported that the amount of cargo carried by trains decreased by 4% after LHVs were implemented in Finland. In a Belgian case, the reverse modal shift in the container transport chain was investigated. The results showed that a decrease in the price for road transport due to LHVs of 5% would shrink the market share of intermodal transport by 15%. A 15% of price decrease would shrink the intermodal market share with 63%.

2. Method

In this section, a method overview will be given for each (sub) research question. Additionally, the two datasets that were used in this research will be described.

3.1 Method overview

The research in this thesis will follow a sequential design (Lieber, 2009). This means that both qualitative and quantitative research will be used to answer the research questions. This is because some of the research questions can better be investigated by using different types of research.

3.1.1 Sub question 1

First, sub question 1 will be answered by performing qualitative research. Data will be collected from employees by informal conversations and semi-structured interviews. Semi-structured interviews offer a general structure that can be followed but also offer the possible to explore other branches as they arise in the conversation. The data can then be used to perform a thematic analysis. In this type of analysis emerging themes in qualitative data can be found (Bell et al., 2019). Themes are topics that are re-occurring in the data and have been emphasized as important aspects. These themes can help to better understand the topic of interest. Thematic analysis does not have clearly specified procedures and therefore it is applicable in many different contexts. The identified themes can be used to create a diagram that shows the relation of the theme to LHV implementation.

3.1.2 Sub question 2

The second part of the research will be of a quantitative nature. Sub question 2 will be answered by analyzing data provided by Van Der Wal and combining this with existing findings in the literature. For the CO_2 emission factors a dataset with all Dutch Van Der Wal truck and tractor units will be used to calculate the emission values.

3.1.3 Main research question

The main research question will be answered by diving into a dataset of customer orders. Within this dataset transportation lines will be identified that have a high potential for being used as LHVs. In order to be classified as a highly potential line the line must be sufficiently long, it must be used often enough and must not be satisfied by LHVs already. The emission rates can then be used to calculate the total emission savings on a line per trip and per week. For each line the costs savings can also be calculated. For the cost calculations a cost-benefit analysis will be conducted (Karam & Reinau, 2021).

In an attempt to find high potential customers it is also possible to look beyond existing single transportation lines. Since Van Der Wal has many customers in The Netherlands and in neighboring countries, it could be beneficial to combine smaller orders on different transportation lines into LZV shipments. This combined orders could be from different customers but also the same customer that ships to different locations. To find orders that can be combined efficiently, which means that trucks drive with not fully utilized capacity as few as possible, transportation lines have to be found that are closely located together. From the data only the length of current transportation lines are known. The distance between lines will be calculated with using the postcodes of the origin and destination location of the existing lines.

$$
\begin{aligned}
&Distance(Line\ 1, Line\ 2) \\
&\qquad = Distance(Origin\ 1, Origin\ 2) + Distance(Destination1, Destination2)
\end{aligned}
$$

In order to calculate this line distance an external source has to be used. This external source is a geospatial mapping platform (Huber & Rust, 2016). A application programming interface (API) will have to be used to calculate the distances from the geospatial mapping platform in the data analysis platform of Jupiter Notebook. The mapping platform that will be used is *bingmapsportal*, as an API key is freely available for academic purposes. A Python function was created based on an existing code (Kyle, 2012).

3.1.4 Sub question 3

Next to identifying high potential customers, a mixed integer linear programming model will be created that meet the specific business case. The model will be able the reassign trucks to specific orders in a one week planning horizon, such that the total emission of that week's operations are minimized. The program will be created through the Gurobi library in Python. The model will be an adjusted version of the Vehicle Assignment and Scheduling model (VASP) (Khooban, 2011). However some of the parameters and constraints will be changed such that the model applies to the actual business case. A planning horizon of one week is chosen because many transportation lines do not have daily orders. By examining a weekly time horizon, smaller order (i.e orders that are currently fulfilled by smaller configurations) will be able to be combined into LHVs. This is also the most realistic planning horizon to analyze since shorter horizons might not have enough orders. Longer horizons on the other hand will have enough orders but combining orders that occur in different weeks are most likely not appreciated by the customers. They want the throughput time of the goods they receive to be as short as possible such that holding costs are minimized and storage space is used efficiently.

3.2 Data

3.2.1 Truck Data

As stated before two different datasets are used in this research. The first dataset contains information about each truck and tractor unit at Van Der Wal in the Netherlands over the entire year of 2021. For each vehicle the total travelled distance, average speed, total and average fuel consumption, total and average CO_2 emission was specified. Table 2 shows the minimum, maximum, mean and standard deviation for each of these variables

	Total Distance (km)	*Total fuel usage (l)*	*Average speed (km/h)*	*Total CO_2 emission (kg)*	*CO_2 emission (g/km)*
Min	49.967,20	10.975,80	54,9	28.871,60	563,60
Max	151.755,50	38.858,60	70,3	102.213,80	826,90
Mean	91.902,93	23.499,83	63,15	61.804,52	670,76
St. Dev	15.144,74	4.534,56	2,85	11.925,59	50,827

Table 2. Min, max, mean and St dev for different variables of all Dutch trucks.

3.2.2 Order data

The second dataset contains customer orders. For each order the client, origin and destination location, shipment date and delivery date, type of truck that is ordered, shipment costs, weight and distance are specified. The dataset consists of 8531 orders over the period of 3 months in 2021. The orders come from 113 different clients. The orders originate from three different countries (The Netherlands, Germany, Belgium) and are destinated for the same three countries. The orders are shipped from 339 different locations in 279 cities and shipped to 1548 destinations in 970 cities. Figure 6 shows the number of shipments between each of the three countries. As can be seen in the graph the majority of shipments are national shipments within the Netherlands. There are no shipments within Germany. The distance values are not always given for every order, since this information was not always known in the information system that Van Der Wal uses. Therefore, these distances had to be calculated. Since the data was delivered in an Excel file the unknown distances were calculated using a custom function created in the Visual Basic Editor within Excel. The function uses the same API source as described in the method section and was adjusted from an existing code (Kyle, 2012).

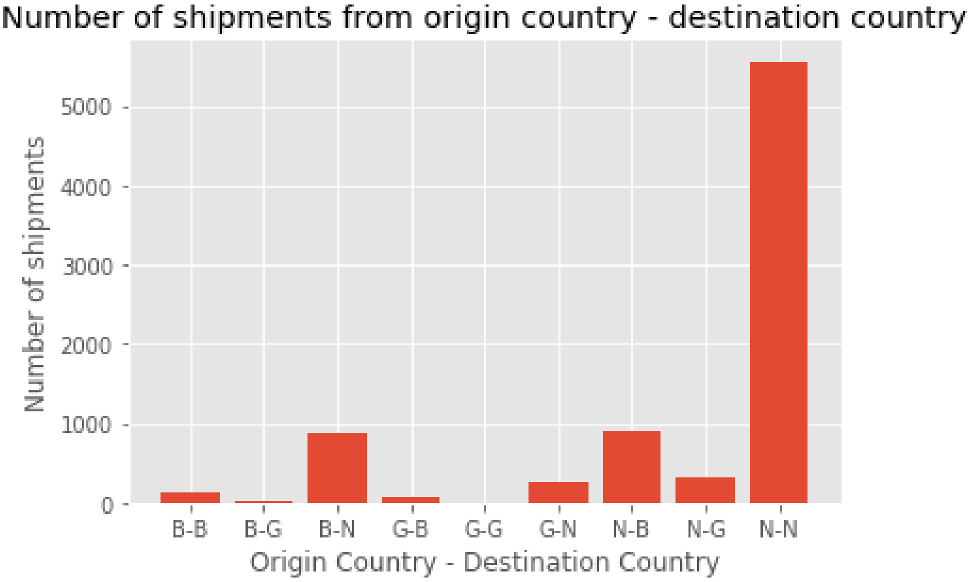

Figure 6. Number of shipments between Belgium, Netherlands, and Germany

3.2.3 Transportation Lines

In total there are 1837 different transportation lines. The amount of orders in a single line ranged from 1 single order up to 815 order but heavily skewed to the lower amounts. The five most used lines were used 815, 246, 206, 182 and 112 times respectively, while there were 1059 transportation lines that were used only once, 289 lines that were used twice and 129 that were used trice. Four different truck configurations are used to complete the orders. The longest transportation line had a length of 766.75 km. The shortest transportation lines had a length of 0 km. This happens when customers have two different departments or warehouses at a single location and goods are transported from the one to the other before embarking on a longer trip. The average line length is 114.8 km. Figure 7 shows an overview of the transportation line lengths. As can be seen in the graph the most common length is around 100 km. Single swap units are used in 5.65%, Volume combi's in 38.20%, mega's in 49.74% and LHVs in 6.23% of the cases. More often than not one type of vehicle configuration is used on one specific transportation line but this is not necessarily always the case.

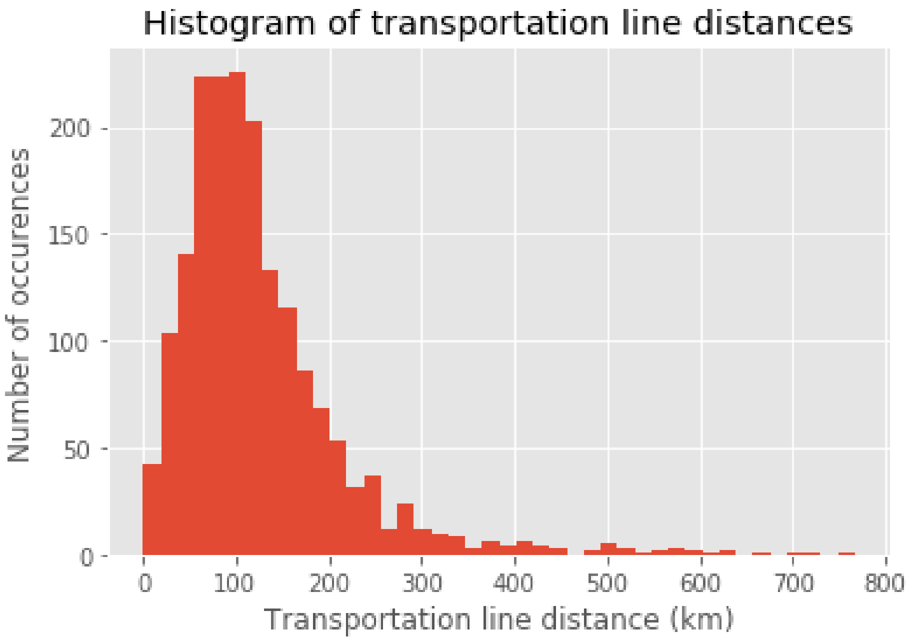

Figure 7. Histogram of transportation line distances

4. Findings of main analysis

In this section the findings of the different sub-research and main research question will be displayed. First, the influencing factor regarding LHV implementation are shown. Next, the emission factors for the truck configurations that Van Der Wal uses are calculated. These factors are then used to answer the main research question and in the further analysis. The results of the main research question are shown, by providing an overview of interesting clients and transportation lines for LHV implementation.

4.1 Influencing factors for implementing LHVs for Van Der Wal's clients.

The themes in the Table 3 below have been acquired from interviews with multiple entities within the company. Next to the CEO of the company, a driver, drivers coach, sales representatives and customer support personnel have been interviewed. The themes are terms that are mentioned by multiple interviewees or are stressed to be of significant importance. The themes do not have a ranking between them which states what theme has to most importance relative to the others. For this not enough people have been interviewed. Next to that, the goal of this thematic analysis is to gain an idea of what some of the impeding but also supportive factors of LHV implementation are. This will provide with a better understanding of the problem why customers are reluctant to adopt LHVs.

Theme	*Description*
Focus for sustainability	VDW has a strong desire for making the transport sector more sustainable. Clients do not always share this desire. Switching to LHVs can be good publicity for firms as they can show that they are actively pursuing sustainability.
Customer departmental issues	When VDW wants to implement LHVs for their customers they do not always talk to the right people at the customers. Customers sometimes feel that making the switch is too much work because transportation schedules have to be reworked. Also sometimes products have to be adjusted to better suit LHV transport.
Costs of transportation	Using LHVs will increase the cost of transportation per truck but less trucks will be needed and therefore total costs can be lower. This is dependent on a number of other factors that will be discussed in the next thematic analysis. Customers want to know what the switch will cost/save them.
Driver certificates and certified trucks	In order to drive LHVs truck drivers need an extra certificate. VDW has enough drivers that are capable of driving LHVs and VDW also promotes young drivers to get these certificates. Furthermore, trucks and tractor units need to be certified to be used as LHVs. VDW has 87 of their Dutch trucks and tractor units certified for LHV usage, while only around 20 are used as LHV.
Driver willingness to drive LHVs	VDW has two types of drivers: VDW drivers and contractors. Contractors get paid per km or per hour and get more for driving LHVs and therefore they prefer to drive LHVs. Younger (< 35 years) VDW drivers are less committed and just do the work they are assigned to. They do not prefer to drive LHV's.
Legislation	In different countries, different legislation exists for using LHVs. For national transports implementing

	LHVs is easier because there is one dimension and weight restriction for the entire trip. The only things that has to be looked into is, which roads are accessible to LHVs (dwo.nl). When transports become international different rules for different countries exist. Therefore some trips are not possible with LHVs because certain countries cannot be accessed.
Storage space availability	LHVs can only be implemented if there is enough storage space at both the supplier and the receiver of a transport. There are less transports so there needs to be more inventory space. VDW offers to leave behind their swap bodies as additional storage space for the customers.
Delivery deadlines	Transports often have delivery deadlines. These deadlines are often earlier in the day. When LHVs are used more deliveries in a day can be made but that will take longer. Because of these deadlines more transports have to be done earlier and that might only be possible with 2 trucks while capacity wise 1 LHV would have been sufficient. Therefore VDW lobbies with customer to achieve broader delivery times and (store) opening times and less timed deliveries.

Table 3. Overview of themes mentioned with LHV implementation

Figure 8 shows a diagram of the themes and how they are related to LHV implementation. The relation is either positive (+) or negative (-) which indicates if it is an supporting or hindering factor. Firstly, the supporting factors will be discussed. Driver willingness is listed as an indirect factor. Drivers could become willing to drive LHVs because it provides an additional challenge in their job. Next to that, they can earn a higher salary by driving LHVs (this is especially the case for external drivers). However, willingness by the driver is not enough. Both driver and vehicle need to be certified before LHVs can be taken into use. The company can pay for the drivers certification as it sees it as an investment to improve both the driver and the versatility of the business. Next, a focus or desire for sustainability can also help with LHV implementation. Van Der Wal already has this focus, so now their customers need to show their desire to succesfully implement LHVs. Another factor is that LHVs provide lower transportation costs. There is enough evidence in the literature that LHVs can significantly decrease operational costs. Therefore lower costs will help customers to choose for LHV. The following three factors, are hindering factors on the side of the customers. First off, departmental issues can hinder LHV implementation. Often Van Der Wal talks to the wrong representatives on the other side of the table. Next to that LHV implementation requires different departments within the customers business to communicate clearly with each other. Changes are needed in the customer's planning when LHVs want to be implemented succesfully. An additional impediment are delivery deadlines that customers impose on Van Der Wal drivers. LHVs will make it possible to combine more orders in one truck. However since more locations need to be visited, strict delivery deadlines will make it difficult for LHVs to reach all locations in time. The last restrictive factor from the side of the customer is that LHVs may require customers and the companies they deliver to and from to have more storage capacity. If transports happen less often more storage space is needed. This will lead to higher holding costs next to the fact that customers may not have the actual space available. The final factor is legislation. The Netherlands is one of the most liberal countries in Europe with regards to LHV legislation. All main roads are accessible for LHVs, smaller local roads need to be approved. The main problem arises when transports have to cross borders. Within the European Union different rules regarding length and maximum weight exist for different countries. France for example does not allow LHVs on their roads, which makes LHV transportation to Southern Europe difficult.

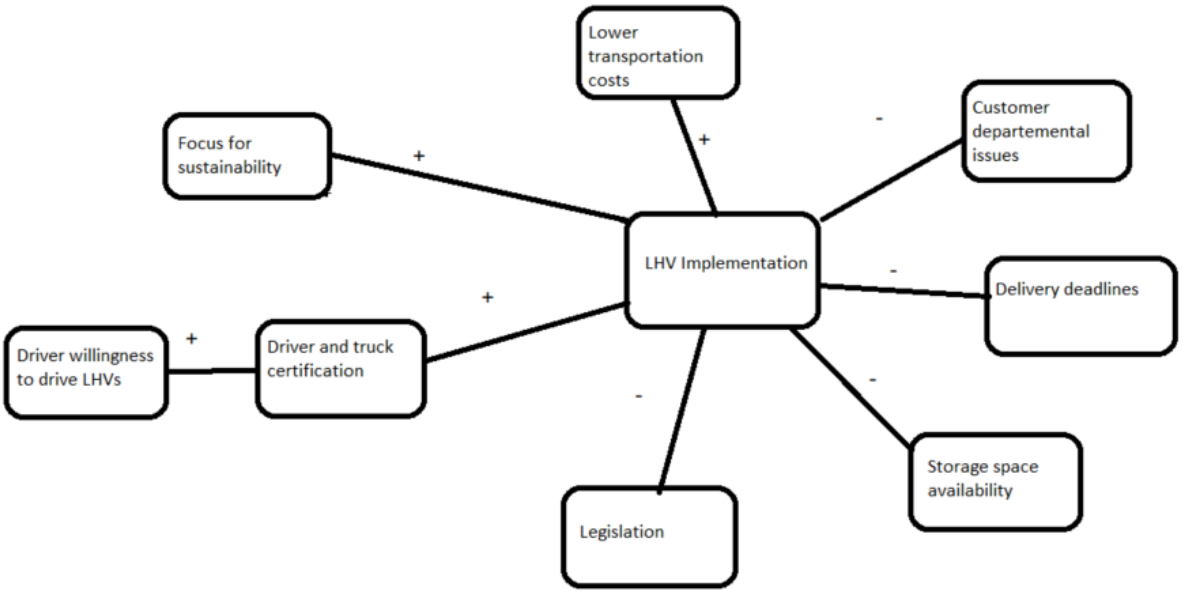

Figure 8. Diagram of factors influencing LHV implementation decision

4.2 Emission Factors

In this research, for each of the four truck combinations Van Der Wal uses, an emission factor is calculated that will be used to answer the main research question. The truck data at Van Der Wal only specifies the average emission per truck but not in which configuration this truck was used. Only few scholars have calculated exact values for CO_2 emission for different configurations (Knight et al., 2008). Also research on this topic has been performed over a decade ago and therefore modeled emission values might not be relevant anymore, because combustion engines have become more efficient and have to adhere to stricter rules with respect to emission and pollution.

The emission values at Van Der Wal are calculated from the data provided by the company and the report by Panteia (2021). The average emission factor of 670,76 g/km was equated to the sum of the unknown emission factors per configuration multiplied by the proportion of kilometers that the specific configuration is used in practice. The ratio of emission factor between two configurations could be calculated with the fuel costs per kilometer in the Panteia report. Since the fuel consumption is proportionate to the total CO_2 emission and all trucks use the same fuel (diesel), the ratio of the fuel costs between two configurations will be the same as the ratio between the emission factors. The data indicates that each liter of diesel creates 2.63 kg of CO_2, which is similar to values used by other scholars (Liimatainen et al., 2020), who used a value of 2.66 kg of CO_2. This lead to the following emission factors.

$$0.0500 * Emission_{Swap} + 0.5106 * Emission_{Mega} + 0.3724 * Emission_{Combi} + 0.0670 * Emission_{LHV} = 670{,}67$$

$$Emission_{Mega} = \frac{4335}{4250} * Emission_{Swap}$$

$$Emission_{Combi} = \frac{4480}{4250} * Emission_{Swap}$$

$$Emission_{LHV} = \frac{4634}{4250} * Emission_{Swap}$$

Truck configuration	*CO_2 emission factor (g/km)*
Single Swap	647.10
Mega	660.05
Volume Combi	682.12
LHV	705.57

Table 4. CO_2 emission factor for each truck configuration

4.3 LHV potential in Van Der Wal's business

4.3.1 Single Transportation Lines

To compare different truck configurations a measure has to be established on which all configurations can easily be compared. The trucks will be compared based on their capacity expressed in m^3. The capacity for each truck configuration is shown in Table 5.

Truck configuration	*Capacity (m^3)*
Single Swap	58
Mega	105
Volume Combi	116
LHV	160

Table 5. Capacity for each truck configuration

For each transportation line the amount of trucks of each configuration is extracted from the data and used to calculate the total capacity that is required on that line. From this the amount of LHVs that can be implemented were calculated and which configuration has to be used for the residual capacity. The configuration that was chosen for the residual capacity is the smallest configuration for which the capacity was higher than the residual required capacity, since a smaller configuration is accompanied by a lower CO_2 emission. For both the old and new situation the total CO_2 emission is calculated. All lines were then compared and ranked on three measures, namely relative total savings, absolute total savings and absolute trip savings.

	Min	Max	Mean
Absolute savings (kg of CO_2)	-18.15	17256.06	59.27
Relative savings (%)	-3.49	60.28	4.86
Savings per trip (kg of CO_2)	-9.07	189.54	6.27

Table 6. Min, max and mean of each savings category

Sometimes the savings are negative which means that implementing an LHV is not beneficial. This situation occurs when a line is used very few and the total capacity of an LHV cannot be fully utilized. Therefore it is more efficient to use a smaller configuration.

4.3.2 Combining Transportation Lines

Next to analyzing single transportation lines on which LHVs could potentially be implemented, it could also be relevant to find lines that are in close proximity of each other. Orders on two closely located lines could then be combined so that LHVs can be used. In this analysis only lines which occurred five or more times in the dataset were considered. This decreased the number of transportation lines from more than 1800 to 256 unique lines. There are multiple reasons for only analyzing lines that are used 5 times or more. Firstly, lines that are used less are not efficient to further investigate for LHV usage, since an LHV could only be implemented once or twice over the timespan that the data was collected (3 months). Furthermore, it would also be difficult to find lines that are both close and require order around the same point in time. When two lines, although they are conveniently located relative to each other, both have one or two orders over a period of 3 months, the probability of orders occurring in the same week would be low. Additionally, comparing all 1800 lines to each other would computationally too intensive, since every calculation has to go through an API. Lastly, the API key that was utilized, had an annual limit for the number of API calls. The analysis outputs the information shown in Table 7.

Line	This is the currently line that is being compared
Line distance	The distance from the origin to the destination location of the current line (km)
Count	The amount of orders on the current line
Closest Line	The line that is closest to the current line
Distance Closest	The distance of the closest line to the current line (km)
Relative Distance Closest	Indicates how the Distance Closest compares to the Line distance. $Relative\ Distance\ Closest = \frac{Distance\ Closest}{Line\ Distance} * 100\%$
Closest Line Count	The amount of orders on the closes line
2^{nd} Closest Line	The line that is 2^{nd} closest to the current line
Distance 2^{nd} Closest Line	The distance of the 2^{nd} closest line to the current line (km)
Relative Distance 2^{nd} Closest	Indicates how the Distance 2^{nd} Closest compares to the Line distance. $Relative\ Distance\ 2nd\ Closest = \frac{Distance\ 2nd\ Closest}{Line\ Distance} * 100\%$
2^{nd} Closest Line Count	The amount of orders on the second closest line

Table 7. Information outputted by closest line analysis

4.3.3 High potential customers

The customers that have a high potential for LHV discussion are discussed below.

Client A: Odin Warehousing and Logistics BV

For this client two high potential lines were identified. Line 1 was used for 32 shipments and for all these shipments mega trailers were used. All these orders occurred relatively close together and therefore LHVs could have been implemented relatively easily. The line also has a significant distance of 275 km, which makes it even more suitable for LHV usage. The second line used the same origin location as line 1 but the destination was slightly different. The destinations were only 9 km apart and therefore would have been ideal to be combine shipments for both locations. Two smaller orders could be combine in one LHV trip which is only 3,3% longer. However, the orders on line 2 occurred earlier in time than the orders on line 1. Line 2 was used 18 times with mega trailers and three times with LHVs. The relative savings and savings per trip after LHV implementation at customer A are shown in Table 8.1.

	Emission Savings (%)	*Savings per trip (kg of CO_2)*
Line 1	29,85	82,72
Line 2	24,39	62,99

Table 8.1. Potential LHV lines for client A

Client B: Greif Nederland BV

Client B is the third largest customer for Van Der Wal in terms of shipments. One high potential line was discovered at this client, which will be referred to as line 3. It has a length of 172 km and currently only used by swap trailers. Therefore high savings are possible on this line. This line has the highest relative emission savings of all lines and one of the highest savings per trip. In total this line was used 11 times and therefore it might be difficult to convince the customer to switch to LHVs on this line, since orders appear mostly every week or every other week. The closest line is located at a distance of nearly 47 km. On this line LHVs are already in use and it has a usage rate that is more than 3 times of line 3. It should therefore be possible to combine shipments from line 3 with this other line which will increase the length of the trip 27% (Table 8.2).

	Emission Savings	*Savings per trip (kg)*
Line 3	60,28	184,13

Table 8.2. Potential LHV line for client B

Client C: Mauser Benelux BV

This is another large customer for Van Der Wal. For this client a line was found that provides an opportunity for high relative savings. This line was used 21 times and could be changed to 9 LHV shipments. The length of the trip is as high as earlier lines and therefore the savings per trip are less. There is one line from the same origin that can be used to combine shipments with. This line is used only 6 times however and will increase the distance of a trip with nearly 40% (Table 8.3).

	Emission Savings	*Savings per trip (kg)*
Line 4	53,81	54,41

Table 8.3 Potential LHV line for Client C

Client D: DHL Supply Chain Netherlands

This is the largest customer for Van Der Wal in the Netherlands and Belgium. For this client 5 potential LHV lines were found. On all these lines currently only mega trailers are used and are referred to as line 5 till 9. All these lines are used multiple times a week and therefore well fitted to host LHVs. Of these lines line 7 is the shortest and line 6 is the longest with lengths of 114 and 222 km respectively. Furthermore line 5 and 6 are located closely together. Combining these lines would increase the length with only 7,7%. Results for this client are shown in Table 8.4.

	Emission Savings	*Savings per trip (kg)*
Line 5	29,75	65,18
Line 6	28,02	60,98
Line 7	29,85	60,5
Line 8	29,75	57,37
Line 9	29,75	57,35

Table 8.4. Potential LHV lines for client D

5. Optimization of vehicle allocation

Next to analyzing data about the current Van Der Wal operations, a Linear Program model was created that can assign trucks to a transportation route such that the total CO_2 emission is minimized. The problem is based on the Vehicle Assignment and Scheduling Problem (VASP) (Khooban, 2011). This problem however has some unique features which are not present in the standard VASP. Firstly the VASP assumes that there are a certain amount of origin locations which can all be used to satisfy the demand at all destination locations. It is thus assumed that the cargo transported is homogeneous. However in this problem, instead of looking at origins and destinations we focus on routes. On each route different products are transported and therefore the demand on each transportation route is unique. The standard VASP also assumes that vehicles are unique, which is not the case for this problem. There are four different vehicle configuration that each have a specific capacity and emission value. Lastly, a maximum amount of trucks per specification is specified. This is especially important for the configuration 'LHV', since it has the lowest emission per unit of capacity. By implementing a maximum number of vehicle configuration the model can show which on which route LHVs are most efficient to implement.

5.1 MILP model

Below the MILP that is used is shown. The model consists of two sets, five parameters and one decision variable. The set of routes is different for every weekly dataset, however often routes are used in multiple weeks. The set of truck configurations are the same four configurations that were described during the report.

Sets:

R: Set of routes

C: Set of truck configurations

Parameters:

$s_r \geq 0$: amount of m^3 that has to shipped on route $r \in R$.

$d_r \geq 0$: distance of route $r \in R$.

$e_c \geq 0$: emission value for configuration $c \in C$ in g of CO2/km.

$y_c \in \mathbb{N}$: maximum number of trucks with configuration $c \in C$ that can be used

$c_c \in \mathbb{N}$: capacity of truck with configuration $c \in C$ in m^3.

Decision variables:

$x_{rc} \in \mathbb{N}$: discrete number of vehicles of configuration $c \in C$ that are used to transport freight on route $r \in R$.

Integer programming model

Min $\quad \sum_{r \in R} \sum_{c \in C} x_{rc} d_r e_c$

s.t $\quad \sum_{c \in C} x_{rc} c_c \geq s_r \qquad \forall\, r \in R$

$\sum_{r \in R} x_{rc} \leq y_c \qquad \forall\, c \in C$

$x_{rc} \geq 0 \qquad \forall\, r \in R, \forall\, c \in C$

This model was implemented in Python with the Gurobi library. However in the order data, sometimes routes existed with a length of 0 km. These routes had to filtered out because since the objective function will not increase, independent of the decision variable for a specific route. The model will automatically assign an as high as possible value for x_{rc}. Therefore the model will always try to implement the maximum amount of vehicles while this is not necessary, if a route exists with a length of 0 km.

The full order dataset was divided in weekly datasets for this analysis. The reason for using weekly data is rather simple. Firstly, when only examining daily data, shipments on the same transportation line are uncommon. When examining data over a week of time, shipments on the same route appear more often and are close enough together that it could be possible to combine those shipments in less shipments with larger trucks. In total, there are 13 different weeks, with week 1 being the first week of September 2021 and week 13 being the final week of November 2021.

The graph below shows the total capacity and amount of trips in vehicles for each configuration type (Figure 9 & 10). It is important to note that in Figure 10 does not mean that the amounts given in the graphs are also the amount of trucks that Van Der Wal used in that period, but it refers to the amount of trips made by trucks in that specific configuration. A single trucks can be used for multiple deliveries on a given day, however which unique vehicle is used is not tracked for each delivery.

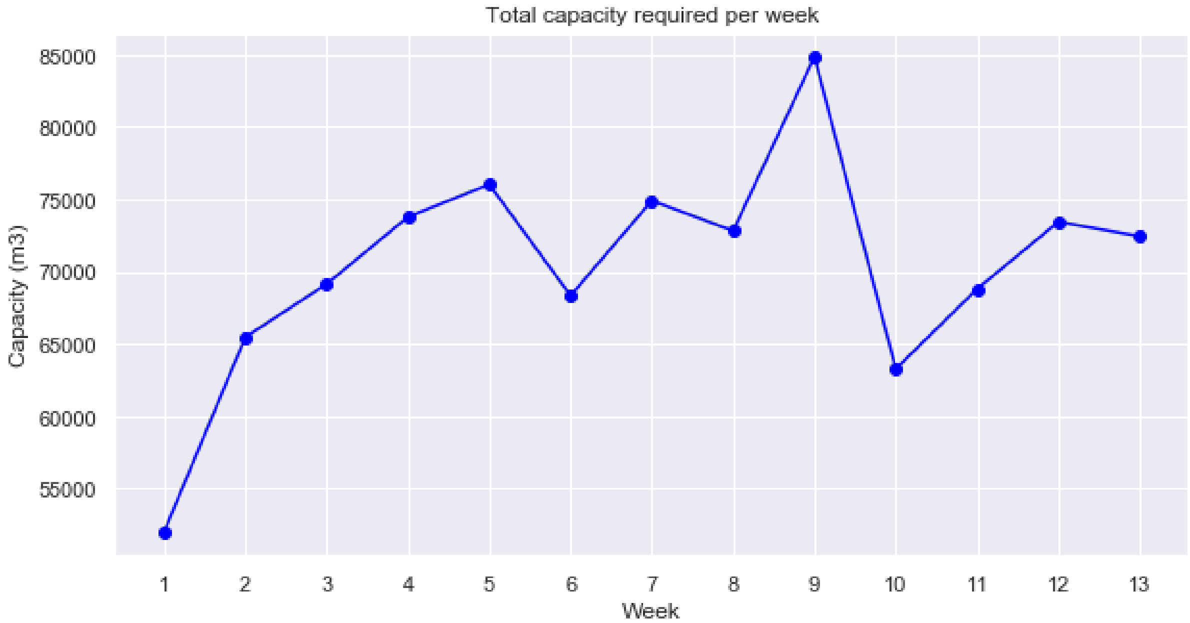

Figure 9. The total capacity needed (in m^3) each week in the current situation

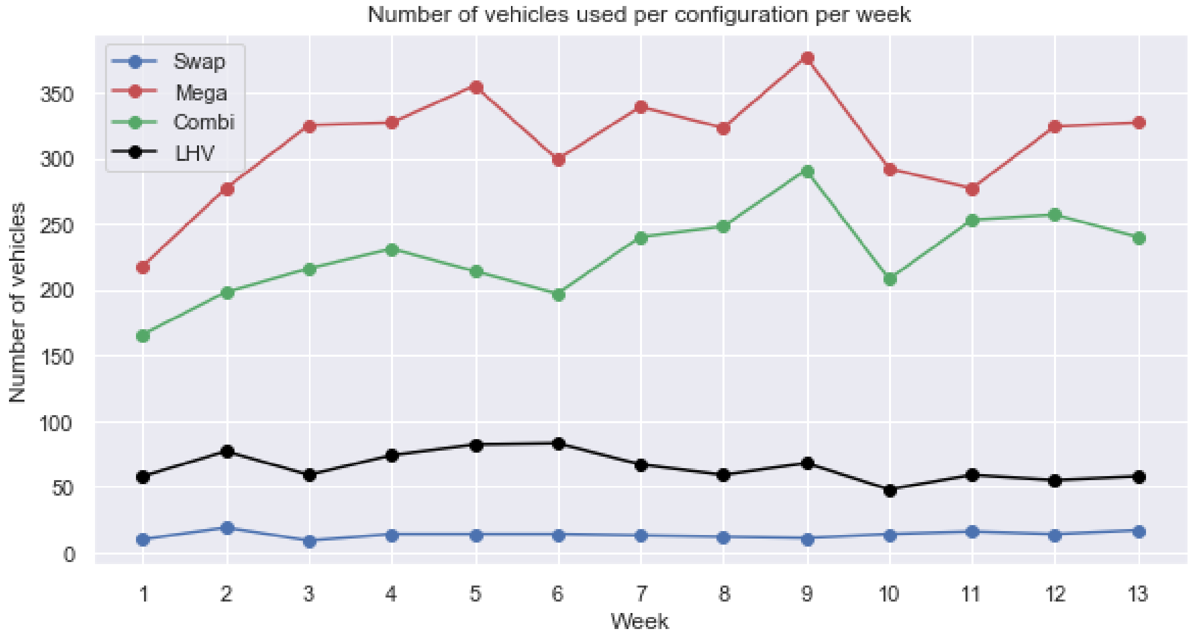

Figure 10. Number of trips in each configuration per week in the current situation

Figure 11 below shows the current CO_2 emission on a weekly basis. The graph shows more or less the same pattern as the graph for the capacity. The difference is mostly the steepness between points and is caused by the distances of the routes. This can clearly be observed by looking at the capacity and emission for week 12 & 13. The required capacity for week 13 is lower than for week 12, however the CO_2 emission is higher in week 13. The reason for this is thus that the weighted average of the route distances is higher for the routes in week 13 compared to the routes travelled in week 12.

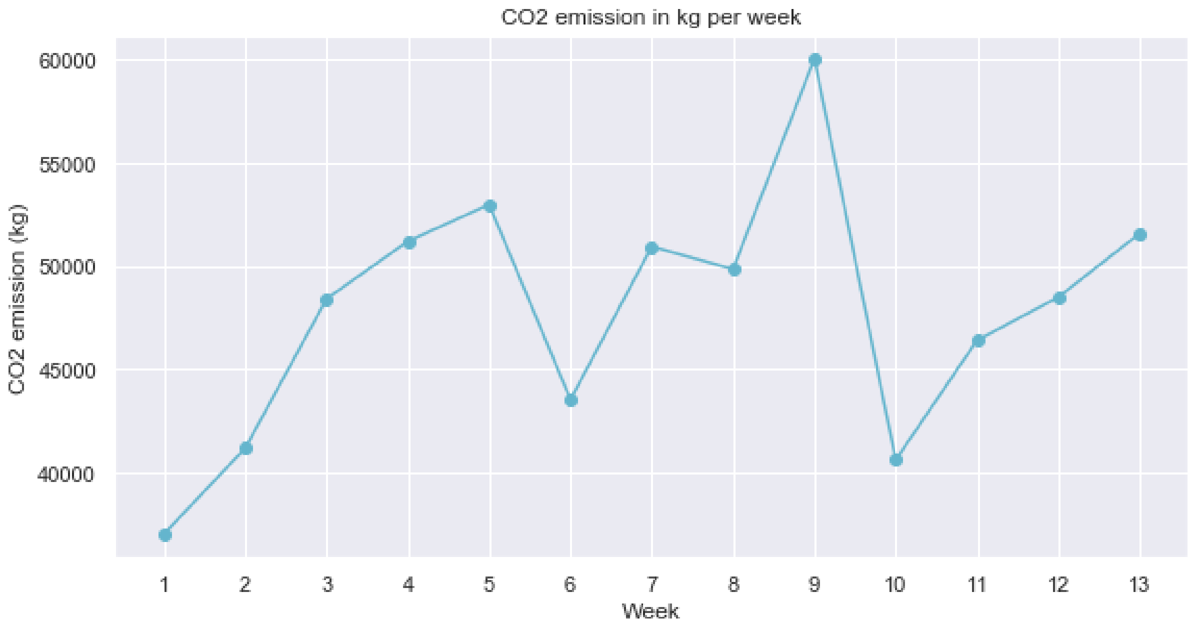

Figure 11. CO_2 emission in kg per week in the current situation

When applying the current model to the dataset (without adding additional LHVs), the model will reassign all trucks to the routes such that the emissions will be minimized. In this step, additional vehicles of the configuration ‘Swap’ are made available and are about 2% of the total trips in each week. This is because it will make it easier to reassigning the already in use

LHVs to other routes, while keeping in mind the capacity constraint. Otherwise it would only be possible to assign LHVs to specific lines if the old vehicle configurations used on that line could exactly be applied to other lines, meaning that the demand (in m^3) would exactly be fulfilled. Figure 12 below shows the emissions in the current and in the optimized situation. In Table 9 the exact values for the emissions in both scenarios are given along with their relative savings. The highest savings can be realized in week 1, where the savings are 3,19%. The lowest savings can be realized in week 3, with savings of 2,01%.

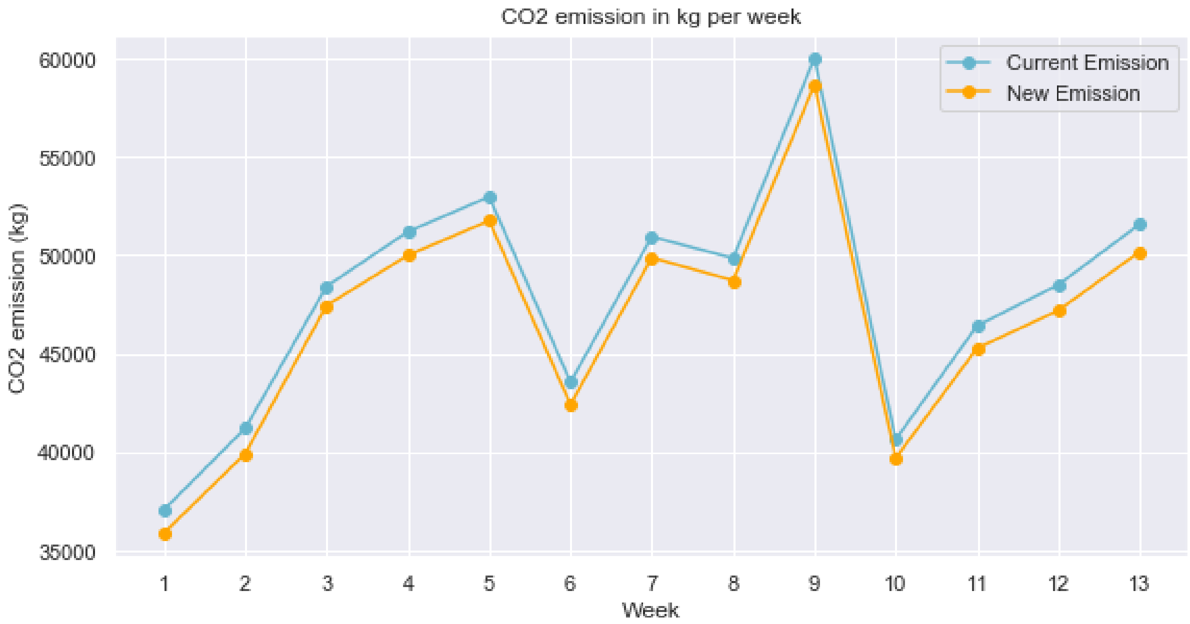

Figure 12. Current and optimized CO_2 emission (in kg) per week

	Current Emission (kg)	Optimized Emission (kg)	Savings (%)
week 1	37054	35872	3,19
week 2	41202	39915	3,12
week 3	48415	47444	2,01
week 4	51199	49997	2,35
week 5	52973	51754	2,3
week 6	43546	42482	2,44
week 7	50943	49874	2,1
week 8	49850	48719	2,27
week 9	60022	58669	2,25
week 10	40630	39684	2,33
week 11	46411	45269	2,46
week 12	48495	47189	2,69
week 13	51575	50176	2,71

Table 9. Current and optimized CO_2 emission (in kg) per week

5.2 Sensitivity analysis

In this section, the sensitivity of the CO_2 emission will be analyzed with different levels of additional LHV utilization. In the previous part, additional LHVs were not considered so that the base capability of the model could be examined. Now, different levels of additional LHV availability are used to measure the impact on CO_2 emissions. These levels do not indicate the amount of unique LHVs that are assigned but the amount of trips on which LHVs can be assigned that currently do not use LHVs. The levels that are analyzed range from 5% to 25%. Table 10 shows the CO_2 emission in kg for each level of additional LHV trips and savings compared the current situation. The savings are also shown visualized in Figure 13. As can be seen in the Figure the savings increase less when the level of LHVs increases. For each of the utilization levels all available LHV trips are used, except for the 20% level. In this scenario, using all available LHVs would increase the total emission.

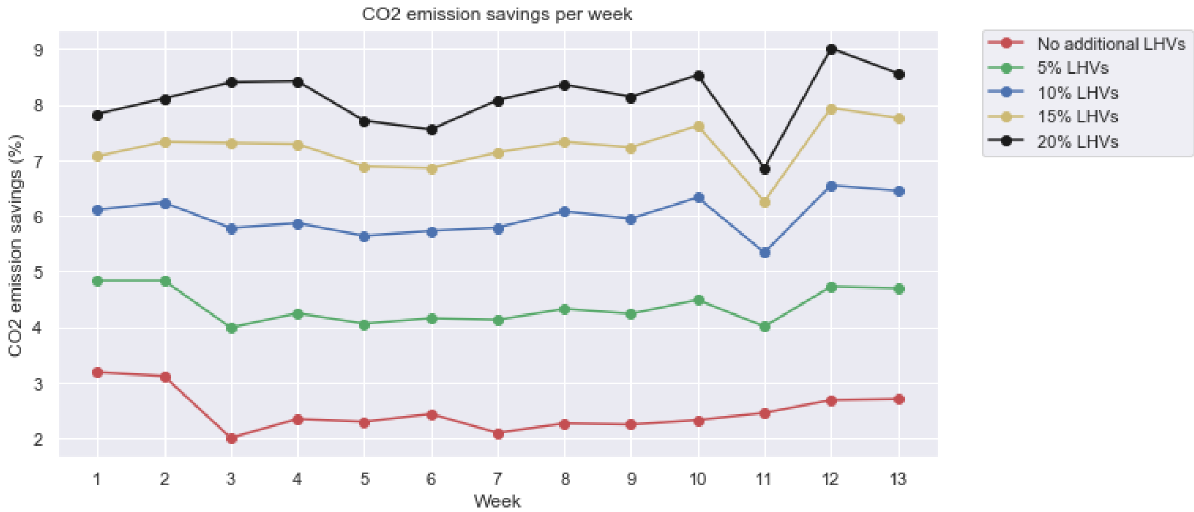

Figure 13. CO_2 emission savings for different levels of additional LHVs

		No additional LHV		*5% LHV*		*10% LHV*		*15% LHV*		*20% LHV*	
	Current Emission	Optimized Emission	Savings (%)	Optimized Emission	Savings (%)	Optimized Emission	Savings (%)	Optimized Emission	Savings (%)	Optimized Emission	Savings (%)
week 1	37054	35872	3,19	35260	4,84	34789	6,11	34434	7,07	34153	7,83
week 2	41202	39915	3,12	39209	4,84	38633	6,24	38181	7,33	37861	8,11
week 3	48415	47444	2,01	46481	3,99	45617	5,78	44878	7,31	44347	8,4
week 4	51199	49997	2,35	49021	4,25	48196	5,87	47468	7,29	46890	8,42
week 5	52973	51754	2,3	50824	4,06	49986	5,64	49324	6,89	48890	7,71
week 6	43546	42482	2,44	41733	4,16	41050	5,73	40559	6,86	40259	7,55
week 7	50943	49874	2,1	48841	4,13	47992	5,79	47308	7,14	46829	8,08
week 8	49850	48719	2,27	47692	4,33	46820	6,08	46194	7,33	45683	8,36
week 9	60022	58669	2,25	57477	4,24	56450	5,95	55683	7,23	55137	8,14
week 10	40630	39684	2,33	38807	4,49	38059	6,33	37532	7,62	37163	8,53
week 11	46411	45269	2,46	44551	4,01	43933	5,34	43504	6,26	43227	6,86
week 12	48495	47189	2,69	46203	4,73	45319	6,55	44643	7,94	44127	9,01
week 13	51575	50176	2,71	49149	4,7	48249	6,45	47571	7,76	47162	8,56

Table 10. Total emission in (kg of CO_2) for each scenario in every week

It could also be interesting to look at the characteristics of lines that are turned into LHV lines. The main attribute of interest is the length of such transportation lines. Table 11 shows the weighted average length of the lines on which LHVs are used in each of the scenarios. The weighted average is chosen because not all lines are used equally often. In the current situation the average length of an LHV line is around 100 km. The highest average length always occurs in the optimized scenario without additional LHV. The reason for this is that LHVs are assigned to the lines with the greatest length as that will lead to the lowest emissions. Therefore the average length will slowly decrease for every additional LHV trip available. In the scenario with the highest average line length the average length lays between 136,39 and 186,36 km. Anything in or above this range could be considered a good potential LHV line. Van Der Wal can use this to quickly asses if new lines, when they are requested by new or existing customers, are worth to be supplied by LHVs.

	Weighted average length of LHV lines (km)					
	Current Situation	No additional LHV	5% LHV	10% LHV	15% LHV	20% LHV
week 1	112,47	186,36	166,15	150,3	136,81	124,66
week 2	95,8	136,39	127,65	119,94	111,92	102,98
week 3	109,9	166,37	149,44	141,26	132,82	124,37
week 4	110,58	165,14	150,6	140,4	131,66	125,4
week 5	102,88	154,91	143,04	133,64	125,75	115,35
week 6	106,13	139,72	129,81	122,74	115,52	106,12
week 7	97,8	149,53	139,43	130,18	121,23	113,99
week 8	99,96	165,75	151,79	140,2	128,62	118,77
week 9	97,68	162,44	147,74	138,85	127,36	117,13
week 10	88,66	143,62	133,31	126,19	115,1	105,0
week 11	90,17	140,07	129,99	117,6	107,31	97,0
week 12	100,7	170,5	152,02	140,58	129,75	119,75
week 13	94,23	174,05	155,97	144,94	131,71	119,08

Table 11. Weighted average length of LHV transportation lines for each week

6. Discussion

This section will reflect on the main findings of this thesis. Furthermore, the limitations will be describes along with future research suggestions. Lastly, the research will be concluded with the business implications.

6.1 Discussion and limitations of main analysis

The first finding of this thesis was the overview of which factors have to be considered when implementing LHVs at Van Der Wal's customers. With these factors a diagram was created that shows the relation if each of the factors to LHVs. Most of these factors are hindering factors, which is intuitive as these vehicles are larger and are attached with multiple constraints. Many companies are already sufficiently content with their logistic operations and therefore are not always will to change up their way of working. They know that their current operations work accordingly and are not always willing to take the risk to switch up their operations. Additionally, transportation costs quite often make up a small parts of the total costs that an organization incurs and therefore is not worth the effort of changing up the operations for (financial) benefits that LHVs provide. The factors discussed mostly have to be considered in the final stages of LHV implementation and can therefore help to see if LHVs can be implemented efficiently. However, first the customer must be convinced to adopt LHVs. Since financial incentives might not be enough to persuade another approach has to be taken. Instead of purely focusing on the financial side of things, customers can be addressed on their societal obligation for sustainability. LHVs have clear environmental benefits. By showing customers directly the emission savings they can make by adopting LHVs they might be convinced to make the switch. Additionally, customers can promote their own brand as an environmental conscious company by showing that they actively pursue a 'greener' policy.

In order to help customers of Van Der Wal to increase sustainability of their business, the right customers and their potentially most relevant transportation lines had to be found first. To begin with emission factor for all vehicles configuration that Van Der Wal uses had to be established. Since Van Der Wal collects data from all their trucks (including emissions) these values could be used for the calculation of the factors. However the trucks and tractor units do not ride in fixed configurations and therefore the emission factors could not easily be established. Eventually, a method was established to calculate the emission factors using a combination of the data provided by Van Der Wal and the literature. Compared to emission factors established in literature, the values found in this study are significantly lower. This could be due to the fact that the factors established in literature are outdated and newer more efficient engines are used nowadays. The emission factors used in this research are approximations and are assumed to be static, however in reality this is not the case. The factors are variable with the loading weight of the truck and the characteristics of the road. More hilly environments will negatively impact the emission for example.

The findings of the main analysis showed 9 potential lines for LHV implementation. A ranking of these line was not created since there are many different criteria that can be considered. When purely focusing on relative savings, the best lines that were found were lines that currently only used swap trucks. However most of these lines were relatively short and therefore the savings per trip would not make a massive difference. One the other hand, sometimes the absolute savings (per trip) were high but the relative savings were not as high. This happened for example when a line had a long distance but was already being used by combi trucks. The additional capacity that an LHV provides over a combi is the least compared to all other configurations and therefore the relative savings that these lines can provide are not all that high. Not only the absolute and relatively savings were important when identifying potential LHV lines. The most important aspect may even be the frequency of which lines are used. When a line provides high potential savings but is not used that often it is not worth the effort of convincing the customers to adopt LHVs for the overall minimal savings it provides. Lastly, next to the lines being used often is it also important to notice if the line is used regularly over a longer period of time or of it used intensively over a shorter period. In the first case LHV implementation would be a good option as savings can be made over a longer period of time. In the second case, the line itself is probably not a sustainable line which means it will not be used in the future anymore. However, if the customer stays at Van Der Wal and wants to open new routes of similar characteristics, LHVs could be a possibility.

6.2 Discussion of further analysis

The further analysis focused on how emissions can be minimized by reallocating configurations to trips. The MILP model created served its purpose well. Without using additional vehicles the CO_2 emissions can already be decreased with a few percent. By implementing LHVs on some the trips emissions can be brought down even more. From the sensitivity analysis it became clear that the optimal amount of additional LHV trips lays between 15%-20%. Making more LHVs available for some trips will not further decrease the emissions as the model would choose not to use them. The biggest emission savings occurred for the first few percentages of additional LHVs. This is logical as the model tries to minimize the total emission, and therefore will try to implement LHVs on the trips which offer the highest possible savings. In theory, these savings seem possible to acquire, since Van Der Wal has the available vehicles. However, in practice it will be much more difficult. The model looks at all the orders in hindsight and then decides what would have been the optimal vehicle allocation. In practice, real time decisions about vehicle allocation have to be made often without knowing the orders that will appear in the future. Additionally, customers often come to Van Der Wal with a specific request for a truck, for example a mega, and want the shipment to be planned immediately. If LHVs were to be implemented on a line the frequency of the orders will have to be changed, since less orders will be needed. This is something which has to be decided within the customer’s company and thus is it out of control for the hauler. Van Der Wal representatives can only lobby at their customers for these changes by showing them what they could potentially save in terms of emissions and costs. All these factors will make it difficult to bring down the emissions to the optimal level that the model proposes.

6.3 Limitations

One of the limitations of this thesis are the emission factors that are used for all calculations. These were approximated as discussed in *section 6.1.* Therefore the validity of these numbers are unknown. However, although the exact number may not be entirely true to reality, they were sufficient to find potential LHV lines.

Another limitation is that the found potential LHV lines are not ranked to shows which exact line is most suitable. This is because different assessment criteria were used to identify potential lines.

6.4 Future research

The research conducted in this paper provides multiple opportunities for further research. The process of how to convince customers to adopt LHVs could be investigated in depth and a general methodology can be created on how this can be done most effectively. This could be extremely helpful to Van Der Wal on convincing more of their clients to switch to LHVs. However, all customers have different reasons why they currently are not using LHVs and therefore this research will require to speak to many different customers.

Another future research direction could be to further investigate the optimization process. Instead of looking at the number of trips, the research can focus on the actual fleet that is used. This will require that for each order the specific truck (for example the license plate) is tracked. With this approach, Van Der Wal can learn how many additional LHVs they need to buy or make available to reach lower emissions.

Lastly the monetary costs can be analyzed when LHVs are implemented. As the scientific literature already suggests, LHVs can lead to costs savings. By calculating the costs savings that Van Der Wal can make each transportation line when using LHVs, they can also offer their customers better prices. This could be a reason for them to adopt LHVs quicker.

6.5 Conclusion and Practical Insights

The aim of this thesis was to gain more insight on how and where Van Der Wal can implement LHVs in their business. First the scientific literature was reviewed on four main aspects that were often investigated. An overview of factors related to LHV implementation was created by speaking to Van Der Wal employees that are concerned with LHVs on a daily basis. These factors are either supportive or hindering factors for LHV implementation. This factors can be used as a quick assessment to see if LHV implementation is likely to be successful at a customer.

The main focus of this research was to find where in the business LHVs can be used to achieve the highest emission savings. First a measure had to be created so that different vehicle configuration could easily be prepared. This measure showed the emission of CO_2 in g/km. These measure were then used to analyze all transportation lines that are in use by Van Der Wal. For each line savings were calculated. From all these lines, a total of 9 lines with a high LHV potential were identified.

Next to analyzing which lines are most suitable for LHV implementation, a further analysis was conducted on how vehicle allocation can be optimized in order to reach minimal emissions. For this the order data was divided into weekly datasets. A MILP model was created to find how vehicle configurations could be optimally linked to trips. This lead to some useful practical insights. The optimal additional LHV trips that Van Der Wal can implement in order to reach the lowest emissions are 15%-20% of the total amount of trips on a weekly basis. Additionally, the length of LHV lines in the current and optimal situation were examined. Currently the average length of LHV lines is closely to 100 km. However in the optimized scenario, the average length increases around 40%-80% on a weekly basis. Therefore, a cut off value can be established of for example 140 km. New lines that are longer than this value can then be seriously considered to be used by LHVs. Also a higher value can be chosen if Van Der Wal wants to be stricter with which lines should be considered for LHV implementation.

References

Aarts, L., & Salet, M. (2012). Experiences LHV's in the Netherlands: typical Dutch or valid for Europe? *12th International Symposium on Heavy Vehicle Transport Technology, May 19-22*.

Af Wåhlberg, A. E. (2008). Meta-analysis of the difference in accident risk between long and short truck configurations. *Journal of Risk Research*, *11*(3), 315–333. https://doi.org/10.1080/13669870701797129

Åkerman, I., & Jonsson, R. (2007). *European Modular System for road freight transport-experiences and possibilities*.

Bâdescu, M., & Purcar, C. M. (2017). Considerations on oversized transportation in the UE(Community). *MATEC Web of Conferences*, *121*, 06001. https://doi.org/10.1051/MATECCONF/201712106001

Bell, E., Bryman, A., & Harley, B. (2019). Business research methods. In *Business Research Methods* (Fifth Edition). Oxford University Press Inc.

Castillo-Manzano, J. I., Castro-Nuño, M., & Fageda, X. (2021). Analyzing the safety impact of longer and heavier vehicles circulating in the European market. *Journal of Safety Research*, *77*, 1–12. https://doi.org/10.1016/j.jsr.2021.01.001

Directorate-General for Mobility and Transport (European Commission). (2018). *EU transport in figures - Publications Office of the EU*. https://doi.org/10.2832/919583

Grislis, A. (2010). Longer combination vehicles and road safety. *Transport*, *25*(3), 336–343. https://doi.org/10.3846/TRANSPORT.2010.41

Huber, S., & Rust, C. (2016). Calculate Travel Time and Distance with Openstreetmap Data Using the Open Source Routing Machine (OSRM): *Https://Doi.Org/10.1177/1536867X1601600209*, *16*(2), 416–423. https://doi.org/10.1177/1536867X1601600209

Karam, A., & Reinau, K. H. (2021). Evaluating the effects of the a-double vehicle combinations if introduced to a line-haul freight transport network. *Sustainability (Switzerland)*, *13*(15). https://doi.org/10.3390/su13158622

Khooban, Z. (2011). Logistics and Operations Management - Concept and models. In *Logistics Operations and Management* (pp. 109–126). Elsevier. https://doi.org/10.1016/B978-0-12-385202-1.00007-4

Klingender, M., Ramakers, R., & Henning, K. (2009). In-depth Safety Impact Study on longer and/or heavier commercial vehicles in Europe. *PEITS 2009 - 2009 2nd Conference on Power Electronics and Intelligent Transportation System*, *1*, 368–373. https://doi.org/10.1109/PEITS.2009.5406992

Knight, I., Newton, W., Mckinnon, A., Palmer, A., Barlow, T., McCrae, I., Dodd, M., Couper, G., Davies, H., Daly, A., McMahon, W., Cook, E., Ramdas, V., & Taylor, N. (2008). *Longer and/or Longer and Heavier Goods Vehicles (LHVs) – a Study of the Effects if Permitted in the UK: Final Report*. http://www.nomegatrucks.eu/deu/service/download/trl-study.pdf

Kyle. (2012). *Getting Distances and DriveTimes*. https://www.excelforum.com/tips-and-tutorials/808661-getting-distances-and-drivetimes.html

Leach, D. Z., Savage, C. J., & Maden, W. (2013). High-capacity vehicles: An investigation of their potential environmental, economic and practical impact if introduced to UK roads. *International Journal of Logistics Research and Applications*, *16*(6), 461–481.

https://doi.org/10.1080/13675567.2013.856390

Leduc, G. (2009). Longer and Heavier Vehicles: An overview of technical aspects. In *JRC Scientific and Technical Reports*. https://doi.org/10.2790/12649

Lieber, E. (2009). Mixing Qualitative and Quantitative M ethods : insights into design and analysis issues. *Journal of Ethnographic & Qualitative Research*, *3*(1935–3308), 218–227. https://eric.ed.gov/?id=EJ906599

Liimatainen, H., Pöllänen, M., & Nykänen, L. (2020). Impacts of increasing maximum truck weight – case Finland. *European Transport Research Review*, *12*(1), 1–12. https://doi.org/10.1186/S12544-020-00403-Z/TABLES/6

Lindqvist, D., Salman, M., & Bergqvist, R. (2020). A cost benefit model for high capacity transport in a comprehensive line-haul network. *European Transport Research Review*, *12*(1), 60. https://doi.org/10.1186/s12544-020-00451-5

Pålsson, H., & Sternberg, H. (2018). LRN 2016 SPECIAL–high capacity vehicles and modal shift from rail to road: combining macro and micro analyses. *International Journal of Logistics Research and Applications*, *21*(2), 115–132. https://doi.org/10.1080/13675567.2018.1430232

Panteia. (2021). *Kostencalculaties in het beroepsgoederenvervoer over de weg*.

Saglietto, L. (2013). Towards a Classification of Fourth Party Logistics (4PL). *Universal Journal of Industrial and Business Management*, *1*(3), 104–116. https://doi.org/10.13189/UJIBM.2013.010305

Sanchez Rodrigues, V., Piecyk, M., Mason, R., & Boenders, T. (2015). The longer and heavier vehicle debate: A review of empirical evidence from Germany. *Transportation Research Part D: Transport and Environment*, *40*(1361–9209), 114–131. https://doi.org/10.1016/j.trd.2015.08.003

Speirs, J., Balcombe, P., Blomerus, P., Stettler, M., Achurra-Gonzalez, P., Woo, M., Ainalis, D., Cooper, J., Sharafian, A., Merida, W., Crow, D., Giarola, S., Shah, N., Brandon, N., & Hawkes, A. (2020). Natural gas fuel and greenhouse gas emissions in trucks and ships. *Progress in Energy*, *2*(1), 012002. https://doi.org/10.1088/2516-1083/AB56AF

The Danish Road Directorate. (2011). *Evaluation of Trial with European Modular System: Final Report.* https://www.vejdirektoratet.dk/udgivelse/danish-trial-ems-european-modular-system-evaluation

Tunnell, M. A., & Brewster, R. M. (2005). Energy and Emissions Impacts of Operating Higher-Productivity Vehicles: *Https://Doi.Org/10.1177/0361198105194100113*, *1941*(1), 107–114. https://doi.org/10.1177/0361198105194100113