A promising vision to make global logistics more sustainable is 'Physical Internet Logistics'. This vision suggests an open, global and interconnected network with different spokes, hubs and routes. This report is focused on a service network design in the Dutch parcel delivery industry based on Physical Internet characteristics. The objective is to reduce the environmental impact of transportation regarding parcel distribution by applying Physical Internet characteristics to environmental network optimisation.

Written as a master thesis to obtain the degree of Master of Science at the Delft University of Technology.

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Physical Internet in parcel delivery - R.J. van Ouwerkerk

Applying Physical Internet characteristics to environmental network optimisation in the parcel delivery industry

Transport, Infrastructure & Logistics

R.J. van Ouwerkerk

Applying Physical Internet characteristics to environmental network optimisation in the parcel delivery industry

A case study at PostNL

by

R.J. van Ouwerkerk

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Thesis committee:	Prof. dr. R. R. Negenborn,	TU Delft, chair
	Ir. M. B. Duinkerken,	TU Delft, supervisor
	Dr. J. M. Vleugel,	TU Delft, supervisor
	Drs. G. H. Dermowidjojo,	PostNL, external supervisor

This thesis is confidential and cannot be made public until September 12, 2021.

Preface

With this report, I complete my Master of Science in Transport, Infrastructure and Logistics after my Bachelor of Science in Civil Engineering. This graduation work has been drawn up in cooperation with PostNL, which gave me the opportunity to start as graduate student in January 2018. In the first month, my graduation project was focused on PostNL's impact concerning CO_2 emissions and gathering information from scientific papers. I tried to find optimisation opportunities with regard to CO_2 reduction. During the first meeting with the complete thesis committee, the vision of Physical Internet Logistics was introduced by the chairman Prof. dr. Rudy Negenborn as a source of inspiration. In the following months, I did a lot of research regarding this vision and its application in the parcel delivery industry. I learned a lot about the parcel delivery industry as well as the working environment at large companies like PostNL. With this report, I tried to bridge the gap between theories from science with the business in reality. After 7 months of research and writing, this report shows the application of a theoretical vision on a day-to-day business.

However, this report would not exists without any help from others. First of all, I would like to thank my parents for the opportunity to study at the University of Technology in Delft. Their support during the last years was a key factor in increasing motivation. Moreover, I would like to thank my thesis committee for the guidance and support during the process of preparation and executing my thesis. I am grateful for the support of Dr. Jaap Vleugel and his expertise in process management from the orientation stage of the project. Besides, I would like to thank Ir. Mark Duinkerken and Prof. dr. Rudy Negenborn for their guidance and thorough critiques of this research report. I would also like to thank George Dermowidjojo as an external supervisor from PostNL. His expertise in strategy consulting was very valuable to work systematically. Since this report is written in cooperation with PostNL, I would like to thank them regarding their willingness to help and data availability. Without PostNL this report would lack its link with the reality. Also, I would like to thank my brother and friends for supporting me over the last few months. Especially my friends from Delft with their sharp eye on spelling and grammar. Finally, I wish to thank Hadassa Stevens, my partner in crime throughout the process of graduation. Without her help, listening, complaining moments and free cups of coffee, my graduation would not be that successful.

R.J. van Ouwerkerk
Rotterdam, Summer 2018

Executive summary

After the Climate Change Conference in 2015, a lot of sectors were confronted by their impact regarding CO_2 emissions and the effect on the environment. A promising vision to make global logistics more sustainable is the vision of ’Physical Internet Logistics’. This vision, based on the way ’Digital Internet’ sends packages information through a network, is focused on optimisation of handling, storing, realising and supplying objects. According to this vision, global logistics deals with objects in a very unsustainable way currently. For example:

1. Carriers are shipping air and travel often empty
2. Intermodel transport is currently cost inefficient and risky
3. City distribution is a nightmare
4. Objects are unnecessarily moved through a network

Physical Internet Logistics suggests an open, global and interconnected network with different spokes, hubs and modes. Objects are encapsulated in standardised containers whereafter they will be distributed through a network. Routing of the container is focused on network balancing. Every container will follow its own path through the network from origin to destination by using different hubs. Different origin-destination pairs will be bundled and transported on the same link. Besides, similar origin-destination pairs could follow different paths through the network. At hubs, transhipment takes place to transfer containers to different routes. Each route and mode has its own characteristics like capacity, speed, environmental impact and price. In this way, Physical Internet tries to support a fast, reliable and robust network which is able to distribute demand in a sustainable way. Despite the fact that the vision of Physical Internet is mainly focused on global logistics, characteristics of this vision could be interesting for smaller networks as well. This report is focused on a service network design in the Dutch parcel delivery industry based on Physical Internet characteristics. A service network design model is used to allocate a fleet focused on the transportation of demand in the most optimal way regarding minimisation of CO_2 emissions.

Case study

A case study at PostNL shows the effects of applying some Physical Internet characteristics on a service network design. This report used two network designs with their difference in the network structure. First, a network design is suggested which makes use of the same hub locations as currently defined by PostNL. The open character of Physical Internet is performed by multi allocation of the hubs. This means that every spoke is connected with every hub. Only at these hubs transhipment takes place. Every path between origin and destination makes use of a hub. This means that there are only spoke (origin)-hub-spoke (destination) paths. The second network design allows transhipment at every node (spoke or hub). This design is fully focused on the open character of Physical Internet. A parcel can follow a spoke-spoke or spoke-hub-spoke path from origin to destination. For both designs, encapsulated demand in roll cages is able to travel their own path through the network. Besides, both designs allocate trucks only to single routes between nodes. In addition, volume reduction per parcel is taken into account since the vision of Physical Internet defines transportation of empty objects as unsustainable.

Currently, PostNL makes use of a network with 20 nodes of which 5 act as hub and 15 as spoke. However, almost every node produces and attracts demand. Each node represents a smaller region of collection and distribution. Demand is collected during the day in each region and sorted in that corresponding spoke. After sorting, the demand will be distributed through the network which is structured according to a single allocated web structure. This means that every origin is connected with every hub but every hub is only connected with a couple of destinations. However, measurements show that some spokes are served by more than one hub and thus multiple allocation is applied. Analysis regarding the measured fleet allocation shows that on an average working day 46.19 tCO_2 is emitted by heavy trucks. This amount of emissions is emitted during 728 trips which travelled 64,788 kilometres. Regarding emptiness of the distribution, 2,411 kilometres were travelled completely empty. Analysis with regard to volume per parcel shows that the implementation of tailored packaging could reduce the volume per parcel with 10%.

By using an optimisation model based on literature and unique characteristics of the parcel delivery industry and Physical Internet, this report was able to allocate trucks on a specified network given a certain demand. The objective is to minimise the total amount of emitted CO_2 which is based on the total distance travelled, fuel consumption and a constant conversion factor. The model tries to minimise the total travelled distance since the fuel consumption is assumed to be constant is this report. By focusing only on CO_2 minimisation, this report is able to mention the reduction potential without taking costs into account. Earliest departure time and latest arrival time in combination with speed and (un)loading time ensure that the allocation will be performed within a realistic time-window.

Both network designs make use of the same locations as defined by PostNL. Table 1 shows the results of the used optimisation model. Concerning the number of trips, it can be concluded that a network design using the given 5 hubs and allowing only spoke-hub-spoke paths will result in more trips, more empty trips and more empty kilometres relative to the measured state or open network design. This increase of empty kilometres is a result of two things. First, this increase could be a result of allowing only spoke-hub-spoke trips. Secondly, the chosen hub locations are not optimal with regard to CO_2 minimisation. Although there are 1.1% more trips allocated to the network, the total driven distances decreased by 6.4% which has a positive effect on the total amount of CO_2. The main reason for a decrease in kilometres is because of the application of multiple allocation. An open network design which allows spoke-spoke as well as spoke-hub-spoke paths performs the best in terms of the emitted amount of CO_2 per day. Despite the fact that the number of empty trips is still larger than in the measured state, the total amount of empty kilometres and total travelled kilometres decreased relative to the current state and hub network design. Mainly the combination of spoke-to-spoke and spoke-hub-spoke results in this reduction. For example, when 78 rollcages have to be transported from Amersfoort to Born it is much more interesting to send one truck from Amerfoort to Born fully loaded (48/48) and one truck with the other 30 to Den-Bosch combined with other pairs. This way of allocation results also in a higher average utilisation as well as a reduction in the amount of empty kilometres. Focusing on the number of trips, it became clear for both designs that these trips are mainly concentrated at a node that only attracts demand. It can be concluded that it is not desirable to have nodes which only attract or produce demand.

Table 1: Performance of ’5 hub’ and ’open’ network design based on Physical Internet in relation to the measured state

Network design case study PostNL	Trips (#)	Total distance (km)	Empty trips (#)	Empty kilometres (km)	Avg. Utilisation	tCO_2 per day
Current state	728	64,788	28	2,411	0.84	46.19
5 hub network	736	60,610	56	3,363	0.92	43.21
Open network	630	54,560	44	2,141	0.94	38.90

Analyses of the different parameters showed that demand, capacity and fuel consumption are directly proportional to the amount of CO_2 emitted.With regard to transportation of air, as defined by Physical Internet as unsustainable, the effects of volume reduction are researched. By reducing the average volume per parcel, the capacity per roll cage increased. In this way, fewer roll cages are necessary to transport the same demand. By reducing the demand in terms of roll cages as input for the model, different outputs were outlined. In general, it can be concluded that every per cent in reduction results in a directly proportional reduction in CO_2. So, when the volume per parcel decrease with 10 % the amount of emitted CO_2 decrease also with 10%. The downside to this fact is that the volume reduction is in hands of the shipper, not the carrier. More technical measures to reduce the amount of CO_2 is the application of double deck trailers. These trailer with an increased volume of 60% in combination with 10% fuel increase, could reduce the amount of emitted CO_2 with 30 % concerning the optimisation model. When double deck trailers are allocated in the measured state for connection with more than 2 trips, the reduction in CO_2 could be 19% a day.
Application of Physical Internet characteristics result in a decrease in total amount CO_2 emitted per day. Sensitivity analysis shows that mainly the degree of openness results in a reduction. Of course, the more open a network is the more routes are possible. However, the level of encapsulation and so path individualisation slightly influence the total amount of CO_2. Even when every parcel is treated individually, the decision model

bundles them in quite the same volumes as encapsulated per truck.

Recommendation

This report concludes that some characteristics of Physical Internet logistics do have their potential in the parcel delivery industry. The more open a network is, the fewer emissions are emitted due to an increase in path possibilities. In particular, the openness of a network has the most influence on the total amount of CO_2 emitted relative to path individualisation. It is recommended for further research to focus on the consequences of an open network on warehouse level. Important for an open network is that origin-destination pairs are known by forehand. Forecasting, and so the dynamic and stochastic characteristics of the parcel delivery industry, will play an important role. It is recommended for further research to take these characteristics into account. Besides, also the cost related characteristics should be taken into account in further research. Finally, it is recommended for further research to take a look at the effects of single truck allocation instead of tours.

PostNL should focus on better information supplying from shippers to allocate the fleet in a more efficient way. Besides forecasting, PostNL should better report their current emissions to find potential measures of improvement. Currently, the emissions are determined using internal distribution keys based on Service Level Agreements. This way of distribution is too vague to see potentials in optimisation.

Moreover, it is recommended to a carrier as PostNL to upgrade more of their nodes to hubs where transhipment is possible. In this way, the network is more open and so more paths possibilities arise which have a positive effect with regard to CO_2 reduction. Besides, multiple allocation of the current network should be applied more. Nodes should produce as well as attracts demand. In this way, empty trips are avoided and the fleet is allocated more efficiently. For PostNL, a place like Dordrecht should be avoided because it only attracts demand.

Besides network design, reduction in terms of CO_2 could also be accelerated by applying double deck trailers or volume based pricing. This last mentioned suggestion is focused on the supporting of volume reduction. However, it is expected that this measure will have a negative effect regarding PostNL's position in the market. A certain measure should be suggested by interests groups like Lean & Green or Topsector Logistiek. Nevertheless, this and other effects of volume based pricing are not taken into account in this report.

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Abbreviations & Definitions

Abbreviations

Acronym	Definition
B2B	Business to Business
B2C	Business to Consumer
Benelux	Belgium, Netherlands, Luxembourg
C2X	Consumer to Business or Consumer
DHL	Adrian Dalsey, Larry Hillblom and Robert Lynn
DPD	Dynamic Parcel Distribution
EU-28	The 28 Members of the European Union
GHG	Greenhouse Gas
GLS	General Logistics System
HHI	Herfindahl-Hirschman Index
HR	Heavy Road
IEA	International Energy Agency
IoT	Internet Of Things
IPCC	Intergovernmental Panel on Climate Change
LR	Light Road
PI	Physical Internet
PUP	Pick-Up-Point
RC	Roll Cage
SBA	Sectoral Based Approach
SBT	Science Based Target
TTW	Tank to Wheels
UPS	United Parcel Service
vkm	Vehicle Kilometre
WTT	Well to Tank
WTW	Well to Wheels

Depot locations

Location	Acronym
Amersfoort	AMF
Born	BORN
Breda	BD
Den-Bosch	HT
Den Hoorn	HBD
Elst	ELT
Goes	GS
Halfweg	HW
Hengelo	HGL
Kolham	KHM
Leeuwarden	LW
Nieuwegein	NIWG
Opmeer	OPM
Ridderkerk	RD
Sassenheim	SSH
Son	SON
Utrecht	UT
Waddinxveen	WVN
Zwolle	ZWL
Dordrecht	DOR

Definitions

Definition	Interpretation
Carrier	Performer of the shipper's demand transportation between origin and destination (Maknoon, 2017)
Depot	A node in the intern transport network of PostNL defined as spoke
Depot+	A node in the intern transport network of PostNL defined as hub
Path	A subsequent of routes/arc and terminals (Van Riessen et al., 2013)
Shipper	Generator of freight transportation demand between from origin to destination (Maknoon, 2017)
Route	Synonym for arc and is defined as a connection between two nodes
Trip	Realised ride from one node to another node

I

Define

1

Introduction

This chapter introduces the run-up to this report as structured in figure 1.1. First, the research context in section 1.1 will be defined, in which the need for CO_2 reduction will be mentioned. Moreover, this section discusses the international and national allocation of CO_2 focused on the parcel delivery industry in the Netherlands. Besides, PostNL as market leader in the domestic transportation of parcels is introduced as a case study for this report. Next to an introduction of this company, their environmental impact and targets in line with the Paris agreement concerning climate change will be defined. A research problem and objective as focus of this report is defined in section 1.3 and 1.4. Further, section 1.5 shows which parts of PostNL's business are taken in to account in this report. After the research question in section 1.6, the used methodology is defined in section 1.7 including the structure of this report. This chapter will conclude by defining the scientific relevance in section 1.8.

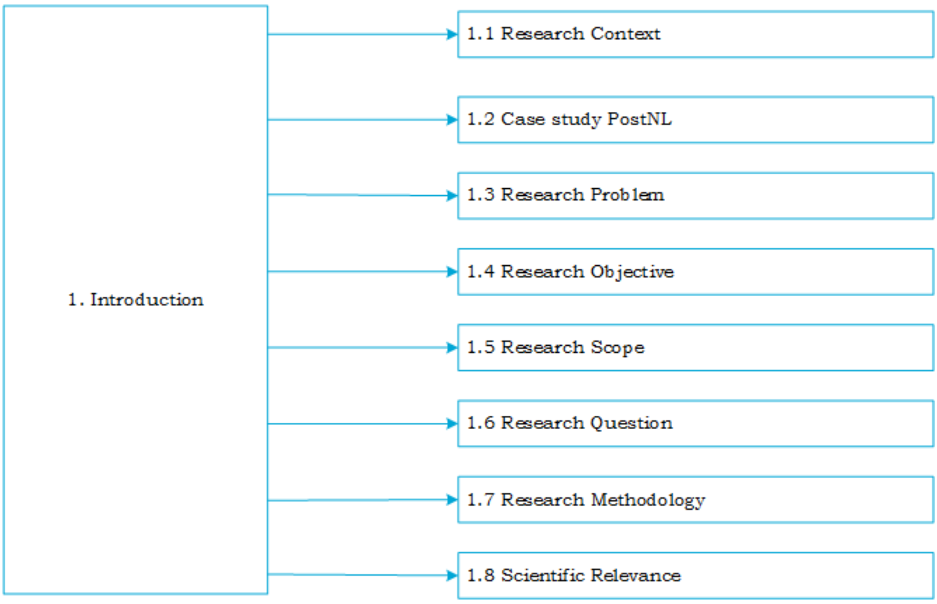

Figure 1.1: Structural overview of chapter 1

1.1. Research Context

The 21st Climate Change Conference in 2015 created a turning point in the approach of CO_2 emissions. ‘The agreement of Paris’, signed by 197 [1] member states of the United Nations, state that the temperature on earth may not increase more than 2.0 Celsius degrees, seeking to an increase of 1.5 Celsius degrees, relative to the pre-industrial age to reduce the effects of global warming (J.P.M. Ros et al., 2016). One of the main heat-trapping greenhouse gasses is carbon dioxide (CO_2) which is, inter alia, released through human activities as burning fossil fuels (Schmidt et al., 2010). As figure 1.2 shows, there is a clear relation between emissions of CO_2 and increase in temperature (Rogelj et al., 2015). The 2.0 as well as the 1.5 Celsius degrees scenario shows that a significant reduction in CO_2 is necessary to deviate from the ‘the business as usual’scenario. An agreement as signed in Paris asks for action to reverse the rising in temperature.

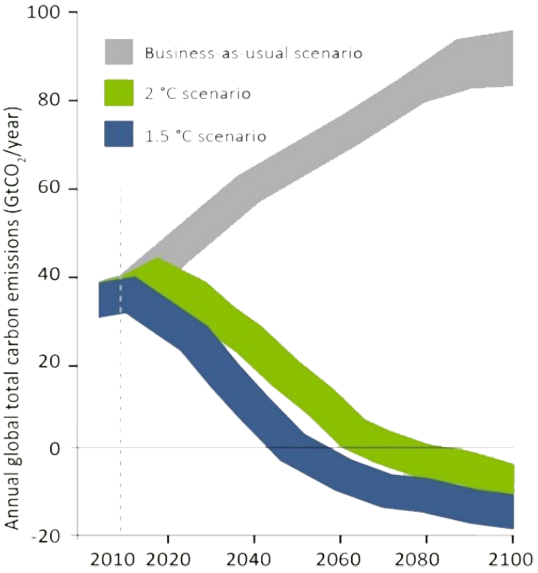

Figure 1.2: Total emitted $GtCO_2$ globally for different scenarios per year (Rogelj et al., 2015)

To get a better picture of the contributors of CO_2 emissions globally, the following relevant facts are outlined:

- China (30%), United States of America (14%) and the European Union [2](9%) were responsible for more than half of the emitted CO_2 emissions globally in 2015 (European Commission, 2015)
- The Netherlands were responsible for 0-1% globally emitted emissions. Concerning the European emissions, The Netherlands were responsible for 5% in 2015 (European Commission, 2015)
- Road transportation was in 2015 responsible for 18% of the global emitted emissions due to fuel combustion. Other ways of transport contribute with 6 % of the emitted CO_2 globally (International Energy Agency, 2017)
- In Europe, road transportation emitted 27% CO_2 of Europeans total. Other modes of transport were responsible for 1% (International Energy Agency, 2017)

Although the Netherlands seems to be a small player relative to other countries with ’only’ 0-1% of the total emitted CO_2 globally, measures by government, companies and people are necessary to meet the requirements of the agreement of Paris. Allocation of CO_2 emissions based on sectors in the Netherlands, as shown in figure 1.3, shows that sectors with regard to energy production, industry and transport & storage [3]are responsible for more than half of the Dutch emitted CO_2 contribution. Concerning the transportation & storage sector, CBS (2017) shows that this sector is responsible for 14 % of the total emitted CO_2 emissions in the Netherlands relative to other sectors.

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[1] April 2018: 175 Parties have ratified of the 197 Parties to the convention (United Nations, 2018)

[2] EU-28

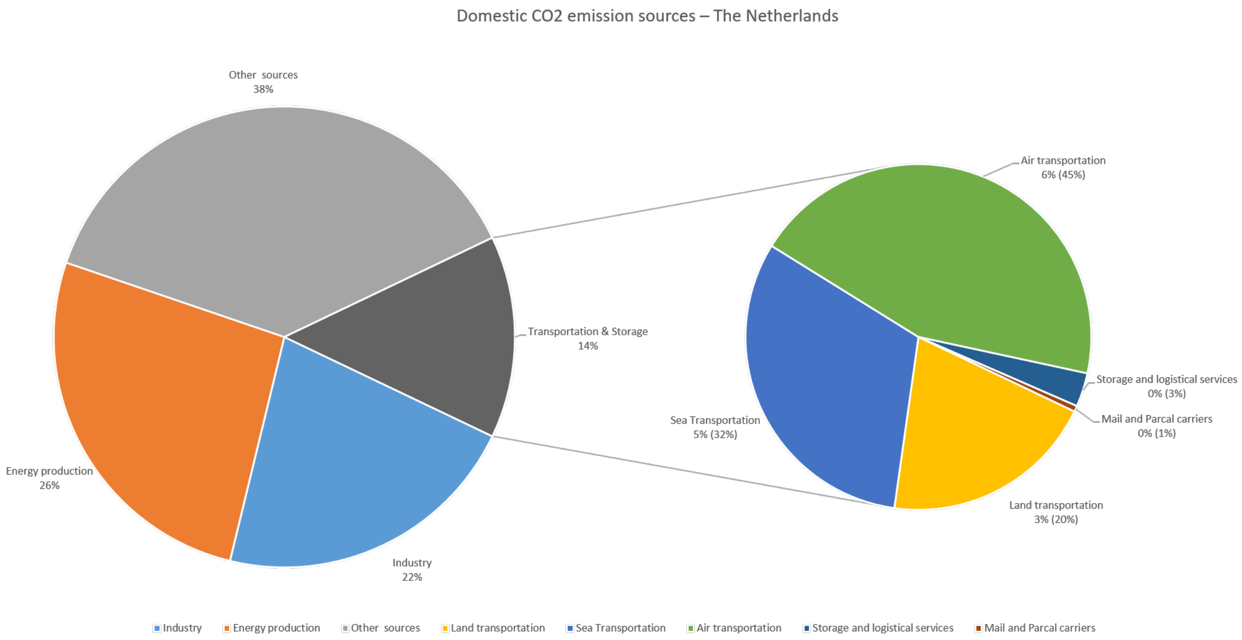

Figure 1.3: An overview of sectors that together contributed to over 50% of the total CO_2 emissions in the Netherlands in 2016 (CBS, 2017). The sub chart shows the CO_2 of different contributors with regard to Transportation & Storage [3] , in which the value between the brackets shows the contribution relative to other Transportation & Storage contributors.

Research by den Boer et al. (2017) shows that the transportation and mobility sector [3] in the Netherlands have to reduce their total amount of emitted CO_2 with 60% in 2050 relative to 1990. The challenge of this reduction is accompanied by the enormous growth in demand. Besides the increase in emissions, den Boer et al. (2017) conclude that the demand for transportation increased with 90% in 2015 relative to the base year 1990. A continuous economic growth will lead to a continued increase in freight transport demand and so result in more emission of CO_2. Topsector Logistiek, Lean & Green and Connekt as interests organisation bundled together and came up with the plan called 'Factor 6'. This plan has the objective to achieve a logistical future where the transport demand, in general, is 2.5 times higher against 2.5 times less emissions. One of the industries that deals with this plan is the parcel delivery industry in the Netherlands.

In 2011, a new logistical concept was introduced to meet the challenge with regard to the sustainability of logistics, called 'Physical Internet' (Montreuil, 2011). This vision characterises thirteen factors which should result in an efficient and sustainable way of object transportation globally. This research report will show different potentials of Physical Internet logistics for a company in the parcel delivery industry focused on a case study at PostNL, a parcel delivery carrier in the Benelux.

1.2. Case study PostNL

PostNL is a leading service provider concerning the domestically parcel transportation in the Netherlands with 60-65% market share in 2016 (Authority for Consumer & Market, 2017). As figure 1.4 outlines, PostNL was responsible for the transportation of 202 million parcels in 2017, a volume growth of 17.2% relative to 2016 (PostNL, 2017). Besides economies of scale of their capillary network, favourable tax treatment [4] for a certain part of the demand (around 2%) has been beneficial for PostNL with regard to their market position (Authority for Consumer & Market, 2016). Besides parcels, PostNL is active in other fields as PostNL mail in the Netherlands, as Spring in cross border solutions to and from Europe, as Naxive mail provider in Italy and as Postcon delivery in Germany. With the collection, sorting and distribution of mail and parcels every day, it is the core business of PostNL to connect millions of people. However, this value-creating process by connecting people also has a downside regarding their environmental impact.

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[3] Transportation & storage sector consists of 1) the transportation of persons and goods by air, rail, road, water or pipeline, 2) Supporting activities as storage, 3) Mail and parcel services, 4) Rental services of transport modes

[4] Due to European regulations, PostNL is excluded for VAT on parcel deliveries which can be included with universal mail service

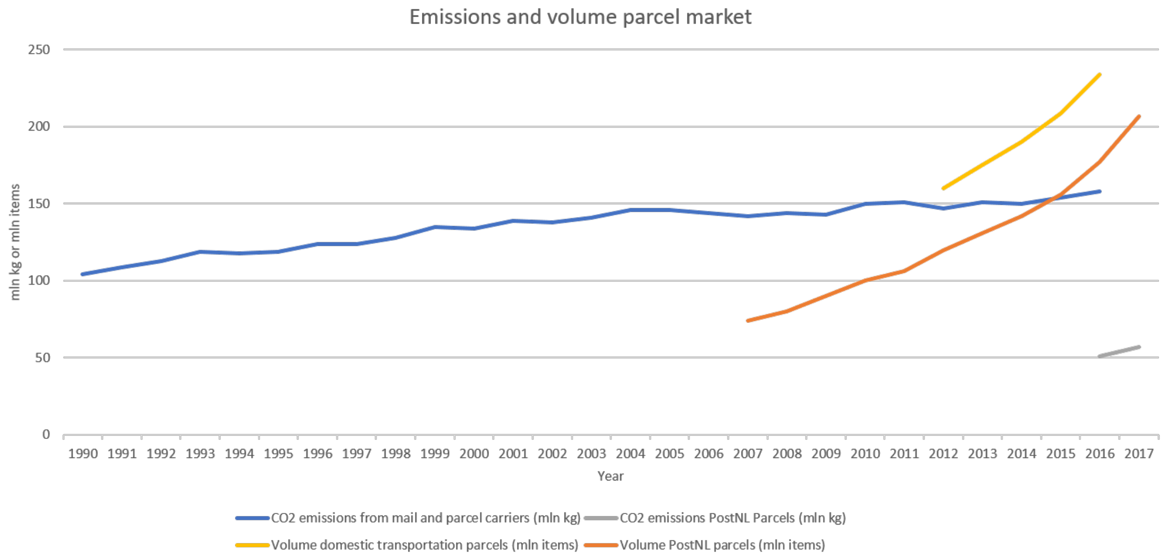

Figure 1.4: An overview of the CO_2 emissions emitted between 1990 and 2016 related to transportation of Mail & Parcels market (CBS, 2017) and concerning PostNL (2017). Also the development in volume of the parcel transportation market (Authority for Consumer & Market, 2017) as well as PostNL (PostNL, 2017) are shown

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Providing a parcel delivery service as PostNL does, has its impact on the environment with regard to CO_2 emissions. Although figure 1.3 shows that mail & parcel delivery contributes to 'only' 1% of the total transportation & storage emissions in the Netherlands, PostNL has the ambition to do something with regard to CO_2 reduction for a couple of reasons. First of all, it is a moral duty for every company to reduce their CO_2 footprint as much as possible. Secondly, because environmental friendly deliveries get a ton of good press. Every day, vans of PostNL are driving in the streets to distribute parcels in the neighbourhoods noted by customers and other public. Since delivery vans are dealing with a negative image concerning their emissions, PostNL has to do as much as possible to improve that reputation. For these reasons, PostNL sets their ambition to become a CO_2 neutral company [5] by 2030, which brings a lot of challenges on different levels. Besides, contributing the reduction of CO_2 as agreed in the 'Factor 6'plan asks for action by PostNL. Ecofys, a consulting company which is specialised in energy, made some calculations of the current CO_2 emission of PostNL as well as CO_2 reduction targets in line with the agreement of Paris (van de Brug et al., 2018). To set up certain targets as Ecofys did, different methods can be used to set up a science based target: Absolute approach, GEVA methodology or Sectoral Decarbonization Approach (SDA) as outlined in Appendix A. For PostNL, the most interesting method is the SDA since this method takes the differences in CO_2 reduction potential between industries or sectors into account. The main advantage is that targets that are set for a specific sector aimed to be realistic for that sector. Moreover, the method considers the growth potential in time of the sector. In this way, the goals become more realistic and provide insight into potential saving areas. Calculations by Ecofys made clear that PostNL was responsible for 313,362 tCO_2 distributed over the different divisions Mail, Parcel, Germany, Italy and Spring as shown in figure 1.5 (van de Brug et al., 2018). The reason why the division 'Spring' was responsible for the largest part of PostNL's emitted emissions, has something to do with its type and category. For the calculation of the current and the target situation, there are three types of emission data collected for different categories: Scope 1, Scope 2 and Scope 3. The first type, scope 1, concerns emissions from sources that are owned and controlled by an organisation like company-owned vehicles or facilities. Scope 2 are emissions from the consumption of purchased electricity, steam or other sources of energy generated upstream from an organisation. Finally scope 3, which are emissions emitted by outsourced processes and not being controlled by PostNL. An example of those are emissions by third-parties regarding distribution and logistics, production of purchased goods or emission from sold goods. In the case of PostNL, the emissions of scope 1 and 2 are mainly based on fuel consumption tank to wheel (TTW) of the fleet and energy consumption for operating buildings. However, since there are also emissions emitted concerning the production and transportation of fuel called Well-to-Tank (WTT), a correlation factor of 18%

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[5] Net zero carbon footprint: Energy use that neither contribute to nor reduce the amount of carbon into the atmosphere. This can be accomplished by saving energy, using sustainable energy or compensate the emission of CO_2 by buying Gold Standard credits

was used by van de Brug et al. (2018) to upscale TTW emissions to Well-to-Wheel (WTW) [6]. With regard to scope 3, a lot of estimations are made to create a rough idea of their environmental impact. The main reason why estimations are used instead of detailed information is the fact that subcontractors of scope 3 are not willing to share data concerning their environmental impact. Those estimations are mainly based on own experience and calculations of PostNL in combination with the expertise of Ecofys. For Spring, the largest part of figure 1.5, a lot of outsourced transportation by plane (scope 3) provides that Spring is responsible for the most emission in absolute terms. Since this report is focused on parcel logistics of PostNL, figure 1.5 shows in a more detail way how the emitted emissions of PostNL parcels distributed in relation to other divisions.

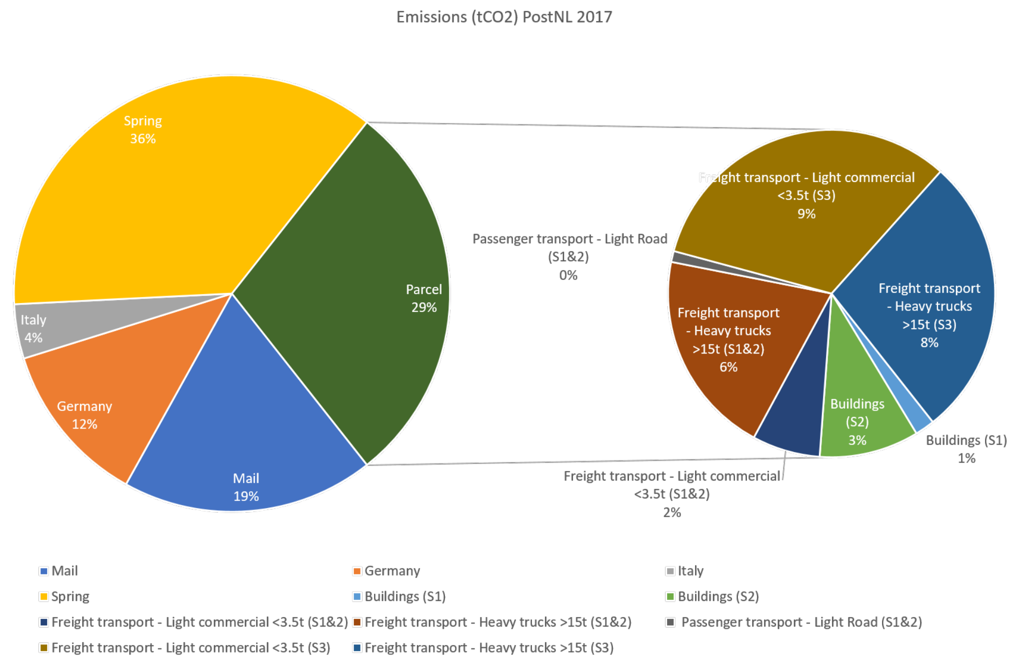

Figure 1.5: Distribution of emissions in 2017 over the different divisions Mail, Parcel, Germany, Italy and Spring based on table A.1 of Appendix A. Concerning parcels, a detailed representation is shown to outline the different sources. S1 = scope 1, S2 = Scope 2 and S3 = Scope 3

Parcels, which are in second place of figure 1.5 and the focus of this research, are responsible for 29% of the total emitted CO_2 emissions. Van de Brug et al. (2018) calculated in more detail the current emissions and targets for 2030 and 2050 with regard to different categories and scopes concerning the division parcels. Those results are outlined in detail in table 1.1 as well as table 1.2, whereby the used percentage shows the differences relative to the base year 2017. A short-term target (2023) is presented based upon a linear assumption in emission and growth between the current state in 2017 and the target 2030 (den Boer et al., 2017). For the calculation of prospective targets as shown in table 1.1 and table 1.2, Ecofys make use of growth rates per activity. For this study, the expected growth scenario is used in which ‘buildings’are related to the activity ‘m^2 ’and ‘transportation’related to the activity ‘ton.kilometre ’. Ecofys concludes in their report that the expected growth scenario of transportation expressed in ton.kilometres will be +8%. With regard to buildings, a growth of 5% expressed in m^2 is expected (van de Brug et al., 2018). By using SDA, which takes inherent differences among sectors such as mitigation potential and how fast each sector can grow relative into account, in combination with the given annual activity growth rate result in mainly increasing target of emissions in absolute terms for PostNL parcel (table 1.1). As can be concluded from table 1.1 and table 1.2, there are some differences between absolute emissions results versus emissions intensity. As previously mentioned, absolute emissions of table 1.1 are allowed to increase while table 1.2 shows that the amount of CO_2 emissions should reduce per activity unit over the years.

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[6] Appendix C shows the difference in emissions due to the combustion of fuel in relation to WTW

Table 1.1: Absolute targets in gross emissions for PostNL Parcels. The percentages are relative to base year 2017. A growth rate as shown in table 1.2 is used to calculate future targets

SDA	Scope	2017 (tCO_2)	2023 (tCO_2)	2030 (tCO_2)	2050 (tCO_2)
Buildings	Scope 1&2	10,626	12,954 (22%)	15,670 (32%)	35,448 (234%)
Own freight transport	Scope 1&2	24,251	27,109 (12%)	30,444 (20%)	70,000 (189%)
Own passenger transport	Scope 1&2	976	850 (-13%)	704 (-39%)	265 (-73%)
Subtotal Scope 1&2	Scope 1&2	35,853	40,914 (14%)	46,818 (23%)	105,713 (195%)
Outsourced freight transport	Scope 3	54,191	55,780 (3%)	57,634 (6%)	110,181 (103%)
Total	Scope 1,2,3	90,044	96,694 (7%)	104,452 (14%)	215,894 (140%)

Table 1.2: Transport intensity targets for PostNL Parcels relative to base year 2017, defined by van de Brug et al. (2018). The given growth rate is based on the expected scenario concerning the division parcels.

SDA	Scope	Growth rate	2017	2023	2030	2050
Buildings	Scope 1&2 (gCO_2/m^2)	5%	42,212	33.236 (-21%)	22.765 (-46%)	10.957 (-74%)
Light commercial	Scope 1&2 (gCO_2/t.km)	8%	1,159	787 (-32%)	354 (-69%)	104 (-91%)
Heavy trucks			103	80 (-22%)	53 (-49%)	28 (-73%)
Passenger transport	Scope 1&2 (gCO_2/p.km)	8%	164	143 (-13%)	119 (-27%)	45 (-73%)
Light commercial	Scope 3 (gCO_2/t.km)	8%	1,653	1107 (-33%)	471 (-72%)	104 (-94%)
Heavy trucks			103	79 (-23%)	52 (-50%)	28 (-73%)

It is important to take in mind that both quantifications are not comparable with each other, in particular not to conclude a better or worse performance. For example, a certain company x is responsible for a million ton of CO_2. Five years later, the emission of CO_2 doubled to two million ton. This means that the absolute emissions also doubled from 1 to 2 million. However, if also the production of a company doubled, the emission intensity stays the same. With the scenario where the production quadrupled, the emission intensity was cut in half and the production got more CO_2 efficient relative to its base year.

1.3. Research Problem

Pressure from governments, by signing the climate change agreement of Paris, or from society asks for action to reduce the environmental impact for all kind of companies. Also, the transportation sector including the growing parcel delivery sector has to start looking for new and innovative ways of setting up their business to reduce the emitted amount of CO_2. This argumentation holds for our case study at PostNL. Due to increasing competition in the parcel delivery market and a downward trend in the distribution of mail, the sky is not the limit to do things based on trial-and-error at PostNL. Moreover, the increasing market of the parcel industry in volume makes it difficult to set up a logistical process in an efficient way with regard to CO_2 reduction. To take the first step towards the target 2030, improvement of the current situation on a short-term should be introduced where also volume growth is taken into account.

1.4. Research Objective

Focused on a case study at PostNL, the objective of this research is to present CO_2 reduction related potentials for a company in the parcel delivery industry by using the characteristics of Physical Internet logistics. This vision, as explained in chapter 3, is a very promising ideology to meet the challenges concerning sustainability. The characteristics of Physical Internet logistics will be addressed to a service network design in the parcel delivery industry. In this way, reduction related potentials will be shown concerning a network design by making use of a decision model. Those models, are focused on the study of decision problems given a certain configuration expressed in parameters, variables and objective (Zhang et al., 2015). For the case at PostNL, this report comes up with a service network design based on Physical Internet's characteristics with the objective to minimise the total amount of emitted CO_2 per day.

1.5. Research Scope

A logistical process concerning parcel delivery is quite complex due to its dynamic character in time. To determine the CO_2 reduction related potentials of Physical Internet Logistics in the parcel delivery industry, this report is only focused on some elements of the logistical process. First of all, this report takes only the transportation of parcels collected, sorted and distributed in the Netherlands into account. Mail, international transport and transport by affiliated companies are out of scope. Otherwise, an optimisation would be too complex and far from reality. Concerning the different performed services by the division of parcels at PostNL, not all the parcel services will be included. Only the main parcel stream including evening delivery, which is the largest stream of goods, will be taken into account. Special parcel services as, 'delivery in a certain time window', 'same day delivery', 'Sunday delivery'or 'fresh food delivery 'will be out of scope because of its complexity and low value in items relative to the main parcel stream. As mentioned before, the vision of Physical Internet will be a guideline through this report. However, this vision is only applied to transportation by heavy trucks between hubs (depots+) and spokes (depots), also called intern transport. This report assumes that parcels are already collected at a certain depot with an intended destination depot. The process of collection or distribution in a certain region is out of scope because of its complexity of different suppliers and customers. Also, the logistical process in this report will only be based on own freight transport modes (scope 1&2). Outsourced transportation (scope 3) is not taken into account during measurement/analysis. The main reason is the lack of data supplied by third parties. It is assumed that outsourced transportation performed by third parties will be done under the same conditions as transportation by own trucks. This report is mainly focused on designing a service network with the objective to reduce the emitted amount of CO_2, involving an optimisation model. By combining the given input, this optimisation model tries to come up with the optimal set of decision variables. Costs of operating a certain service network are not taken into account. Simulation, as defined by Marie (1997), will be done in a static and deterministic way using a spreadsheet. The only output of simulation is the estimated amount of emitted CO_2 concerning a certain set of decision variables. A run pilot or simulation in real life will be out of the scope of this report. Finally, the reduction may only be based on saving energy or using sustainable energy. Compensation of CO_2 by buying carbon credits is out of scope.

1.6. Research Question

This section will define the main research question and several sub-questions related to the proposed research.

Main Question

Based on the research problem discussed in section 1.3, the research question will be as follow:

How should the parcel delivery industry arrange their network to decrease the absolute amount of CO_2 emissions?

Sub Questions

The main research question as outlined in this chapter forms the conclusion of several sub-question. The sub-questions are summed up below and have a clear link with the report methodology showed in figure 1.6. Since this report makes use of a case study at PostNL, the sub-questions are also related to this case study.

1. How is the parcel delivery market dealing with the environmental impact of their business?
2. What does the current logistical process of domestically parcel distribution at PostNL look like?
3. What are the main characteristics of Physical Internet Logistics with regard to the case study at PostNL?
4. How does the current process of parcels at Post NL perform concerning their intended network design?
5. What is the potential of the suggested implementation?

1.7. Research Methodology

Approaching a complex research as discussed in this chapter, asks for a clear and structured methodology. Lean Six Sigma, a management strategy with different methodologies to improve the current state, could bring a suitable method for this research. This strategy combines Lean, which is focused on the reduction of waste of time and materials (Womack et al., 1990; Womack and Jones, 1996), with Six Sigma which is focused on the improvement of the quality of the current process (Dahlgaard et al., 2006). A commonly used methodology derived from this strategy is DMAIC (**D**efine, **M**easure, **A**nalyse, **I**mprove and **C**ontrol) or DMADV (**D**efine, **M**easure, **A**nalyse, **D**esign and **V**erify) (Pyzdek and Keller, 2014). The difference between both methods is mainly based on their goals. DMAIC is focused on improving a current process while DMADV is specialised in setting up a new process. Although this report is focused on the design of a Physical Internet based service network by making use of a case study at PostNL, DMADV will be more suitable than DMAIC. The main reason is that DMADV is focused on a new design and its verification, while DMAIC has its focus on improvement, but most of all, on controlling. This report presents the potential of a Physical Internet Logistics based service network design between hubs and spokes in terms of CO_2 compared to the current state. Verification of the new design plays an important role to make substantiated statements. However, an adaption of the given DMADV method is needed to create a better fit for this research. In the given DMADV methodology, the verification phase the design's effectiveness will be tested in the real world. In this way, it is assured that the design actually procedures the predicted results (Pyzdek and Keller, 2014). However, because a pilot run in the real world will be out of scope, this report will only verify the decision model that is used during design. This model is developed and applied based on the different steps as defined by Duinkerken (2016b). First, the model is defined and data is collected. Further, a mathematical model is constructed of the problem. Thirdly, the mathematical model is solved whereafter it will be tested. Finally, the model will be applied and used. Figure 1.6 shows the outline of DMADV specified for this research report.

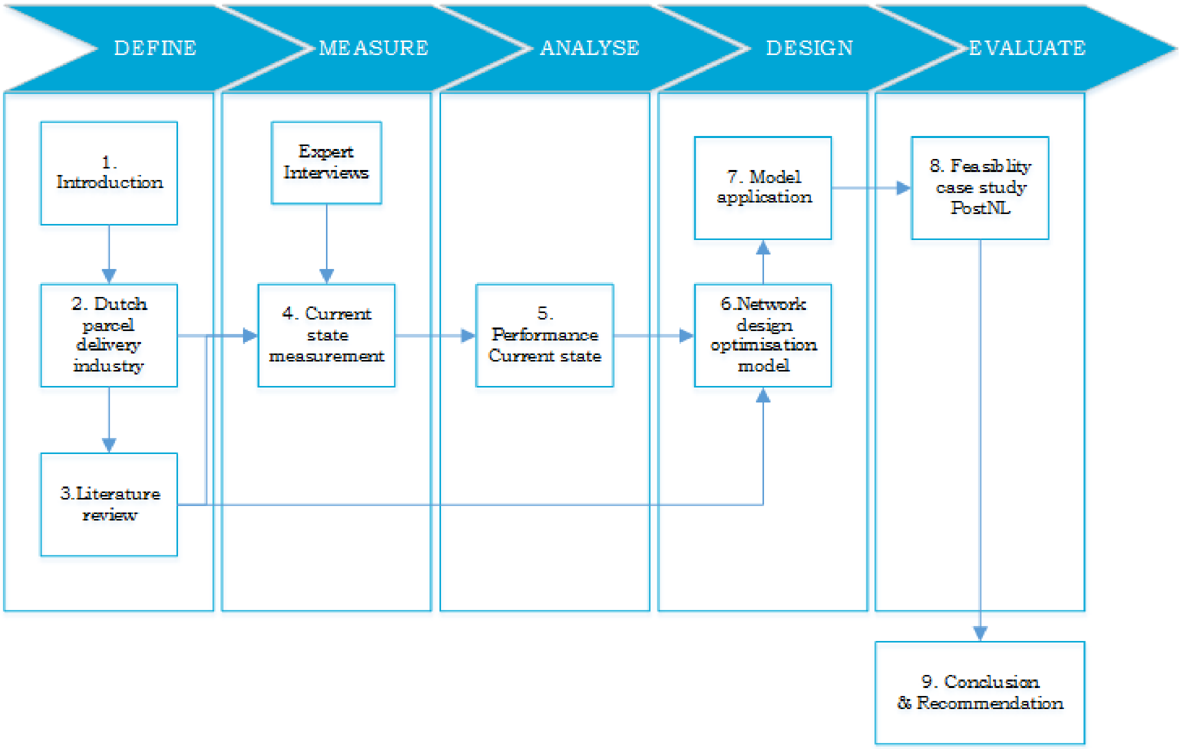

Figure 1.6: Schematic overview of the used method based on DMADV

Research structure

PART I: Define

This part of the research will be focused on defining the problem and the focus of this report. Chapter 1 gives an overview of the context, problem, scope and objectives, in which the contours become clear to shape the research. Section 2.1 will define how PostNL acts in relation to relevant competitors. In addition, measures related to CO_2 reduction in the parcel delivery industry will be discussed taken by competitors of PostNL. Further, chapter 2 defines the current process of PostNL's parcel logistics in section 2.2 to outline the profile for measurements and model development (Duinkerken, 2016a). Finally, chapter 3 discusses scientific related literature about transportation factors related to CO_2. Moreover, the vision of Physical Internet will be discussed which is a guideline through this report as mentioned before. Chapter 3 concludes with research concerning an optimisation model for designing a Physical Internet based network.

Related chapters: 1, 2, 3

PART II: Measure

After defining the problem, environment and literature in PART I, measurements should be taken of the current process to set the current state of the intended process. This phase will show all kind of measurements which are related to the transportation of parcels between hubs and spokes. Data will be collected with regard to the mathematical model (Duinkerken, 2016b).

Related chapters: 4

Related tools: Data collection, SIPOC diagram

PART III: Analyse

This phase analyses the current performance as measured in part II. The characteristics will be identified that are critical to the process and related to the emission of CO_2. With the knowledge of the performance of the current logistical process, a reference is created to compare with a Physical Internet based network.

Related chapters: 5

Related Tools: Data analysis with excel

PART IV: Design

Literature, expert interviews and authors' knowledge will be used to create a network design relating to the vision of Physical Internet Logistics. This report makes use of a service network design model to determine the effects of a Physical Internet based network. Although it is known that a model can be defined as a simplification of the reality and thus will not give the same results as the real performance, it could be useful to promote the understanding of the vision. As defined by Marie (1997), "A model is to enable the analyst to predict the effect of changes to the system". The service network design as introduced in this report will be based on an optimisation model, as mentioned in section 1.4. After model designing, the model will be tested, verified and validated. Further, the designed model will be used to deal with the research question as defined in chapter 1.

Related chapters: 6 and 7

Related Tools: Mathematical optimisation by using CPLEX as solver

PART V: Evaluate

In this phase, design effects will be translated into implementation measures. In this way, conclusions can be made to say more about reduction potentials related to a case study at PostNL. The evaluation phase ends with the conclusion, recommendation and discussion.

Related chapters: 8 and 9

1.8. Scientific Relevance

As discussed in chapter 3, a lot of factors are related to the CO_2 impact of transportation. To the best of the authors' knowledge, most of the published research that concerns the reduction of CO_2 by transportation is focused on one aspect only. For example, research concerning vehicle routing problem is only based on the factors regarding 'Routing Related', research focused on a business' fleet, is mainly based on factors concerning 'Operations Related'. This research will be based on the vision of the 'Physical Internet Logistics'. This vision, which will be explained in chapter 3, combines the aspects Driver, Operations, Routing and Modality related optimisation. A lot of research is already done according to this vision and its key characteristics. However, a case study in the parcel carrier industry by using the vision of Physical Internet has never been done. This paper will fill this research gap by using a couple of key characteristics during a case study of PostNL. The reason why a case study at PostNL is chosen is because the parcel carrier industry is growing with enormous steps while the pressure to reduce their footprint also increases. A case study at a carrier acting in such an industry will be interesting to see what the effects of physical internet based measures could be to reduce the environmental impact.

2

Parcel delivery industry in the Netherlands

This chapter discusses the environment of this research as structured in figure 2.1. First, the parcel delivery industry in the Netherlands will be defined in section 2.1 in order to get a better understanding of the industry and its size. The focus of this section is on PostNL and their performance relative to the market. This section concludes with the ways in which competitors of PostNL are dealing with the environmental impact of their business. The second section of this chapter, section 2.2, defines the current process of parcel logistics originating from and intended for an address in the Netherlands. This section forms an important starting point for the next phase PART II. The sub-questions which are central to this chapter will be as follow:

SQ1: How is the parcel delivery market dealing with the environmental impact of their business?
SQ2: What does the current logistical process of parcels at PostNL look like?

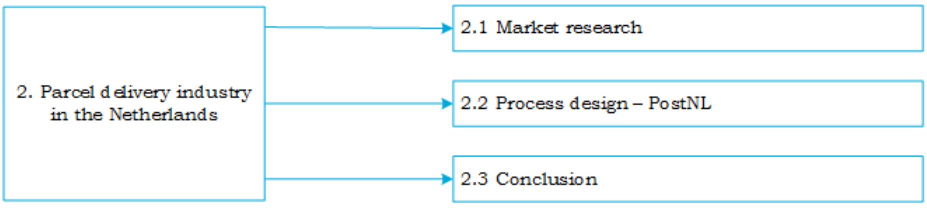

Figure 2.1: Structural overview of chapter 2

2.1. Market research

A lot of different delivery vans colour the streets every day. Ever since online shopping became a thing that consumers would do without a second thought, (parcel) carriers have been rushing across Dutch streets to deliver all those parcels. In 2016, the Authority Consumer & Market, an independent monitor on behalf of consumers and companies, did some research on the Dutch parcel transportation market and its development. On the basis of this research, it became clear that the accelerating e-commerce led to a shift in shopping behaviour from offline to online, was a cause of an increasing pressure on the performances of parcel carriers as shown in a volume growth in figure 2.2. In addition to this development, globalisation and digitisation the international transported volume increased over those years (Clausen et al., 2013).

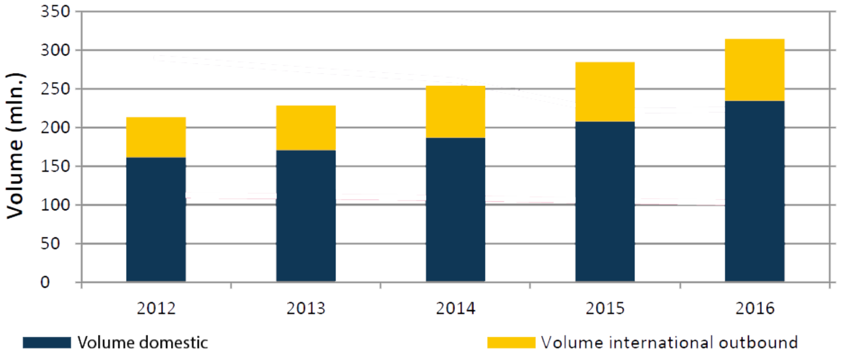

Figure 2.2: Development of the Dutch parcel transportation market from 2012 to 2016 (Authority for Consumer & Market, 2017)

In 2016, 350 million parcels in total were transported in B2B, B2C and C2X with a turnover of 1.8 billion euro. Of this total, 234 million parcels were transported domestically of which 80% was delivered within one working day. These parcels have their origin as well as their destination located in the Netherlands. The remaining 116 million parcels consist of international outbound parcels, which are parcels with an international destination and Dutch origin, and international inbound parcels, which are parcels with an international origin and but a destination in the Netherlands. 90% of the parcels that had its destination in the Netherlands were delivered at the given address, compared to 10% at pick up points.

2.1.1. Main parcel carriers

Nowadays there are a lot of providers for someone that wants to send a parcel in, to or from the Netherlands. Research by the Authority for Consumer & Market (2017), concludes that there are six main carriers active on the parcel transportation market in the Netherlands: DHL, DPD, GLS, PostNL, TNT [1]and UPS. The most important characteristics of these carriers relative to each other are outlined in table 2.1. PostNL is the smallest company in terms of revenue related to parcel transportation relative to its competitors. The main reason is that the market focus of PostNL parcels only concerns the Benelux. However, PostNL is also active outside of the Benelux through different companies. This is briefly discussed in section 1.3 but will be out of the scope of this research.

Table 2.1: Characteristics of the six most important parcel carriers for the Netherlands according to the Authority for Consumer & Market (2017). FedEx is mentioned in the same column as TNT since FedEx acquired TNT in May 2016.

Carrier	Deutsche post DHL Group [2]	DPD [3]	GLS [4]	PostNL (Parcels) [5]	TNT [6] (FedEX) [7]	UPS [8]
Market focus	Global	Europe	Europe	Benelux [9]	Global	Global
Market share globally [10]	38%	-%	-%	-%	5% (29%)	22%
Market share domestically transport NL [11]	25-30%	5-10%	5-10%	60-65%	-%	-%
Market share international transport to/from NL [11]	10-15%	25-30%	5-10%	15-20%	0-5%	30-35%
Employees [#]	519,544	38,000	17,000	44,263 (4,136)	15,239 (400,000)	434,000
Revenue [€m]	60,444	6,800	2,500	3,495 (1,100)	6,914 (60,319)	60,906

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[1] FedEx acquired TNT in May 2016

[2] Annual Report Deutsche Post DHL Group (2017)

Research by the Authority for Consumer & Market (2017) shows that the domestic and international transportation market in the Netherlands is divided as presented in figure 2.3. PostNL is the market leader with 60-65% of the total transported volume followed by DHL with 25-30%. For international transport, inbound and outbound, the tables are turned. PostNL is the third carrier with 15-20% of international transported volumes, mainly performed by partners when the origin/destination is outside the Benelux.

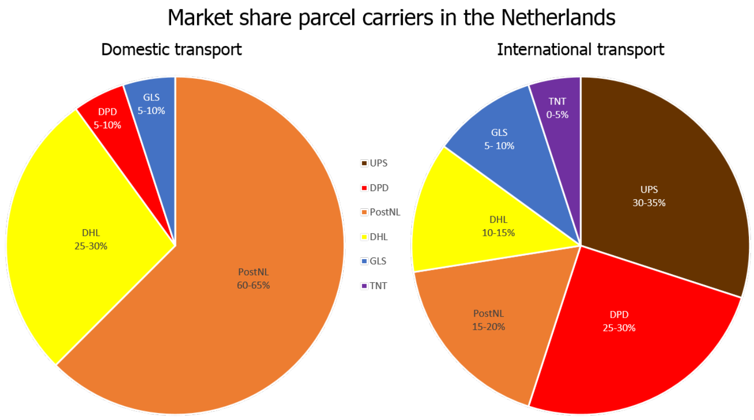

Figure 2.3: Market shares for parcel transportation carriers in the Netherlands for 2016 (Authority for Consumer & Market, 2017)

The difference between domestic logistics and international logistics is mainly on a network level. A domestic transport network is more intertwined relative to an international network. Although for both networks a design using hubs and spokes is not uncommon, a domestic network is characterised by operating on a lower and specified level. Distances between spokes are shorter and outlets are smaller. Going more into detail focused on the market, it can be concluded that the total parcel transportation market for domestic transportation is divided into 3 segments: B2B, B2C and C2X. Reason for this, according to the parcel carriers, is that for every segment the infrastructure is slightly different due to differences in service and demand size (Authority for Consumer & Market, 2016). For example, in the B2B segment deliveries are only made during office hours. Besides, demand is mainly transported by pallets or in large batches. For B2C, the time frame larger (extra in evening or weekends) and there are more delivery options (Pick-Up-Points at shops or machines). Moreover, parcels are transported as individual items and so bundled by roll cages. This means that infrastructure concerning collection, sorting and distribution is totally different from a operations perspective. In the case of the Netherlands, the B2B market is relatively small in market share (3%) relative to B2C (30%) and C2X (67%).

PostNL owns an efficient and high capacity network which creates a strong market position. In 2017, PostNL has around 4,000 parcel points in the Benelux of which 1,500 retail points in the Netherlands. The second largest carrier for domestic transport of parcels in terms of volume is DHL. Although this company has its focus on international transportation, they own 10 sorting facilities and have over 1,800 Pick-Up-Points in the Netherlands (DHL, 2017). Another parcel carrier in the Netherlands is DPD, a subsidiary of La Poste form France. DPD is focussed on the international transportation market with over 500 depots in 40 countries. When it comes to the Netherlands, DPD owns 9 depots in combination with over 750 service points (Verenging van Postale en Bancaire Retailers, 2017). GLS is a parcels carrier with 5-10% market share domestical as well as international transport. This company is a division of the British Royal Mail group and consists of the largest distribution network in Europe on the ground. For the Netherlands, GLS owns a distribution network with 15 regional depots and one central depot in Utrecht (Authority for Consumer & Market, 2016). Parcel carrier TNT, which was acquired by FedEx in 2016, can be seen as an express carrier instead of a parcel

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[3] Annual ReportDPDgroup (2017)
[4] Annual report GLS (2016)
[5] Annual Report PostNL (2017)
[6] Annual ReportTNT (2015)
[7] Annual Report FedEx (2017)
[8] Annual Report UPS (2016)
[9] Global transport through partners
[10] Statista (2017)
[11] Volume based, according to Authority for Consumer & Market (2017)

carrier. However, in 2016, 0-5% of the total international parcel volume was transported by the express carrier TNT for the Netherlands. In order to determine the competitiveness of the Dutch parcel carrier market concerning domestic transport, Authority for Consumer & Market (2017) used an HHI [12] as a measure of market concentration. The calculation concludes that the market was strongly concentrated with a score of 4,351.

2.1.2. CO_2 reduction goals and measures

Competitors of PostNL are also dealing with the environmental impact of their business. In particular DHL, who started a sustainability program called 'GoGreen', based on the burn less and burn clean principles to reduce all logistics-related emissions to zero by the year 2050, and with success (DHL, 2016). In 2016, DHL had improved their carbon efficiency by 30% relative to 2007. The focus of the 'Burn less' part will be on an optimised network, modernised fleet and energy efficient buildings. For 2025, DHL has the objective to operate 70% of their first and last mile with zero emission transport. The 'burn clean' part is concentrating on the use of alternative fuels, energy from renewable sources and the use of multimodal transport. By 2025, DHL wants more than 50% of their sales to incorporate green solutions. Besides the focus on technology and logistics, also employees of DHL have to be certified as 'GoGreen' specialists to think and act sustainably. Finally, DHL offers its 'GoGreen' program as a service. Shippers are able to send parcels environmental friendly and in a carbon-neutral way. DHL strives to emit as little CO_2 as possible and to compensate for the amount of carbon emissions that are produced by way of carbon credits. To set targets relative to their current impact, DHL used the Sectorial Decarbonization Approach based on science based targets which are also used by PostNL. Another method to compensate for the environmental impact is the way DPD do, which claims to have a 100% carbon neutral delivery[13]. This can be achieved by saving energy, using sustainable energy or compensating by taking an equal amount of existing CO_2 out of the atmosphere as is produced, for example by planting trees. Another way to compensate is by buying 'carbon credits'. By means of these credits, like Gold Standard credits or Verified Carbon Standard Credits, a company is able to support sustainable projects that reduce the existing amount of CO_2 in the atmosphere. A credit is equivalent to a certain amount of CO_2 for a certain price. According to DPD (2015), their 100% carbon neutral delivery is reached by the use of efficient routes, delivery at pick-up-points when the receiver is not home and the use alternative fuels, like CNG. These measures are focused on saving energy. The remaining CO_2 impact will be compensated by offsetting them via sustainable projects.

2.2. Process design - PostNL Parcels

This section will discuss the logistical process concerning parcels with its origin and destination in the Netherlands. First, the different locations of spokes and hubs will be discussed in combination with network structure as shown in figure 2.5. Secondly, the logistical process on network level will be outlined followed by subsection 2.2.3 which discusses the collection, sorting and distribution on a regional level. To define the process in this phase, it becomes clear what should be measured in the next phase.

2.2.1. Locations and network structure

The logistical process of collection, sorting and distribution takes place in a network consisting of 19 local regions divided over the Netherlands based on a web structured network design as shown in figure 2.4. This structure is based on several spokes and several hubs. However, every spoke is connected with every hub but every hub is not connected with every spoke. How this principle works, will be explained in subsection 2.2.2 by making use of figure 2.5. The reason why a web structure has been chosen in 2008 as opposed to the hub-spoke network as used before, is because of the following characteristics according to PostNL:

- Its scalability to handle volume growth
- Its flexibility to meet the e-commerce in demand
- Decrease in operational costs

The web structure of PostNL consists of 19 regions in which each region has its own regional depot to process parcels origination from or destined for that region. From those 19 regional depots, 4 depots will act as hub called depot+ to be the link with regional depots during distribution as explained in section 2.2.2.

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[12] HHI: Herfindahl-Hirsch Index is an index to measure the concentration of participants on a market and is calculated by the summation of squared market shares. 0 means a fully competitive market while an HHI of 10,000 means monopoly

[13] Carbon neutral means that the net carbon emission is zero

[13] depot is equivalent to a spoke in terms of PostNL

[13] depot+ is equivalent to a hub in terms of PostNL

Besides, there is one crossdock (Dordrecht) which has the same central hub characteristics as depot+ during parcel distribution without covering a certain region for regional collection/distribution. Table 2.2 shows the different central hub regions consisting of one depot+(+) or crossdock(x). Moreover, figure 2.5-1 shows the coverage of the 5 central hubs (depot+ or crossdock) regions in different shades of grey.

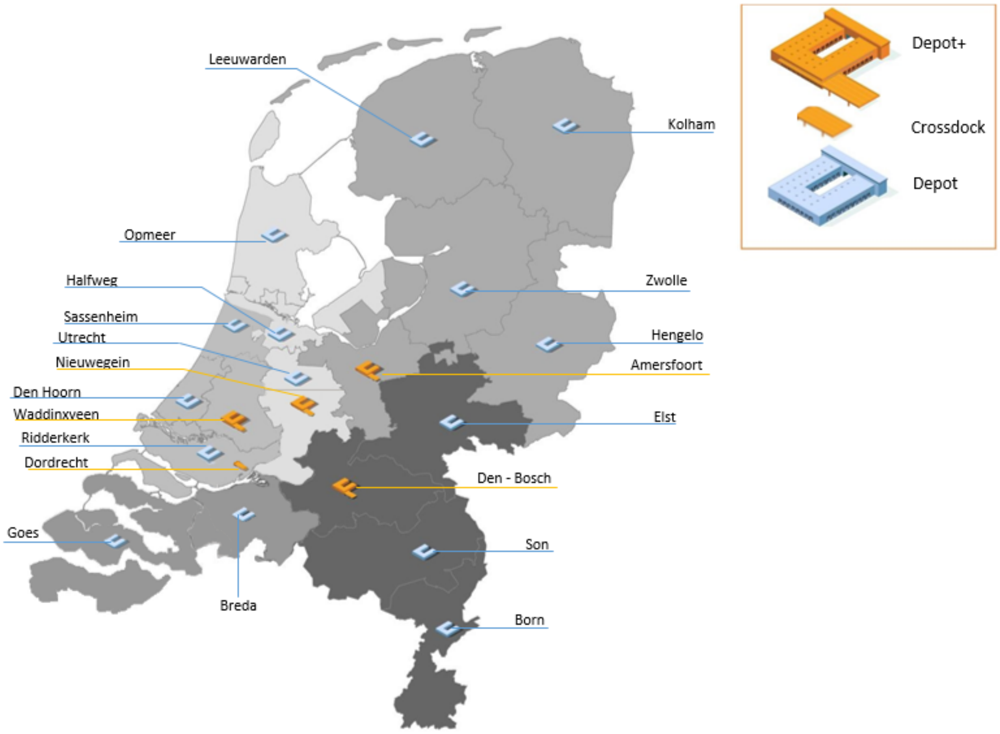


Figure 2.4: Topographical overview of the different depots, depots+ and crossdock in the Netherlands

Table 2.2: The different depot locations. Locations with + (depot+) or x (crossdock) will act as central hub.

Central hub region 1	Central hub region 2	Central hub region 3	Central hub region 4	Central hub region 5
Amersfoort(+)	Dordrecht(x)	Den-Bosch(+)	Nieuwegein(+)	Waddinxveen(+)
Hengelo	Breda	Born	Halfweg	Den Hoorn
Kolham	Goes	Elst	Opmeer	Ridderkerk
Leeuwarden	Belgium	Son	Utrecht	Sassenheim
Zwolle				

As shown in table 2.2 it can be concluded that there are currently 19 depots throughout the Netherlands with their own outlet . With regard to the network structure, every location from table 2.2 is connected with every depot+ from the first row. However, every depot+ from the first row is only connected with the other locations in that column. The only crossdock in the Netherlands, located near Dordrecht, is mainly focused on being the link with Belgium. As mentioned in section 1.5, this research is focused on domestic parcel logistics. However, a lot of transport towards Dordrecht is loaded with parcels intend for Belgium. To make sure that analysis in a further stage of this report is as close as possible to the reality, it is assumed that all the transportation intended for Belgium will be delivered at Dordrecht. How this will be transported further into Belgium from Dordrecht will be out of scope. In the coming 2 years, 11 new depots will be built, which 9 will be built in the Netherlands and 2 in Belgium, in order to make the network more robust in anticipation of the expected growth in demand of parcel transportation in the B2C market. Where in 2017 202 million parcels were transported by PostNL (PostNL, 2017), it is expected that by 2023 this volume will be between 431 million items (base scenario) and 617 million items (extreme scenario) according to the Commercial Strategy department of PostNL.

2.2.2. Logistical process on network level

The logistical process of parcel distribution across the Netherlands is performed by using a web structured network as illustrated in figure 2.5. As mentioned in section 1.5, only the main parcel stream will be discussed. Services as 'parcel delivery in a certain time window' will not be taken into account since they make use of another network. The process starts when the parcels are received at regional depots, outlined as one of the 19 regions in figure 2.5-1. There the parcels will be sorted based on their destined region (depot) and loaded into roll cages (RC). Destinations which belong to the same depot+, as shown in table 2.2 where these locations are placed in the same column, will be bundled and transported to that specific depot+ or crossdock. Figure 2.5-2 shows this collection (yellow line) and transportation towards different depot+ (red line) in case of origin depot Kolham. When the truck arrives from different depots at a certain depot+ or crossdock, the roll cages will be transferred based on their destination depot. In this phase, RC's originating from different depots with the same depot destination will be bundled and loaded into the truck. Figure 2.5-3 shows the distribution of RC's from depot+ towards other depots belonging to that central hub region. When the truck arrives at a specific depot, the RC's will be unloaded, sorted and distributed over the depot's region. As explained before, figure 2.5-2 and figure 2.5-3 show only the transportation movements between hubs originating from depot Kolham. Drawing all the intended movements between origin depot and destination depot, as shown in figure 2.5-4, it can be concluded that there are 90 inward depot+/crossdock trucks and 15 outward depot+/crossdock in total with the intended network structure.

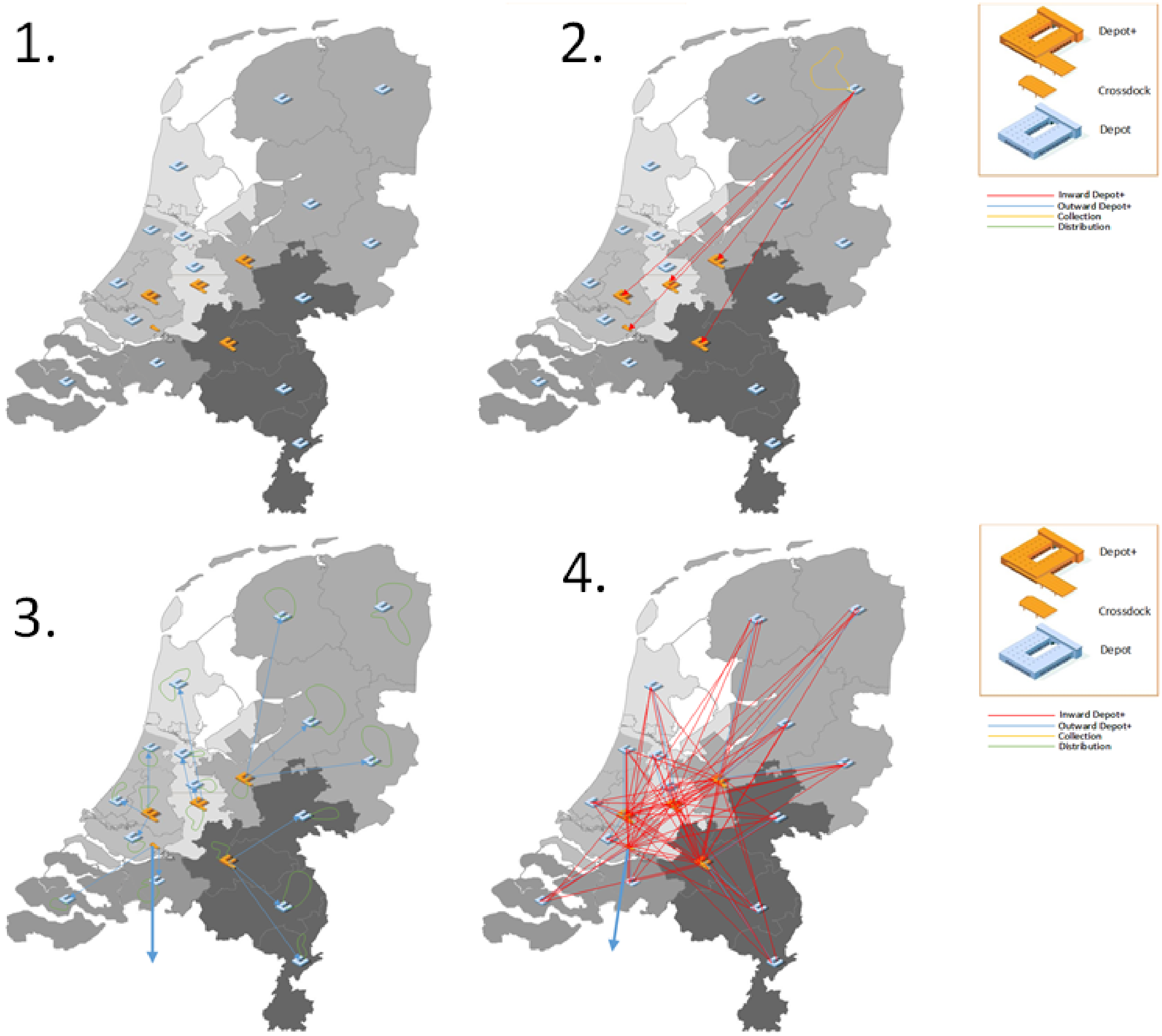


Figure 2.5: Topographical overview of the domestic parcel distribution in the Netherlands by PostNL. Fig. 2.5-1: locations of the hubs including regional hub (depot) and central hub (depot+) regions. Fig. 2.5-2: Inward transport for depot+ or crossdock originating depot Kolham. Fig. 2.5-3: Outward transport for every depot+ or crossdock originating depot Kolham. Fig. 2.5-4: Transport (inward and outward) between depots

2.2.3. Logistical process on regional level

This subsection discusses the different processes performed at or managed by a depot.

Collection. Is a process that can occur in different ways at depot or depot+. The crossdock located in Dordrecht doesn't have its own region of collection. The different kinds of collected parcels are supplied in roll cages (RC) and will never be supplied individually at a certain depot. There are four categories of collection: dedicated collection, pick-up collection, regular collection and special in-feeds. First the biggest volume, originating from dedicated collections. This group delivers the unsorted parcels at the nearest depot itself. Secondly, there is collection via pick-up performed by PostNL. This way of collecting is divided over retail, like pick-up-points in retail shops, and regular collection. For regular collection, drivers of PostNL collect the parcels at the address of different shippers. If the collected items arrive before 22:00h, they will be delivered the next day. Specifically for Depot+, there is another option of supplying, called 'special in-feeds'. Customers have the possibility to deliver sorted parcels themselves at specific depots+ during the night. The advantage for customers, especially e-commerce, is that the delivery of the parcels will be made on the same day. Delivery of the parcels has to be done before 03:00h. However for this report, this stream is out of scope because of its complexity and low volume according to Andre Koelemeijer (Supply Chain Planner PostNL).

Sorting for domestic distribution at depot. After collection, the parcels will be delivered at depots where they will be sorted. The sorting of parcels for a certain destination will be based on depot location which is linked to a certain depot+. Collected roll cages or roll cages with undelivered parcels, will be unloaded and placed on the sorting belt. The sorting machine sorts the parcels based on location and shift. This shift stands for a certain distribution round or local area in the destined region. For example, in case of depot Ridderkerk there are 9 shifts as explained later in this subsection. The whole sorting process starts around 15:30h and ends at 23:00h. After sorting the parcels, roll cages will be loaded and bundled with other roll cages destined for other depots in the same depot+ region. When the roll cages are bundled, the RCs will be loaded into the trucks and transported towards a specific depot+.

Transshipment at depot+. At a depot+, the same sorting process as in a regional depot, as described in the preceding paragraph, takes places. However, an extra central hub function of a depot+ is to transfer RC's destined to a specific region originating from other depots. Additionally, special in-feeds will be supplied and bundled with rest. This happens during the night from 23:00h until 05:00h since the parcels have to arrive at their destination before 08:00h.

Sorting for regional distribution at depot. When parcels arrive at the intended depot, they have to be sorted over different smaller vans with their own route. This process starts at 08:00h and ends, depending on the demand, around 12:00h. As mentioned before, the distribution of parcels in the depot's region is done using shifts. Every shift, in case of Ridderkerk there are 9, covers a number of smaller areas. For example, the truck arrives from the depot+ and the sorting process can begin. First things first, the process starts with shift 1. This shift covers a couple of local areas within the region which is linked to one specific driver. RCs of shift 1 will be unloaded on the belt and the machine sorts the parcels over different docks. Every row of docks is linked to a couple of shifts. For example, the first row of docks (25) in Ridderkerk is linked to shift 1,3,5,7 and 9. This means that a delivery man has 2 shifts (approximately 30 - 35 minutes) to load 110 - 145 parcels (outsourced vans are loaded with +200 parcels) into their van. After the second shift is over, the delivery man has to leave the dock to make space for shift 3. The last shift is, inter alia, intended for the evening delivery. This shift will be distributed later that day.

Distribution. When the delivery man has loaded all the parcels into his van, he goes its own way to shops, companies, houses or P.O. boxes to deliver parcels. The delivery of parcels starts between 08:00h and 12:00h depending on the sorting moment. By the end of the day, the parcels have to be delivered before 21:30h. Every delivery man has his own local area based on their capacity with around 16 stops per hour. Routing is based on a delivery list instead of a navigation routing system. When a parcel cannot be delivered at a certain address, the delivery man has to bring it back to the depot where it will be stored until 22.00h. Customers are able to change their day or location of delivery online until 22.00h. Afterwards, the sorting process starts again as explained at the beginning of this subsection.

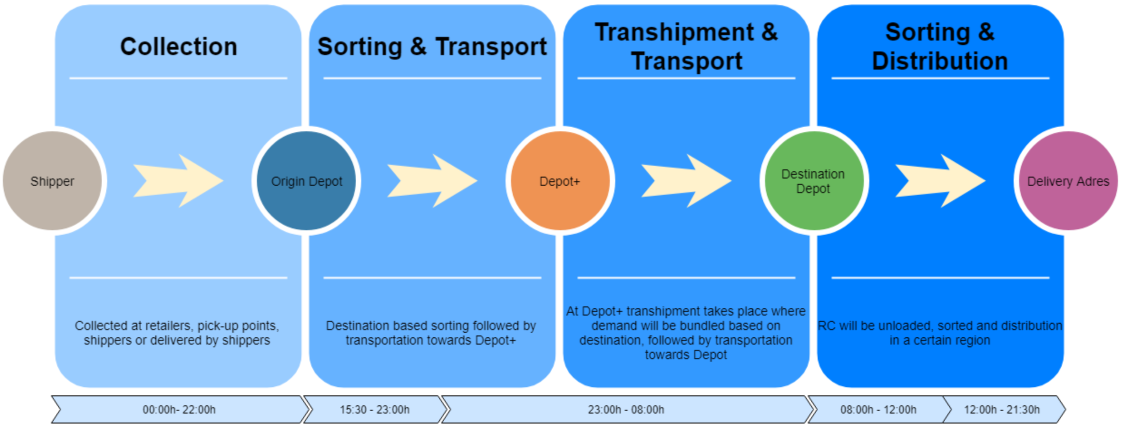


Figure 2.6: Schematic overview of the domestic parcel collection, sorting and distribution in the Netherlands by PostNL

2.3. Conclusion

Focused on the parcel delivery industry in the Netherlands, there cannot be denied that there is an obvious growth in terms of items transported to, from or within the Netherlands. Different kinds of carriers, mainly founded abroad like DHL, DPD, GLS, TNT (FedEX) or UPS, are responsible for carrying this volume. The main Dutch carrier, which is also the market leader concerning the domestic transportation with 60-65%, is PostNL. To reduce the environmental impact of the delivery process from origin to destination, different kinds of measures have been implemented. The following subsection deals with this topic as follows:

SQ1: How is the parcel delivery market dealing with the environmental impact of their business?

A: it can be concluded that the parcel delivery market is focused on three elements with regard to CO_2 reduction: 1) Burn less fuel, 2) burn clean fuel and 3) compensate emissions. By introducing their program 'GoGreen', DHL seems to be a pioneer when it comes to reduction in CO_2 with a 30% reduction in 2016 compared to 2007. By using efficient networks and routes, DHL triest to reduce their impact by burning less fuel. Also, the providing of services with the objective to minimise the total emitted amount of CO_2 instead of minimisation in travel time, makes it possible to reduce the footprint in combination with demand from the market. The other two elements 'burn clean' and ' compensation of CO_2' are also applicable for a company like PostNL. However, those kind of measures are out of scope for this report.

PostNL, the study case company of this report, deals with a lot of complex processes. Besides the division between mail and parcels, there are also other kinds of logistical processes. Scoping in section 1.5, explains that this report is focused on the main and largest stream of parcels that PostNL deals with. What this process looks like, can be concluded from the answer of the following sub question. It should be mentioned that this process description is not the same for every parcel stream, like for example same day delivery, time window related delivery, food delivery or Sunday delivery.

SQ2: What does the current process of domestically parcel distribution at PostNL look like?

A: The current process of parcels could be segmented into 3 stages: Collection, inter transport and distribution. The Netherlands is divided into 19 regions with each its own regional depot and outlet concerning collection and distribution. The depots are connected using a single allocated web structured network. 4 out of 19 depots act as central hub named depot+. Moreover, one extra hub is added without any outlet concerning collection. The logistical process will be as follows. First, parcels will be collected at different companies batched in roll cages (RC) and delivered at local region depots. RCs will be unloaded, sorted based on their destination's regional depot and finally loaded again into RCs. Roll cages with different destination depots but the same central hub (Depot+) link, will be batched and transported towards that certain central hub (Depot+). This stage, also called intern transport, makes sure that the RCs loaded with parcels will be distributed over the Netherlands. At every central hub (Depot+), trucks will be unloaded and RCs with the same destination depot but different origins will be merged. Afterwards, trucks will depart towards the destined depot where after inter depot transport is finished, RCs will be unloaded from the truck and sorted based on their final destination in the local area.

3

Literature Review

This chapter is focused on different studies related to the environmental impact of transportation concerning CO_2 as structured in figure 3.1. In the first section 3.1, the definition of preservation of logistics and transportation will be discussed in a more general way. Moreover, different factors which affect the environmental impact of transportation according to literature will be explained. In the following section 3.2, the origin of the vision and main characteristics of the Physical Internet will be explained. This defined vision will be used in combination with the case study at PostNL further in the report. In addition, different models concerning service network designs will be discussed in section 3.3. The sub-question which is central to this chapter and is concluded in the last section will be as follow:

SQ3: What are the main characteristics of Physical Internet Logistics with regard to the case study at PostNL?

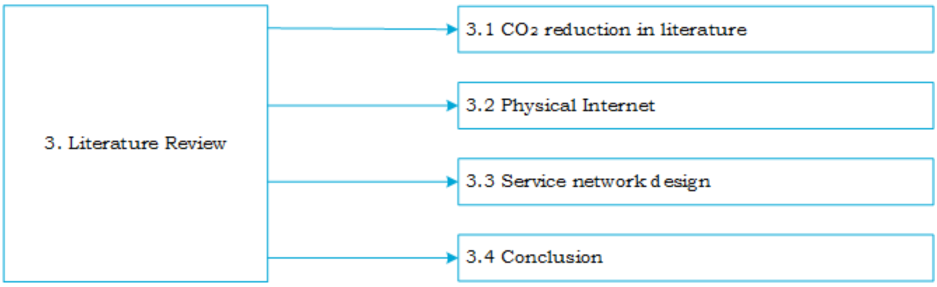


Figure 3.1: Structural overview of chapter 3

3.1. CO_2 reduction in literature

Where optimisation of logistical operations is mainly focused on cost minimisation of the process, inter alia researched by Forkenbrock (1999, 2001) and Crainic (2000), also other objectives began to play an important role since the concern for the environment rises (Mckinnon et al., 2010). With the knowledge that transportation has also its negative impact on the environment due to fuel combustion, optimisation of transportation-related processes should be seen in a wider perspective. The ambition of logistics to find a balance between the pillars Environment, Economic and social, is called 'Green Logistics' as discussed by Seroka-Stolka (2014). Figure 3.2 shows in a graphical way the three pillars including their categories related to logistics, developed by Cardiff University et al. (2010). These pillars should be in balance to create a sustainable process. Maximising one of the pillars, like for example economics by minimising costs, will have a negative influence on the other pillars. Focusing on a specific pillar, the triangle gets out of balance and the operation is not sustainable anymore.

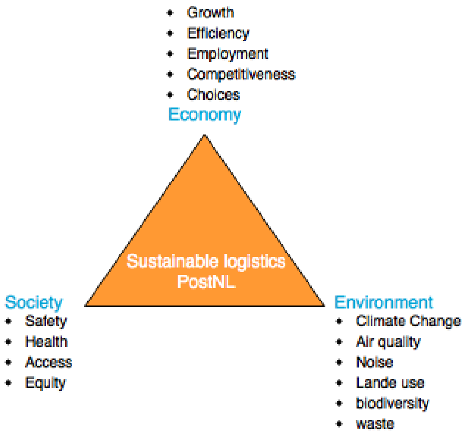


Figure 3.2: The three pillars of Green Logistics including its categories (Cardiff University et al., 2010)

Every pillar of figure 3.2 is relevant for a business. It is common sense that the pillar Economy and Environment are applicable. After all, a business like the case study at PostNL wants to make profit and this will have its influence on the environment. Moreover, the society pillar is also relevant for the parcel delivery industry. Especially the factor ’Access’ plays an important role. By setting up their current business, the parcel delivery industry contribute to the accessibility of people towards the global economy. People are able to send and receive parcels which creates a connection to the rest of the world. This research paper will be focused on the environmental pillar in combination with the growth of the economic pillar.
Demir et al. (2014a) published a review of research on green road freight transport. In their review, related factors are analysed which play an important role in the environmental impact of transportation. Besides, different models were reviewed related to fuel consumption and emissions like the Vehicle Routing Problem with environmental related objectives. It is remarkable that, according to Demir et al. (2014a), the total distance travelled is not defined as a factor that affects the total amount of CO_2 but is seen as fuel consumption model. The total travelled distance, which for example depends on routing or the location of different facilities, is an interesting addition to the defined factors. The paper concludes that most studies are only focused on the routing aspects of green logistics. Also, the relocation and selection of a depot or right vehicles can be a promising area to reduce CO_2 emissions.
Research that takes facilities into account regarding green logistics is carried out by Dekker et al. (2012). The authors reviewed possible developments for the main physical drivers behind a supply chain relative to its environmental impact. In their research, Dekker et al. (2012) came up with an overview to outline the effects of aspects, issues, contributions and challenges of different decision phases and the impact on the three physical drivers ’Facilities’, ’Transportation’ and ’Inventory’ (Chopra and Meindl, 2010). Because the parcel delivery industry plays an important role in the last mile of the supply chain, it is not relevant for PostNL as a carrier to keep the physical driver ’inventory’ in mind since it is outbound towards its suppliers. This means that there is only a focus on ’facilities’ and ’transportation’. Concerning facilities, internal transport and emissions, emissions of transport units used for transport to or from facilities and congestion around the facilities play an important role besides the common energy use for heating and lightning (Dekker et al., 2012). Concerning transportation, the research was focused on mode choice, intermodal transport, equipment choice and efficiency and fuel choice and carbon intensity. Dekker et al. (2012) concludes that new models are required to address the multitude of decisions needed to improve the environment.

Combining the studied papers with the given frameworks by Dekker et al. (2012) and the outlined factors affecting fuel consumption according to Demir et al. (2014a), a framework as shown in figure 3.3 can be constructed which defines transportation-related factors to reduce the environmental impact. Those factors are categorised based on dimension (strategic, tactical and operational (Demir et al., 2014a)) and aspects (mode related, driver related, operations related, network and routing related and finally modality related). The meaning of those levels will be explained as follow.

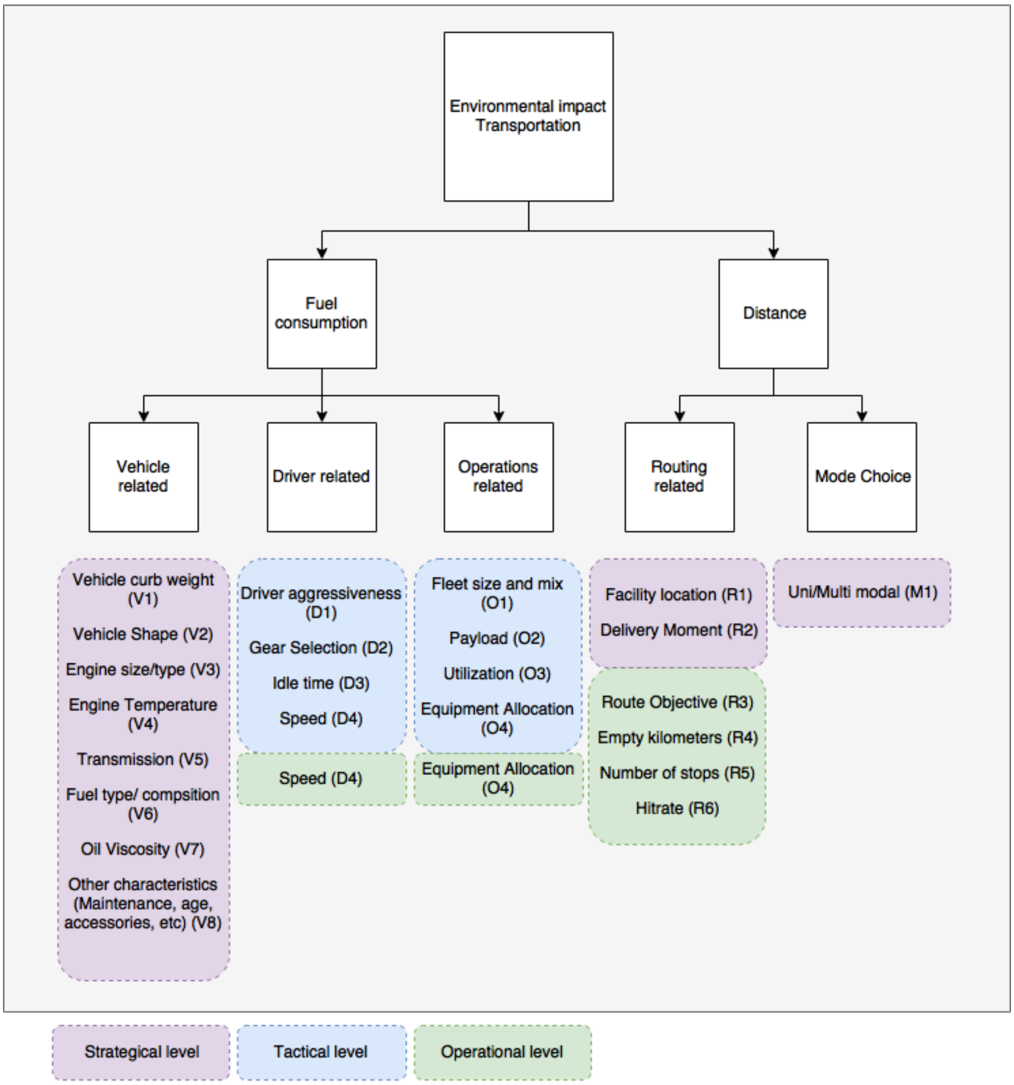


Figure 3.3: Framework with different Transportation related aspects (white of boxes) and its related factor which play an important role concerning the environmental impact in terms of CO_2 based on research by Dekker et al. (2012) and Demir et al. (2014a).

Strategical level - 3 to 5 years

Strategical decision making are planning issues related to long-term investments on present infrastructure or network (Steadieseifi et al., 2014). For example, topics as hub location problems (R1) (Alumur and Kara, 2007), concerns a facility problem which is interrelated with the choice of transport modality (M1) in combination with the mode characteristics (V1-V8). As reviewed by Steadieseifi et al. (2014), Multi-modality can offer a more efficient, reliability, flexibility and sustainability.

Tactical level - a quarter to 1 year

Tactical planning deals with optimising the utilisation of the given infrastructure. The chosen services (R2) in combination with its associated transportation modes (O1-O3) have to be allocated (O4) (Steadieseifi et al., 2014). Research like Kopfer et al. (2012), shows the potential of saving fuel by using/allocation (O4) a heterogeneous fleet (O1) combined with different payloads (O2). Focused on the future, it is unavoidable to replace the current fleet. Where most of the papers are focused on the economical perspective of fleet replacement, Taghipour and Salari (2015) propose to also take the environmental characteristics into account. Besides the topics as mentioned before, it is important to optimise the utilisation concerning the services on the network in terms of routes and frequency (R3-R5) (Rezaei, 2016). According to Demir et al. (2014a), also driver related characteristics (D1-D4) have to be taken into account. This is one of the most significant factors affecting fuel consumption and can bring a difference in fuel consumption between the best and worst driver of 25%.

Since the fact that this report is focused on designing a service network for a given set of locations, which is an element of the tactical level according to Crainic (2000), this report goes further in depth into this topic in section 3.3.

Operational level - 0 to 3 months

Factors belonging to the operational level have some overlap with the tactical level. On this dimension, there is still optimising concerning Operations (O4) and Routing (R6). With regard to the reduction of the environmental impact, Bektas and Laporte (2011) came up with a routing problem focused on the minimisation of emissions, fuel, travel time and costs. Unfortunately, the decision making on the operational level is more on a real-time and deals with a more dynamic and stochastic environment. The factors on this dimension are more influenced by external factors like weather or traffic characteristics (Steadieseifi et al., 2014) . The speed (D4) is also a factor which operates on this level (Dekker et al., 2012). Although the defined differences in level, a lot of studies are focused on subjects with some overlap. For example, Demir et al. (2014b) shows a research focused on a fleet size and mix (tactical level) in combination with a routing problem (operational level). Another example is research by Scott et al. (2010), which combines the factors payload (tactical level) with topology (external) and vehicle routing (operational level).

3.2. Physical Internet Logistics

The way how currently physical objects are transported, handled, stored, realised, supplied and used through the world, occurs in a very unsustainable and inefficient way regarding a economic, environmental and social perspectives (Montreuil, 2011). According to Montreuil (2011), the existing vision of handling physical objects supports unsustainability of global logistics. In particular the following symptoms contribute to this unsustainability assertion:

1. **Carriers are shipping air and packaging:** Trucks, wagons and containers are often half empty at departure. Research by Gerard Peeters (2017) shows that on average a package consists 30% to 40% of air.

2. **Empty travel is the norm:** Vehicles and containers often return empty.

3. **Truckers have become the modern cowboys:** Due to the high shortage of drivers, many truckers are almost always on the road.

4. **Products mostly sit idle, stored where unneeded and not fast enough where they need to be:** Products are often stored in vast quantities through networks of warehouses and DC's.

5. **So many products are never sold, never used:** Many products ending up unsold and unused at some location, while they would have been required elsewhere

6. **Products do not reach those who need them the most:** In less developed countries, the transportation and its characteristics are very low in quality. This makes it difficult, costly and lengthy to reach those in need.

7. **Fast and reliable intermodal transport is still a dream:** Currently intermodal routes are mostly time and cost inefficient and risky.

8. **Getting products in, through, and out of cities is a nightmare:** Cities are not designed and equipped for transport, handling and storage of goods. Besides, a significant amount of traffic, noise and pollution is created.

9. **Products unnecessarily move, crisscrossing the world:** this could have been avoided by routing them smartly and making them closer to their point of use.

10. **Networks are neither secure nor robust:** There is an extreme concentration of operations in a limited number of centralised production and distribution facilitates.

11. **Innovation is strangled:** by lack of generic standards and protocols, transparency, modularity, and systemic open infrastructure.

Decades ago, the information and telecommunication community faced quite the same challenges concerning efficiency and unsustainability. Due to the fast evolution of the digital world from isolated computers towards linked private networks followed by a world with unconnected microcomputers sitting on everyone's desk, authorities agreed that the situation was unsustainable and solutions on the macroscopic level were needed. The Digital Internet was invented, an open distributed network infrastructure leading the way to the digital world wide web and digital mobility as we currently know. The connection between networks which is transparent to the user allows the transmission of formatted data packets in a standard way permitting them to transit through heterogeneous equipment. The vision of Digital Internet and the way in which this has been organised leads to the realisation that the current way physical objects are transported, handled, supplied, realised and used is not sustainable or efficient (Montreuil, 2011). 'Physical Internet', based on the vision of Digital Internet, is a new vision to process the logistics of physical objects in an open, global, interconnected and sustainable way (Sarraj et al., 2014). The following paragraphs outline the thirteen key characteristics of the Physical Internet and its link with Digital Internet. Table 3.1 summarises the similarities and differences between Physical Internet and Digital Internet.

Table 3.1: Similar and different characteristics of Digital Internet and Physicial Internet.

Digital Internet	Physical Internet
Encapsulation of information in data packages	Encapsulation of objects in modular containers
Standard protocols and universal interconnectivity	
Standard handling and storage system	
Smart network thinking with IoT	
Multi-tier network framework	
Open global network	
Network balancing	Minimise physcial moves and storages
Sharing information to stimulate continous improvement	
Prioritise reliability and reslience of networks	
distributed multi-segment network	distributed multi-segment intermodal network

Encapsulation of objects in standard modular containers. Digital Internet deals only with information that is encapsulated in standard data packets whose format and structure are encapsulated independently. Due to the fact that the interfaces and protocols in the Digital Internet are designed to exploit this standard encapsulation, data packets can be processed by different systems through various networks (Kurose and Ross, 2013). However, most of the data packets which have to be sent do not fit optimal in standard packets and have to be repacked. A process like this goes as follow by the example of sending an email: First, the email that has to be sent must have its content chucked into small data components. Those components are encapsulated into a set of data packets according to the universal format and protocol. The packet header contains the information required for identifying the packet and its destination. The data packets go on their journey across the digital networks to end up at their destination. The routing of the package is focused on network balancing. This means that every package follows their individual journey with the objective to optimise the network state instead of the optimisation of the single trip. As a result, it could occur that different data packets follow different routes between the same origin and destination. At the destination, the components will be re-consolidated into a readable email (Montreuil et al., 2014). Montreuil (2011) suggests to use this principle also for the vision of Physical Internet where physical objects should be transported, handled, stored, realised, supplied in specific physical packets or containers. According to Montreuil (2011), these specific containers, also called π-containers, should have the following key characteristics:

- π-containers should be modularized and standardised in various sizes as shown in figure 3.4
- Smart tag enabled by using sensors or RFID to allow proper identification, routing and maintaining
- Minimised packing material which is easy to flow through different modes and means. Packages should be seal-able for security and be capable of having different condition capabilities as necessary

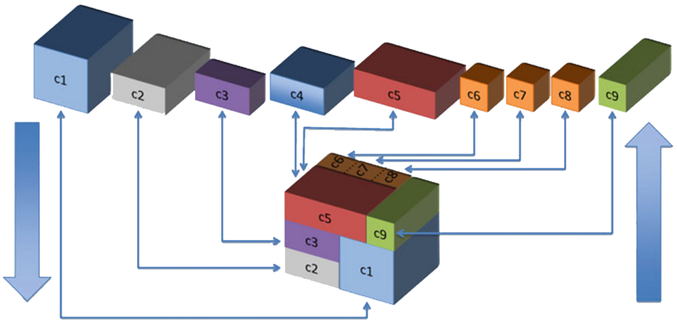


Figure 3.4: Illustration made by Montreuil and Meller (2010) to outline the functionality, modularity of unitary and (de)composition

Universal Interconnectivity. Concerning the Digital Internet, world standard protocols and universal interconnectivity has lead to fast, cheap, easy and reliable transport of data. As currently conceived, the activities that interconnect streams like sorting, storage or handling, brake most often the interconnection. The key objective of applying Digital Internet's interconnectivity to the Physical Internet, is to make load breaking almost negligible temporally and economically.

Evolve to a standard (π-container) handling and storage system. According to the vision of Physical internet, there are no generic all-purpose material handling and storage systems. Only π-containers related systems are used which seamless interface with vehicles and systems to move products in and out. By providing an open live documentation of their performance and capabilities through monitoring, a secure, reliable and fast performance will be enabled.

Smart networked containers including smart objects. Physical internet exploits as best as possible by using smart π-containers based on handling data as Digital Internet does. Smart tags to ensure identification, integrity, routing, condition, monitoring, traceability and security of each π-container is an element of the Internet-of-Things (IoT). The term IoT describes the connectivity between physical objects equipped with smart technologies such as RFID, short-range wireless communications, real-time localisation or sensors (Floerkemeier et al., 2008).

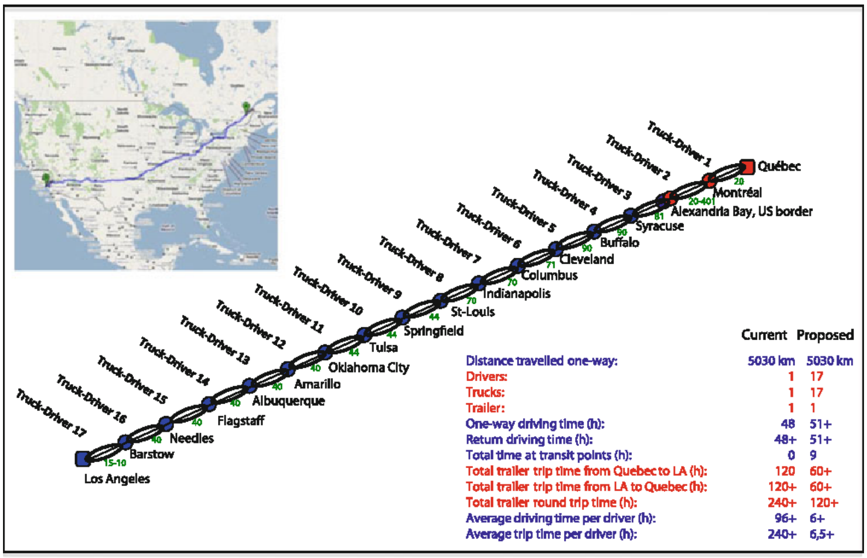
Make use of unified multi-tier conceptual frameworks. The Physical Internet network is based on the same framework as Digital Internet which can be expressed in a Russian-dolls style as follow:

1. Intra-center inter-processor networks
2. Intra-facility inter-center networks
3. Intra-city inter-facility networks
4. Intra-state inter-city networks
5. Intra-country inter state networks
6. Intra-continental inter county networks
7. Worldwide inter-continental networks

Activate and exploit an Open Global Supply Web. At this moment, organisations, producers, distributors and retailers rely mostly on private supply chains and networks constituted of their enterprise and their partners. As the vision of Physical Internet suggests, there should be a shift from private networks to an Open Global Supply web. Nodes should be openly accessible to most actors whereby the capacity is available for a contract on demand, on a per-use basis, be it for processing storage or moving activities.

Minimise physical moves and storage. By digitally transmitting knowledge and materialising object as locally as possible, movement and storage of physical objects can be minimised. It is much easier and faster, and so less expensive, to move and store digital objects of information than physical object composed of stuff. 3D-printing could play an important role to minimise the number of movements and storage in a network.

Evolve network to distributed multi-segment intermodal. Taking a look at the 'logistical process' of sending an email, the data packages do not travel directly from A to B. The packages travel through a series of cables and routers from origin to destination and are not restricted to travel together. The objective of the route is to find the best way as possible provided by the routing algorithms which takes the congestion through the network into account. Since the encapsulated packages are travelling individually, they may all travel its distinct route. At the destination, the arrived packages get reconstructed to a complete file. Taking a look at the current logistics of physical objects, most of the networks are based on point-to-point, hub-and-spoke design or a combination. The vision of Physical Internet shifts the 'classical' way of logistics toward a multi-segment distribution. Distinct carriers and/or modes taking care of internode segments as shown in figure 3.5 instead of only one carrier. Moreover, hubs and transit nodes enable synchronised transfers between carriers. The advantage of the example as sketched in figure 3.5 is that routing could be optimal for the whole network instead of only optimal for the container from Quebec to Los Angeles. Where for the point-to-point case a trip takes 120 hours of driving and sleeping, the PI based network gets the job done within 60 hours of driving without an overnight stay. Another advantage is related to empty trips. When a truck drives from origin to destination, it could be possible that the truck drives back to the origin with an empty trailer. Dividing the total route in smaller trips creates the ability to merge containers or you could drive back with another container after unloading the first container at the first hub. This last mentioned statement is also possible at a point-to-point trip, but in the Physical Internet setting it is more likely that there is a container available in a shorter distance than in a more closed long distance network. However, there are some important differences to take into account between Digital Internet and Physical Internet. First, every single move of a π-containers is costly. Second, every move and operation takes time so there is no apparent instantaneity. Decision-making about budget, time frames or other constraints will play an important role to deal with this.



	Current	Proposed
Distance travelled one-way:	5030 km	5030 km
Drivers:	1	17
Trucks:	1	17
Trailer:	1	1
One-way driving time (h):	48	51+
Return driving time (h):	48+	51+
Total time at transit points (h):	0	9
Total trailer trip time from Quebec to LA (h):	120	60+
Total trailer trip time from LA to Quebec (h):	120+	60+
Total trailer round trip time (h):	240+	120+
Average driving time per driver (h):	96+	6+
Average trip time per driver (h):	240+	6,5+

Figure 3.5: An example of a multi-segment and intermodal route based on the Physical internet as designed by Montreuil (2011). Instead of one single trip from Quebec to Los Angeles, the trip is divided into 17 small trips with different drivers

Deploy open performance monitoring and capability certifications. Sharing information about performance and capability stimulate continuous improvement and fact-based decision-making by using a multitude of actors and elements.

Prioritise webbed reliability and resilience of networks. The Digital Internet aims to transport information in a reliable and resilient manner by instinct nature, protocols and structure. Concerning the Physical Internet, interact in synergy will take place to guarantee the physical and informational integrity. In practise this means that when a link in the network fails, the traffic should be re-routable as automatically as possible.

Stimulate business model innovation. The idea of this model is to occur in various logistics and transportation industries to stimulate innovative revenue models for the various stakeholders.

Design products fitting containers with minimal space waste. The objects within Physical Internet are carried within π-containers which are designed and engineered to minimise the load they generate on the Physical Internet. Besides, the aim of the π-containers to have maximal volumetric and functional density which is defined as the ratio of its useful functionality over the products its weight and volume. The goal is to fit as small as possible in a π-container.

Enable open infrastructural innovation. By enabling open infrastructure innovations like π-containers, the vision of the Physical Internet tries to improve the utilisation of means and modes in terms of modularity and homogeneity. The π-containers move through the network from diverse origins to diverse destinations using facilities like open trailer transit centres, open cross docking hubs, open warehouses (Borangiu et al., 2013).

After the first conceptualised elements of PI as shown in this section, it was time to do some research with regard to assessing the vision. Different studies focused on large-scale supply chain networks, like the transportation of goods in France between two large-scale retailers and 106 suppliers, demonstrates that the vision could significantly improve the efficiency and sustainability of transportation (Sarraj et al., 2014). However, different than the domestic parcel delivery industry in the Netherlands, this research was focused on a multimodal network for the transportation between locations. Focused on the case at PostNL, which deals with only one type of asset, the following subsection presents the relevance of PI elements.

Relevance to case study PostNL

The vision as discussed in this chapter sounds very futuristic. In particular, the willingness to share assets, networks and data are important elements to make a Physical Internet based network to a success. With the absence of these elements, it becomes clear that a PI-based network has its potential for the long term since the fact that economies are established of competing companies. Moreover, this PI vision seems mainly focused on long distance or global transportation. Still, there are some characteristics which are applicable for a case study in the parcel delivery industry to make their network more sustainable on a short term. The used characteristics of Physical Internet Logistics will be as follow:

- Encapsulation of demand
- Individualisation of paths between origin and destination
- Multi-segmentation of routes
- Single allocations of trucks
- Enabling an open network

As discussed in section 2.2, parcels are already encapsulated into roll cages (RC). However, the transportation of RCs with the same origin and destination are mainly bundled. As introduced by Montreuil (2011), to see objects more individually might result in a reduction in CO_2. Another appropriate element of PI is to evolve the current network into a distributed and multi-segment network as given in figure 3.5. The nodes could still be the same, but a truck is only allocated to a single route from node i to j and back from j to i. An optimisation based on the vision of PI makes sure that the right truck departures on the right time from node i towards a certain node j. Besides, the truck travels back from node j to node i with load coming from other nodes with its final destination node i. In this way, the truck driver is always back at the node he/she started from. Despite the potential of 3D printing, as introduced in this section to minimise movement and storage of objects, it is not likely that movement of objects will decrease with regard to the B2C. The main reason is the diversity of products a consumer wants. For the B2B market where companies are often focused on producing or using specific products, 3D printing will have the capability to reduce physical movement of objects. There can be concluded that, despite upcoming technologies, there are still some potentials usable of the Physical Internet's vision concerning a case in the parcel delivery industry at PostNL.

3.3. Service network design

As mentioned in chapter 1, this research is focused on optimisation of decision variables to design a service network based on Physical Internet. A certain design is mainly on a tactical level of planning and focused on the selection and scheduling of services to operate (Crainic, 2000). By using a mixed integer problem based mathematical formulation, a service network can be designed under certain circumstances and focused on a particular objective. There are a couple of elements that make a network design for the parcel delivery industry unique in relation to other networks. First of all, a service network design in the parcel delivery industry is focused on the transportation of demand from origin to destination within a given time window. Different kinds of commodities forms the total demand together. Transportation of demand is done by using assets. Focused on this element, balancing of assets plays an important role. In fact, a certain amount of demand cannot be transported when there is no asset available at that origin. Besides, the used asset has its own characteristics in terms of capacity, speed and costs. Finally, 'time' is one of the priorities of a carrier. By supplying a specific type of service, the carrier tries to perform the transportation within a certain time window. Research by Van Riessen et al. (2013) shows that there are several network designs which are able to deal with a capacitated flow as well as multiple commodities [1]. Since path individualisation between origins and destinations is one of Physical Internet's characteristics, this research is focused on multiple commodity models. According to Van Riessen et al. (2013), two types of model can be distinguished: 'Minimum cost network flow models' (MCNF) and 'path based network design models' (PBND). First MCNF models, which are able to vary demand over different links in the network by using a lot of decision variables relative to PBND models. These PBND models are based on possible paths for each commodity between origin and destination in which a path is defined as a subsequent of routes/arc and terminals (Van Riessen et al., 2013). To deal with a capacity constraint and multi-commodity in combination with a minimum of variables, Van Riessen et al. (2013) suggest the PBND formulation by Crainic (2000). This research is focused on service network designs in a mathematical way with the objective of emission minimisation. Although the model of Crainic (2000) is focused on consolidated transportation like the parcel delivery industry, constraints in terms of time and asset balance are missing in this model. With regard to this research, the given asset model by Andersen et al. (2009) based on Crainic (2000) will be useful to find an optimal set regarding minimisation of CO_2. The reason why published research by Andersen et al. makes their model as best fit for this report, is the integration of assets management in service network design models for consolidation-based freight carriers like the element time and asset balancing. According to Andersen et al. (2009), the goal of a motor carrier such as PostNL is to allocate and utilise resources in the most efficient and profitable way to meet the customer demands. The output of the model shows an operation plan, which indicates the services offered between hubs. A modification of this model in relation to the parcel delivery industry is shown in chapter 6.

Relevance to case study PostNL

The suggested model of this section will be used as input for chapter 6. Although some modification should be made to create a better fit for the case of PostNL in combination with PI logistics, the model as defined by Andersen et al. (2009) is properly to use. First of all, this model combines asset management with a service network design. Besides, this model is focused on the minimisation of costs of flow and asset use. Despite the fact that this report is only focused on the minimisation of emissions instead of costs, the objective can be modified by changing the objective into minimisation in terms of CO_2.

3.4. Conclusion

Montreuil and Meller introduced in 2010 a new vision for the establishment of logistics: Physical Internet. Physical Internet is a vision which based on the way Digital Internet is set up concerning sending information through a network. According to Physical Internet, objects will be encapsulated into standard boxes and follow their own path through the network. An open network in terms of assets, information and willingness to share this is necessary to make this vision successful. Due to the current state of global economies, it is hard to imagine that this vision can become a success in such a competitive market in a short-term. However, research by Sarraj et al. (2014) demonstrates a significant improvement in efficiency and sustainability of a supply chain network concerning the fast-moving consumer goods sector in France. By the author's knowledge, the application Physical Internet's characteristics are never analysed on a network in the parcel delivery industry. Single elements of this vision can be useful to improve the current state of logistical processes with regard to CO_2 reduction. Focused on a case study at a parcel delivery company like PostNL, potential elements of the Physical Internet will be discussed using the following sub-question.

---

[1] The problem deals with multiple commodities between different origins and destinations

SQ3: What are the main characteristics of Physical Internet Logistics with regard to the study case at PostNL?

A: One of the main characters relevant for the case of PostNL is to **encapsulate objects** in standard modular containers, after which it will travel its **own path** through the network from origin to destination. In this case, it could be possible that objects with the same origin and destination will be encapsulated into different containers and will follow different and individual routes through the network. Moreover, the physical internet is focused on transportation on routes between nodes instead of transportation from origin and destination. By connecting different routes a path from origin to destination can be performed by different modes. This vision will result in more transferring of load/trailers but also fewer kilometres empty or with a low utilisation. An **open network** should support this by offering different locations of transhipment. By segmentation of different paths, load could be combined with other origin-destination pairs. Besides, every truck will be **allocated to a single segment**/route. The overall objective is to create balance in different terms. With regard to the case at PostNL, it could be interesting to individualise origin-destination pairs and give them all their own path through the network instead of standard paths focused on CO_2 minimisation.

II

Measure

4

Current state measurement - PostNL

As described in section 2.2 in more detail, the logistical process of the distribution of parcels from origin to destination is deconstructed in multiple steps. Using a SIPOC diagram, as shown in figure 4.2, relevant elements of a process are identified which form the basis of this chapter. With regard to figure 4.2, the decision-making concerning routing through the network starts just after the sorting process when the demand is sorted and loaded on roll cages based on their destination. The demand will be discussed in section 4.1 followed by the network discussion in section 4.2. The fleet, which performs the transportation of the demand from A to B, is outlined in section 4.3. Because this report is focused on the environmental impact of transportation, section 4.4 outlines related measures introduced by literature and the industry regarding the reduction of CO_2 concerning transportation. Summarised, the structure of this chapter is graphically shown in figure 4.1.

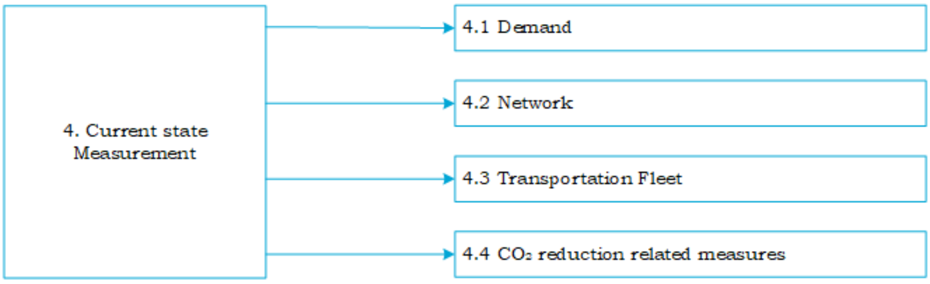


Figure 4.1: Structural overview of chapter 4

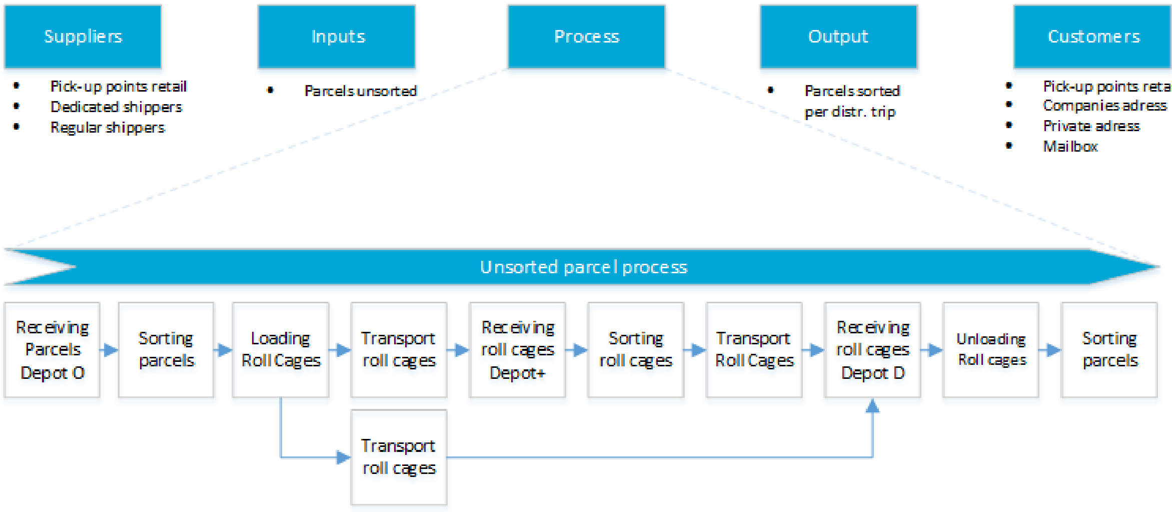


Figure 4.2: Schematic overview of the Supplier, Input, Process, Output and Customer (SIPOC) domestic distribution of parcels from origin (O) depot to destination (D) depot by PostNL parcels

4.1. Demand

This section shows the current state of parcels produced at an origin depot and attracted by a certain destination depot. In terms of items, the average number of items that have to be transported are presented in table 4.1. The demand expressed in m^3 is in table F.1 of appendix F. The presented values in both tables are averages based on 81 measurements between 04-12-2017 and 30-03-2018 on days that all depot are open. Items with their destination in Dordrecht are intended for further transportation towards Belgium. As described in section 2.2, parcels will be loaded on roll cages (RC) at the origin depot and only unloaded at the final destination depot. When a journey of an RC from origin to destination goes through a depot+, no alterations are made to the RC at that Depot+. From an expert interview as described in Appendix I, it became clear that there are two kinds of RCs, 'grey container' with a capacity of 0.66 m^3 and a 'parcel container' with a capacity of 1.04 m^3. Due to the lack of information about the allocation of RCs per type, it is hard to say which kind of RC is used for the transportation of parcels between depots. For this reason, PostNL converts the number of transported containers to 'RC parcel equivalent'. PostNL makes use of the assumption that every RC equivalent has a capacity of 37 items.

Table 4.1: Origin - destination matrix in terms of items from depot (column 1) to depot (row 1) on an average day.

Depot	AMF (+)	BORN	BD	HT (+)	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG (+)	OPM	RD	SSH	SON	UT	WVN (+)	ZWL	DOR (X)
(+) AMF	4653	2895	1602	3684	1817	2026	1273	1917	2464	1611	1193	3342	1887	1662	1689	1889	1877	2301	1995	3777
BORN	2591	6768	2361	3108	2471	2753	1441	2359	2554	2193	1539	3041	2604	2342	2184	2589	2165	2705	2341	3337
BD	2067	2555	4602	3350	1865	2007	1537	1899	2131	1544	1190	2795	1970	2144	1634	2059	1759	2278	1796	13285
(+) HT	3014	3198	2599	5915	2647	2820	1683	2630	2662	2326	1662	3524	2695	2557	2360	2761	2495	3021	2549	3342
HBD	2181	2534	1455	3298	4882	1902	1206	1629	2130	1406	1004	2931	1671	1769	1993	1852	1536	3091	1658	2950
ELT	2146	2460	1626	2989	1518	4721	1230	1427	2289	1695	1141	2594	1812	1628	1440	1865	1349	2126	1874	2172
GS	1526	1742	1331	2131	1504	1397	2537	1429	1418	1144	884	1889	1411	1318	1392	1352	1368	1637	1244	4170
HW	1817	1809	1243	2513	1689	1420	892	5049	1461	1167	963	2476	1749	1286	1594	1407	1856	1920	1334	2072
HGL	2455	2721	1986	2892	2221	2389	1410	2060	4618	2018	1452	2732	2317	2086	2011	2139	1945	2466	2215	1825
KHM	1565	1865	1114	2178	1296	1474	836	1404	1828	3281	1022	2061	1409	1225	1122	1309	1307	1591	1446	1672
LW	1429	1580	1042	1672	1184	1246	753	1098	1393	1290	2660	1648	1363	1140	1111	1161	1044	1434	1308	2809
(+) NIWG	2942	3043	2314	3540	2610	2645	1540	2574	2465	1976	1430	5642	2385	2395	2352	2556	2393	3091	2182	2857
OPM	2407	2931	1941	3325	2340	2228	1312	2238	2368	1841	1352	3169	5397	2125	1932	2190	2042	2597	2106	1996
RDM	1445	2006	1104	2531	1268	1170	925	1188	1624	974	722	2348	1153	3573	1108	1321	1061	1887	1107	1590
SSH	2021	3022	1626	3598	1917	1792	1247	1937	2207	1428	1024	3435	1909	1734	3653	1848	1820	2365	1688	1667
SON	2998	3873	2476	4461	2529	2865	1619	2482	2863	2138	1494	3650	2492	2430	2211	5662	2344	3077	2369	2996
UT	3072	2711	2138	3242	2319	2779	1342	2593	2304	1993	1470	3340	2681	2194	2079	2287	4507	2700	2377	5108
WVN	2571	2426	1598	3110	2192	1965	1243	1874	2232	1741	1165	3045	2046	2093	1791	1744	1743	5601	2053	2772
ZL	2266	2452	1429	2906	1406	1895	1035	1377	2771	2028	1478	2726	1614	1341	1358	1628	1367	2006	4558	2414
(X) DOR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

It is important to mention that the number of items as presented in table 4.1 is not the same as the flow of parcels transported on the routes between the same node. The demand as shown in table 4.1 should be transported via a depot+, where RCs from different depots and with the same final destination will be bundled. Measurements concerning transport between depots using the current network will be discussed in section 4.2. Depending on the location and type of depot, an RC could be transported twice or once between depots as shown in figure 4.2.

4.2. Network

For the transportation of parcels between origin and destination depots, PostNL designed a web-structured network as described in section 2.2. Figure 4.3 shows how parcels should be transported according to the designed network based on visualisations of Swimlane models. This section presents the measurement of trips between locations to compare the current situation with the network design.

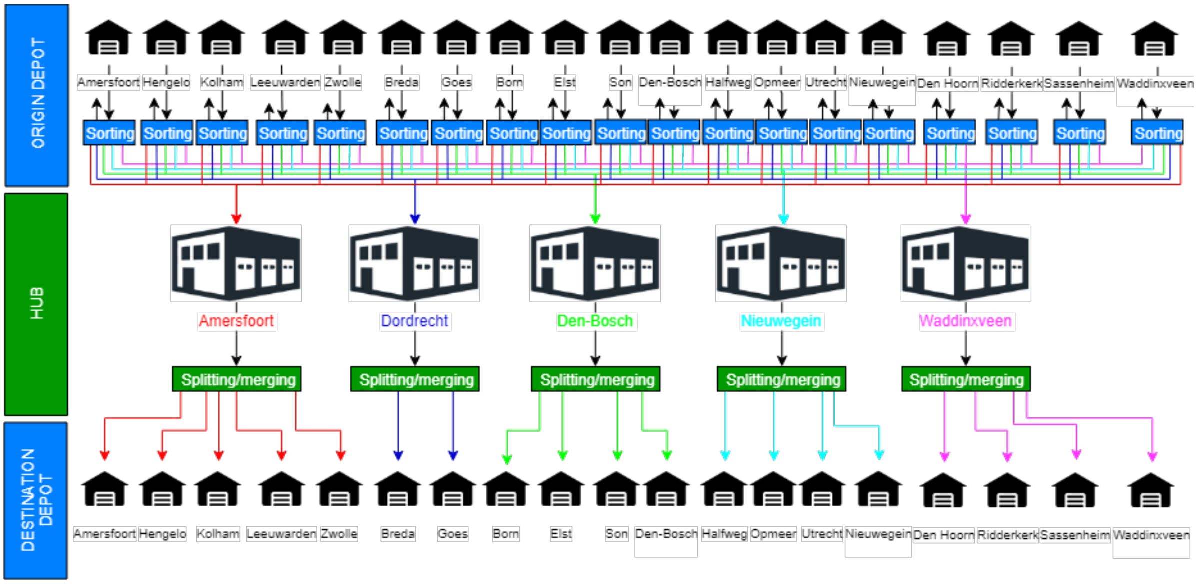


Figure 4.3: Network design by PostNL between origin depot and destination depot based on a web structure

The distribution process of parcels between locations, as depicted in figure 4.3, is intended to be as follow: First, at the origin depot, parcels will be sorted based on destination and loaded into RCs. When the destination of a parcel is the same as the origin, the parcel stays at their origin. After this first sorting, a truck leaves from every origin depot towards every depot+ in which every depot+ is linked with a couple of destination depots. This means, for example, that an outward truck at the depot of Hengelo towards depot+ Amersfoort is loaded with parcels intended for Amersfoort, Kolham, Leeuwarden and Zwolle. Further, inward transport from depots will be transferred at every depot+ based on their final destination. Finally, trucks leave the depot+ and drive to the final destination depot. It is important to mention that the places Amersfoort, Den-Bosch, Nieuwegein and Waddinxveen act as depot as well as depot+. In the case of Dordrecht, this depot+ only acts only as Crossdock (x) where splitting and merging of roll containers take place mainly intended for Belgium. The reason why this web structure is chosen is of its scalability concerning volume growth and flexibility to serve different demand streams. Appendix E shows the distances between the hubs based on Google Maps.

Trips between depots

PostNL's trip registration is be used as input for the determination of the average number of trips between depots. This register holds five parameters:

1. Date of trip
2. Origin and destination depot of the trip
3. Product sort
4. Number of RCs transported

The first two points should be crystal clear; the date concerns the moment of transport, origin-destination explains the pickup location and final destination of the trip. Point three 'Product sort' says something about the characteristics of the transported goods on that trip. In the case of PostNL, the following product sorts are used:

- Depotshift: The truck is loaded with RCs intended for a certain depot. However, this 'certain' depot does not have to be the final destination of the loaded demand. It could be possible that on the trip from Kolham to Waddinxveen demand with Ridderkerk as final destination is loaded.
- Emballage or mpty containers: These containers have to be transported between depots to be secure that every depot has enough containers for their internal processes
- Return shifts
- Export shifts
- Freight
- P.O Boxes
- Waste like paper, plastic, etc

The fourth trip detail given by the trip registration is the number of RCs transported. From expert interview as presented in Appendix I, it is known that a full truck is able to transport 48 RCs. However, when a truck also transports empty containers which are collapsible the truck's capacity increases. The following filter is used to determine the average number of daily trips:

1. Only trips with its origin as well as destination in the Netherlands are measured.
2. Only trips on days that all the depots are open. In other words, from Monday till Saturday that do not fall on a national holiday are taken into account.
3. Only trips with at least one domestic depot shift are taken into account.

Based on the trip registration of PostNL's first quarter from 01-01-2018 to 04-03-2018, it can be concluded that 192,485 individual trips have taken place performed by heavy trucks (>15t) for different purposes. By applying the first two filters, the total number of individual trips decreased from 192,485 to 60,474 with a daily average of 749 containing every product sort. The allocation of these trips are shown in Appendix E table E.2. By applying the last filter the average number of trips between depots comes down to 728 trips a day distributed as shown in table 4.2.

It has to be mentioned that on an average day the total number of trucks that leave a certain depot is not the same as the total number of trucks that arrives. This imbalance will be discussed at length in section 5.2. Another detail that comes from the trip registration document, was the time window of departure at a certain depot+. For every trip, a time window of 25 minutes to departure was measured to load a truck before departure.

Table 4.2: Average number of trips between depots with at least one depot shift loaded.

Depot	AMF (+)	BORN	BD	HT (+)	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG (+)	OPM	RD	SSH	SON	UT	WVN (+)	ZWL	DOR (X)	**TOTAL OUT**
(+) AMF	0	1	0	6	0	1	0	1	12	15	12	5	0	0	0	0	1	7	15	6	82
BORN	4	0	0	4	0	0	0	0	0	1	1	5	0	0	0	1	1	5	0	4	26
BD	5	1	0	6	0	0	0	0	1	0	0	6	0	0	0	0	1	6	1	7	34
(+HT)	6	14	1	0	1	16	0	0	1	1	0	6	0	0	0	17	1	6	1	5	76
HBD	5	1	0	4	0	0	0	0	0	0	0	4	0	0	0	0	1	4	0	3	22
ELT	3	1	0	3	0	0	0	0	1	0	0	4	0	0	0	0	1	4	1	3	21
GS	4	1	0	4	0	0	0	0	0	0	0	4	0	0	0	0	1	4	0	6	24
HW	4	1	0	4	0	0	0	0	0	0	1	3	1	0	1	0	1	4	0	4	24
HGL	4	1	0	5	0	1	0	0	0	0	0	5	1	0	0	0	0	5	2	4	28
KHM	4	0	0	4	0	0	0	0	0	0	1	4	0	0	0	0	0	3	0	3	19
LW	3	0	0	3	0	0	0	1	0	2	0	2	0	0	0	0	0	3	0	3	17
(+)NIWG	8	1	1	9	0	2	1	17	2	1	1	0	19	1	1	2	16	9	1	7	99
OPM	3	0	0	4	0	0	0	0	0	0	1	3	0	0	0	0	1	3	0	3	18
RD	3	1	0	3	0	0	0	0	1	0	0	4	0	0	0	0	0	3	0	4	19
SSH	4	0	0	4	0	0	0	0	0	0	0	4	0	0	0	0	0	3	0	3	18
SON	7	2	0	6	0	0	0	0	1	0	0	7	0	0	0	0	1	7	1	5	37
UT	5	1	1	3	1	1	0	1	1	0	0	3	1	1	0	1	0	3	1	3	27
(+)WVN	7	1	0	6	18	1	0	1	1	0	0	6	1	19	17	0	0	0	1	5	84
ZL	3	1	0	4	0	0	0	0	1	1	1	4	0	0	0	0	0	4	0	4	23
(X)DOR	0	0	16	1	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	30
TOTAL IN	82	28	19	83	20	22	14	21	22	21	18	79	23	21	19	21	26	83	24	82	

4.3. Transportation Fleet

The transportation between depots is called 'intern transport' and is done by heavy trucks of PostNL. As Table 4.3 shows, PostNL owns 151 trucks with a capacity of 23 tonnes and 23 vehicles with a max of 9 tonnes. The capacity of 23-t vehicles is 48 roll cages. The 9-t trucks fall in the category 'euro norm 5' while the other trucks are defined as 'euro norm 6'. These euro norms are focused on the maximum emission of fine dust and NO_x instead of CO_2 as stated by the European Union. Furthermore, from an expert interview it is known that the maximum speed of trucks is 85-90 km/h.

Table 4.3: Fleet intern transportation between depots.

Vehicle	#vehicles	Euronorm	Tonnage
Truck (Renault)	66	6	23-t
Truck (Iveco)	30	6	23-t
Truck (MAN)	55	6	23-t
Boxtruck (Scania)	23	5	9-t

Only MAN and Renault trucks are able to share data of their daily driving. Since these kinds of trucks represents 80% of the 23-t fleet, enough data is collected from which valid statements can be derived. As shown in Appendix D, table D.1 and table D.2 present the driving-related characteristics on a weekly average for the fourteen sample weeks. The weekly results depend on weather, driver, utilisation and mode characteristics as disused in chapter 3. As outlined in subsection 4.4, some measures to reduce the environmental impact of the logistical process at PostNL are already taken into account. One of these measures is 'cruise control' as shown in Appendix D. It is interesting to see that on a weekly basis around 47% of the total distance travelled cruise control is used. This could suggest that the training of drivers is paying off with regard to implementation.

4.4. CO_2 reduction related measures

A lot of measures are introduced by literature and industry to reduce the environmental impact of a transportation service. This section discusses different practical improvements which could have its potential in the parcel delivery industry. Focused on the case study at PostNL, also implemented and considered measures will be discussed. The structure of this subsection will be based on figure 3.3.

4.4.1. Vehicle related

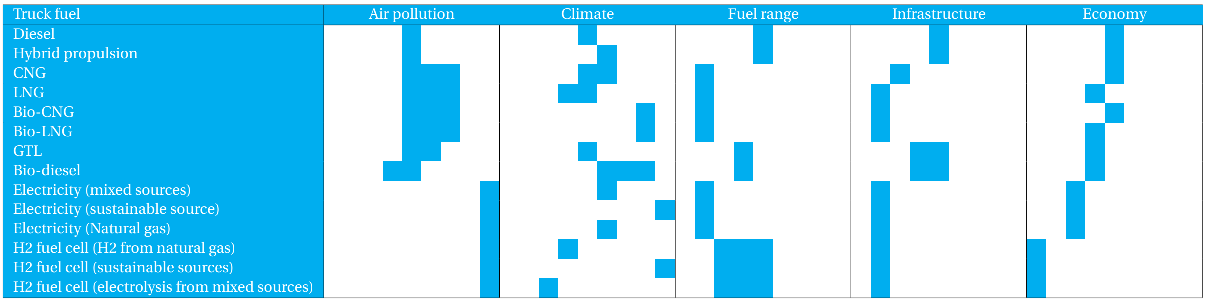
Vehicle-related modifications concern technical changes related to the vehicle. The following mentioned measures are improvements within the range of a company in the parcel delivery industry.

Vehicle Modifications. These modifications are measures focused on the reduction of CO_2 by the vehicle it selves. Research by Balm et al. (2013) shows the following CO_2 reduction related measures:

- Start/stop systems: Engine of the vehicle stops during stil standing moments. With regard to the case study at PostNL, this measure is not implemented because of the many stops during collection and distribution. During an interview with Eduard Veen (Appendix I) it became clear that this feature will not be useful because of the short distances between the many stops. The battery to restart the engine does not have enough distance to recharge in this way.
- Cruise control: In case of light vehicles, conventional cruise control can reduce the fuel consumption by 3.3% and with predictive eco-cruise control between 8% and 16% relative to manual driving (Park et al., 2013). Cruise Control plays an important role in the reduction of CO_2. Currently, the amount of time that a large truck drives by using cruise control is measured on a weekly base. In this way, PostNL is able to control the driver to use cruise control as much as possible.
- Speed limiter: According to TNO (Balm et al., 2013), modelled based research and practice showed that a fuel consumption saving of 6% to 8% is possible when the speed limit of a truck is reduced from 90 to 80 km/h
- Tyre pressure: An appropriate pressure of the tyres ensures three benefits. first, a reduction of the change of falling out vehicles. Secondly, there is a reduction in tyre wear and thirdly a reduction in fuel consumption. Balm et al. (2013) concludes that on a fleet level a reduction of 0.5% fuel reduction can be achieved when the pressure of the tyres is right.

Change in use of fuel. Different kind of fuels may also lead to a reduction in fuel consumption. Most of the changes are linked to the purchase of totally new vehicles which could be very costly. However, a change from diesel towards bio-diesel (a fuel based on organic products or hydrotreated vegetable oil) does not always request a modification of the engine. A rule of thumb by TNO (Balm et al., 2013) says that using biofuel can lead to a reduction in CO_2 of 50% WTW. Verbeek and van Zyl (2014) did research about the characteristics of different fuels concerning air pollution, climate, fuel range, infrastructure and economy. The results are shown in table 4.4. In this table, diesel is used as a reference. The other fuels are assessed relative to diesel.

Table 4.4: Different fuels and their characteristics in relation to diesel(Verbeek and van Zyl, 2014). The more to the left the worse the performance.



There can be concluded from table 4.4 that cleaner fuels on global level (climate) does not mean that the fuel is also clean on local level (air pollution). Despite the fact that bio-diesel emits fewer CO_2 in relation to regular diesel, the air pollution is increased which is also not favourable.

4.4.2. Driver related.

Currently, the driver is the controlling factor of the vehicle. He/she decides when to start,stop, break or speed up. Research by TNO (Balm et al., 2013) shows some interesting resuls about reduction in fuel consumption relating to training:

- Long distance level: up to 3% reduction
- City distribution level: up to 7% reduction
- Fleet reduction level: up to 1-4% reduction
- Driver reduction level: up to 8% reduction

During training sessions, it becomes clear to drivers what the importance is to fuel reduction and how to achieve this. A competition element is a useful tool to get the results high and keep them constant. Driver training is already implemented by PostNL. In particular, the focus on the use of cruise control, idle time or roll out time, plays an important role for PostNL and are measured on a weekly basis.

4.4.3. Operations related.

The mentioned factors in figure 3.3, are factors which are directly related to performing the operation. In particular, decision making on mid- or short term is customary with regard to operation related measures.

Fleet size & mix. This factor is mainly focused on the optimisation of asset management. Optimisation concerning this aspect is a combination between the aspect mode related (with vehicle characteristics as loading capacity, driving range, fuel consumption) and factors related to vehicle allocation. However, most carriers try to get this optimal as possible since the relation between fuel consumption and cost of allocation. Measures related to fuel reduction in fleet size & mix are mainly based on the vehicles, fuel and demand characteristics. For example, a fleet could be powered by different fuels (biofuels, electric engines, LPG or CNG). Currently, an electric truck is not able to drive further than 300 to 400 kilometres in combination with a charging time between 2 and 10 hours (Volvo trucks, 2018). This means that you have to allocate your fleet in a smart way using different types of assets to transport the given demand. The focus should be on the allocation of a heterogeneous with regard to a minimisation of CO_2. The different characteristics of fuels as shown in table 4.4 should be taken into account.

4.4.4. Network & Routing related

Planning. The case study of PostNL is currently based on demand forecasting between depots. However, an interview with Henk Verstraten (Process Manager PostNL Depot Ridderkerk) shows that the predicted and realised volume are quite far from each other. Such conditions, due to fluctuations in demand over time, lead to inefficient allocation of a fleet with empty kilometres at worst. A lot of potentials are possible in this area to make the transportation process of PostNL more efficient with a reduction in kilometres and so CO_2 emissions as result. Internet Of Things (IoT), currently a popular term which outlines the philosophy of an internet-based network between all kind of electronics to share their status and operations, could play an important role to fill the gap between prediction and reality. For example, smart algorithms used by large shippers of PostNL are able to predict the chance of purchasing goods, based on characteristics like user's online behaviour or weather characteristics. With a degree of certainty, this information could be shared with PostNL to make the vehicle planning more efficient. IoT might also be useful for the last mile delivery regarding communication between delivery man and customer.

Delivery service. In the parcel delivery industry, the delivery is mainly focused on time. The customer pays for a certain service related to delivery in a certain time window. Taking a look at the case study, the process at PostNL is currently focused on a certain area/region which has to be served. When a customer is not at home and the parcel cannot be delivered at a neighbour, it will be offered the next day unless the customer indicates online [1] that he/she wants to receive the parcel at another moment or place. When a customer is not able to receive the parcel the next day during the second offer, the parcel will be stored at a local pick up point of PostNL nearby. Situations as here described happens a lot and lead to many unnecessary driven kilometres and so unnecessary emissions of CO_2. Solutions as parcels boxes in apartment buildings or other public places should bring the hitrate [2] to a higher level. To increase the number of supplied services, PostNL also

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[1] untill 22 p.m. that day

[2] The number of delivered parcels against the total number of transported parcels in a van

performs a delivery service in a certain time window. The customer is able to select a desired time window of delivery and PostNL ensures that the job of shipping is done. Although the fact that the amount of unnecessary driven kilometres decrease because of a higher hitrate, there are some extra kilometres driven because of the time window constraint. Due to this constraint, it is too complex to perform this service in combination with the bulk stream of PostNL which means that this service will go through a different network. A different network means a less consolidated stream and so more driven kilometres with a lower utilisation. Based on the delivery service of DPD, a competitor of PostNL, it could be an improvement to bring the parcel to a local pick up point after the first moment a customer is not at home instead of the second moment. This should also lead to a reduction in needless distance travelled. Finally, this paragraph suggests to put the focus more on the total amount of CO_2 instead of time. Transportation is currently performed because of the delivery within a certain time window, small or large. Taking this constraint less strict into account, bundling of demand and reduction in the amount of empty kilometres can be a result. However, in this way the choice is in hands of the customer, which is focused on time, instead of the company. It will be quite hard to realise due to the high level of competitiveness in the parcel delivery market.

4.4.5. Modality related.

Modality is currently hot topic in the industry of parcel delivery. A lot of companies offer to deliver the last mile by environmental friendly modes, like electric bicycles or Pods. Also for postNL there are a lot of possibilities in this area. For example, PostNL as a company may do the last mile by electric bikes in the bigger and denser cities. However, depots at suburbs are required to distribute parcels over different areas since the fact that a bicycle has a lower range or lower capacity in terms of volume and weight.

III

Analyse

5

Performance current state

This chapter will discuss the performance of the current logistical processes between depots as measured in chapter 4. By analysing the measurements, the performance of the current state will be defined to be comparable with suggested improvements in coming chapters. Besides, assumptions and constraints of the current process as used in further chapters will be justified by analysis from this chapter. This chapter will be structured like figure 5.1: First, section 5.1 will outline the demand for PostNL that has to be transported on an average day. Because the encapsulation of load plays an important role, subsection 5.1 shows the relation between the transported items, volumes and Roll cages (RC). Besides, an analysis has been carried out regarding the potential of volume reduction per parcel by shippers. Section 5.2 discusses the characteristics focused on the used network and the number of trucks that are allocated to it. Since the vision of Physical internet sees empty travelling as unsustainable, the utilisation of trucks will be outlined in section 5.3. Consequently, section 5.4 will define the fleet characteristics as used in this report. The environmental impact of the current state will play an important role in the comparison with a Physical Internet based service network. For this reason, the total amount of CO_2 per day is calculated in section 5.5. To summarise the most impotent indicators for this report, section 5.6 is outlined. This chapter concludes in section 5.7 with the sub-question as stated below:

SQ4: How does the current logistical process of parcels at Post NL perform concerning their environmental impact in terms of CO_2?

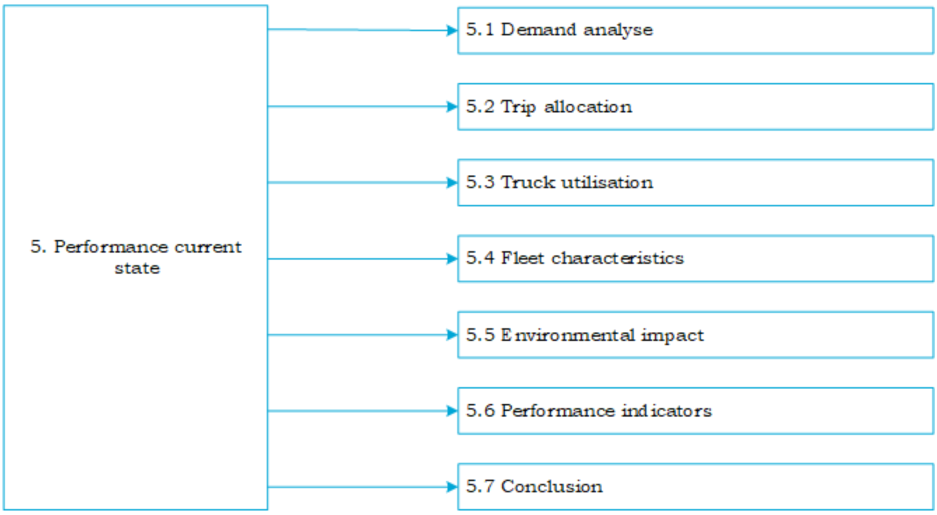


Figure 5.1: Structural overview of chapter 5

5.1. Demand Analyse

This subsection will discuss the analyses concerning the transported load between depots. Table 4.1 shows the average number of items that have to be transported between origin and destination. However, forecasting is performed for everyday to determine the expected demand. This forecast is based on a lot of factors like historic demand, expected growth, weather characteristics, sales periods of large shippers, payday of salary, holiday pay or social security checks. During a tour through one of the spokes (depots) of PostNL, it became clear that the forecast does not correspond to the real demand in most of the cases. During the day, the real demand becomes more clear during collection or by notifications. Corporate customers of PostNL have to register their shipments by online connections with PostNL. Parcels which are collected at PostNL pick-up-points are only registered during receiving.
Summation of the number of items between every origin-destination pair, concludes that the total number of transported parcels should be 863,395 items on average. To analyse this value with regard to its distribution, a measurement is taken over the same 81 days. This measurement, as shown in figure 5.2, present the total number of transported items per day including the average over these days. As can be concluded from figure 5.2, the average of 863,395 items per day based on origin-destination pairs differs only one item with the average transported items per day of 863,394 items per day.

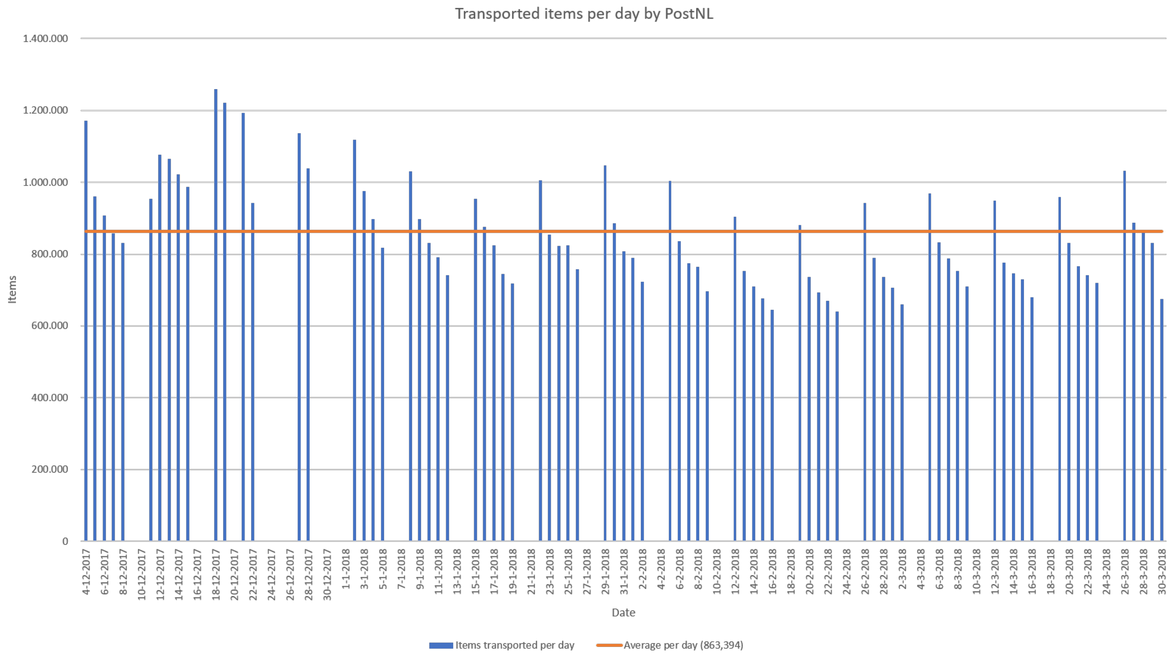


Figure 5.2: The total demand per day transported by PostNL in terms of items

Another observation from figure 5.2, is the clear structure in demand over the week. The week starts with a peak and decrease in demand as the week goes. Since this report takes an average weekday into account, it is sufficient to take the daily average into account. Of course, relative to Mondays this value will be too low and relative to Fridays this value will be too high. To say something about the reliability of the used average, a confidential interval is used concerning a sample of 81 measurements based on the total number of items per day instead of averages on origin-destination pairs. The last column of table 5.1 shows with 95% confidence the interval of the average total number of items transported.

Table 5.1: Confidence interval total number of items transported per day

Sample mean	Sample deviation	Sample size	$t_{0.05,80}$	95% Confidence interval
863,394	148,366	81	1.99	[830588, 896200]

Since the fact that 863,395 lies within the range of [830588, 896200], it should be reliable enough to use the measured number of items as shown in table 4.1. However, from the standard deviation as shown in table

5.1 it becomes clear that the total number of items transported fluctuates a lot.

Conclusion: Due to the pattern during the week, it is sufficient to use an average in items between origins and destinations to say more about the transported demand on average. The average volume of 863,395 is confident enough to use in relation to the average based on total transported items per day.

5.1.1. Relation item - volume - RC

For the period between 04/12/2017 and 30/03/2018, the total transported items and volumes have been measured. The results of transported items and volumes between origin and destination on average are presented in chapter 4. From analysi of the total volume per parcel per day transported in that same period between origin and destination, it can be concluded that there is a lot of variances. Figure 5.3 shows the average volume per parcel per day between 04/12/2017 and 30/3/2018.

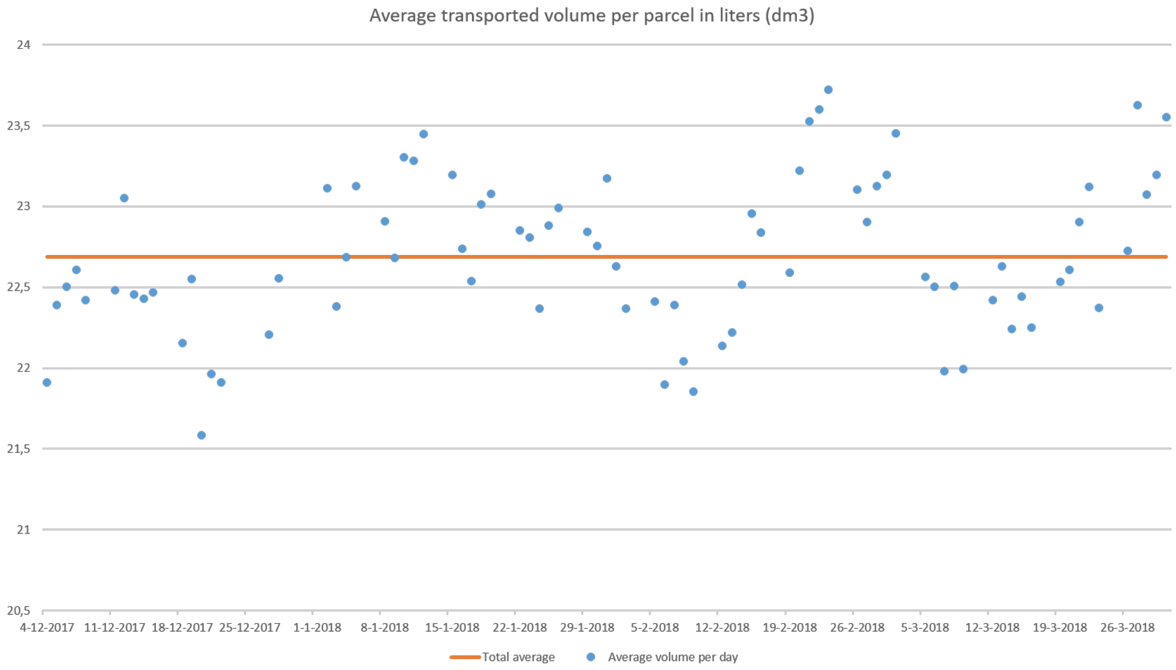


Figure 5.3: Calculated average volume per parcel between 04/12/2017 and 30/03/2018

A couple of trends are noticeable from figure 5.3. First of all, the period between 04/12/2017 and 30/03/2018 consists of at least two holidays which contributes to an increase in parcel items, Christmas and Valentine's day. In the run-up to these days, it is prominent that the average volume per parcel decrease compared to other days due to the increase in small parcels like presents. For the days besides Christmas and Valentine's day, it can be concluded that the average volume per parcel increases. This could be a result of buying more winter-related attributes by shipper its customers. Based on the data measured between 04/12/2017 and 30/03/2018,, the average volume per item is 0.0227 m^3 or 22.7 litre (horizontal line in figure 5.3). A statistical test with regard to the measurement shows the confidence interval as shown in table 5.4. There can be concluded with 95% confidence that the average volume per parcel is between 22.68L and 22.79L.

Table 5.2: Confidence interval average volume per parcel in liters.

Sample mean	Sample deviation	Sample size	$t_{0.05,80}$	95% Confidence interval
22.68	0.47	81	1.99	[22.58, 22.79]

Validation: This average volume of 0.0227 m^3 per parcel suggests that on average a 'Gray container' with a capacity of 0.66 m^3 is able to transport 30 parcels and a 'parcel container' with a capacity of 1.04 m^3 is able to transport 46 items. Assuming that a truck trailer is 50/50 loaded with both kind of containers, there can be said that every roll container is loaded with 37 items on average. Although this calculation is quite rough and based on averages, the calculated capacity of 37 items per roll cage is the same as the assumed by PostNL (Expert interview Appendix I).

Conclusion: On average one single parcel will have a volume of $0.0227\,\mathrm{m}^3$. Moreover, it will be assumed that one single roll container is able to transport 37 items.

5.1.2. Reduction in volume per item

One of the first mentioned supporting factors of unsustainable logistical networks is the shipping of air and packaging by carriers (Montreuil, 2011). Research by Gerard Peeters (2017) supports this statement by showing that on average a package consists of 30% to 40% air. Although this space could be used to protect the product by paper or plastics, in most cases it is the laziness of the shippers which leads to big standardised boxes for small products. To say more about the effects concerning volume reduction per parcel further this research, analyses have to be performed concerning volume reduction.

Since December 2017, one of PostNL's largest customers made an important change in packaging. By making use of a new machine, Coolblue as a customer of PostNL is able to make tailored boxes for every parcel they send. In this way, the machine is able to reduce packaging material and air which results in a lower volume per item. To analyse the implementation of such a machine, it was necessary to plot the average volume per parcel relative to the date as shown in figure 5.4.

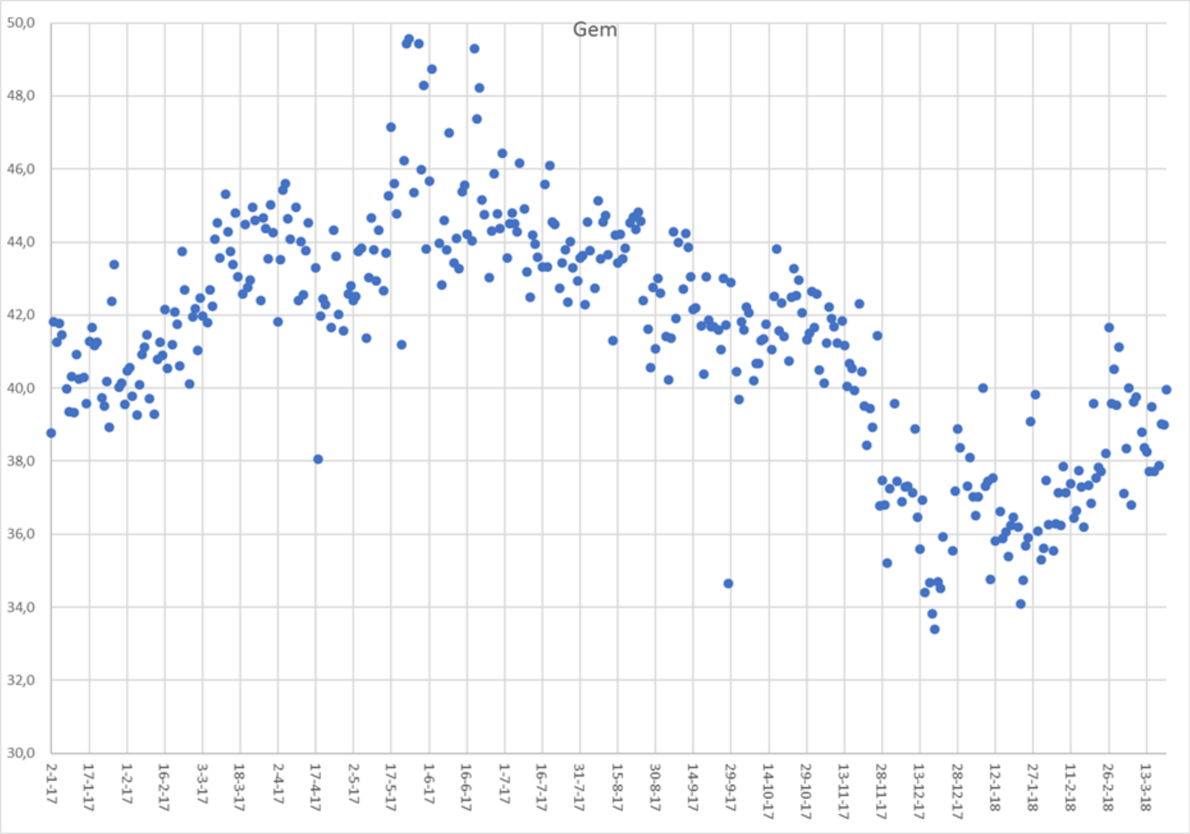


Figure 5.4: The average volume per parcel over time collected between January 2017 and March 2018 at Coolblue in Tilburg

Comparing the first quarter of 2017 with the first quarter of 2018 in figure 5.4, it can be concluded that there is a reduction in volume per parcel on average as a result of using the new machine. In Q1 2017 the average parcel volume collected at Coolblue was 41.4L. It is remarkable to see that the average volume per parcel is reduced by 9% to 37.5L in Q1 2018. This reduction shows that there is enough potential to reduce the amount of air per parcel. Despite the potential for reduction and possible effects as discussed further on in this research, it will be quite hard to force shippers to reduce their supply in terms of volume per parcel from a commercial perspective. The competition is pretty high in the delivery industry. A measure like volume based pricing may scare customers and result in depopulation.

Validation: According to Mike Zuurbier, sales consultant packaging at PostNL, there are a couple of reasons why there is not much attention to volume reducing measures by customers. First, because a machine to make tailored boxes as introduced before is way too expensive for small customers. The cost range of such a machine is between 800,000 and 1.3 million euros. Secondly, when PostNL enforces customers to reduce their weight, for example by implementing volume based pricing, it is expected that customers will switch towards competitors. This statement highlights the fact that "The customers are always right" and so it will be hard to force customers. However, this research will take a possible volume reduction into account in upcoming chapters and show the effects concerning internal transport between hubs.

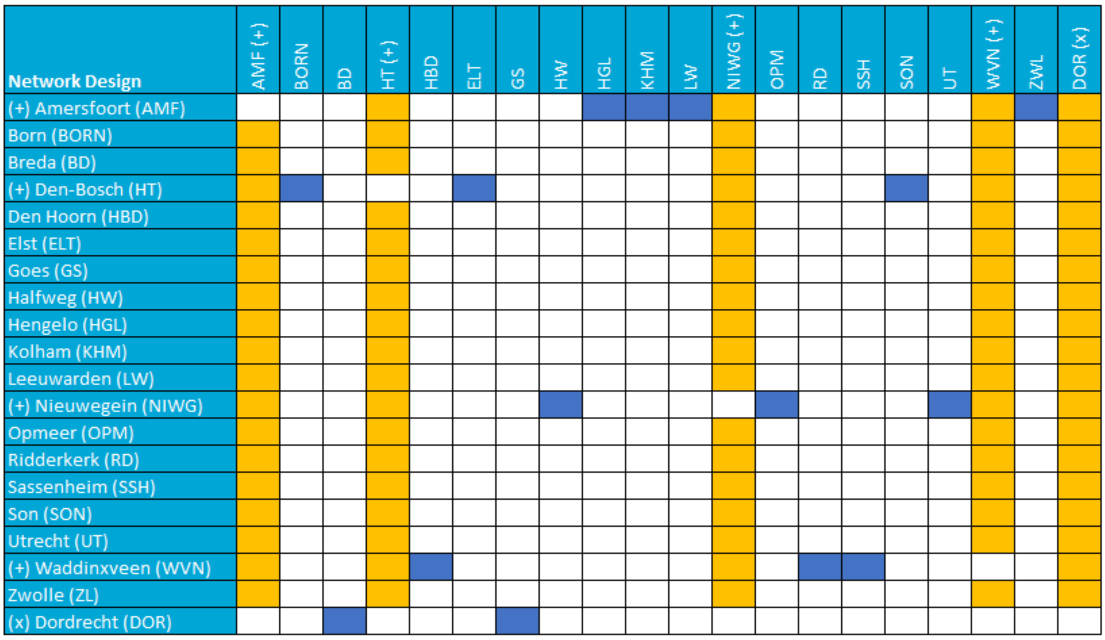
Conclusion: There is a lot of potential in terms of volume reduction per parcel. However, concerning commercial interests, it is expected that it will be hard to pressure customers.

5.2. Trip allocation

This section will discuss characteristics concerning the trip allocation as measured in chapter 4. Currently, allocation of trucks is based on demand prediction. When a certain demand is predicted per single day, the planning department of PostNL allocated different trucks to the network for the transportation of demand as discussed before. Besides, during the day extra information becomes clear coming from shippers which result in anticipation of the planning department. In the following paragraphs, the measured number of trips which create a network between locations will be compared with the designed network as described in section 2.2.

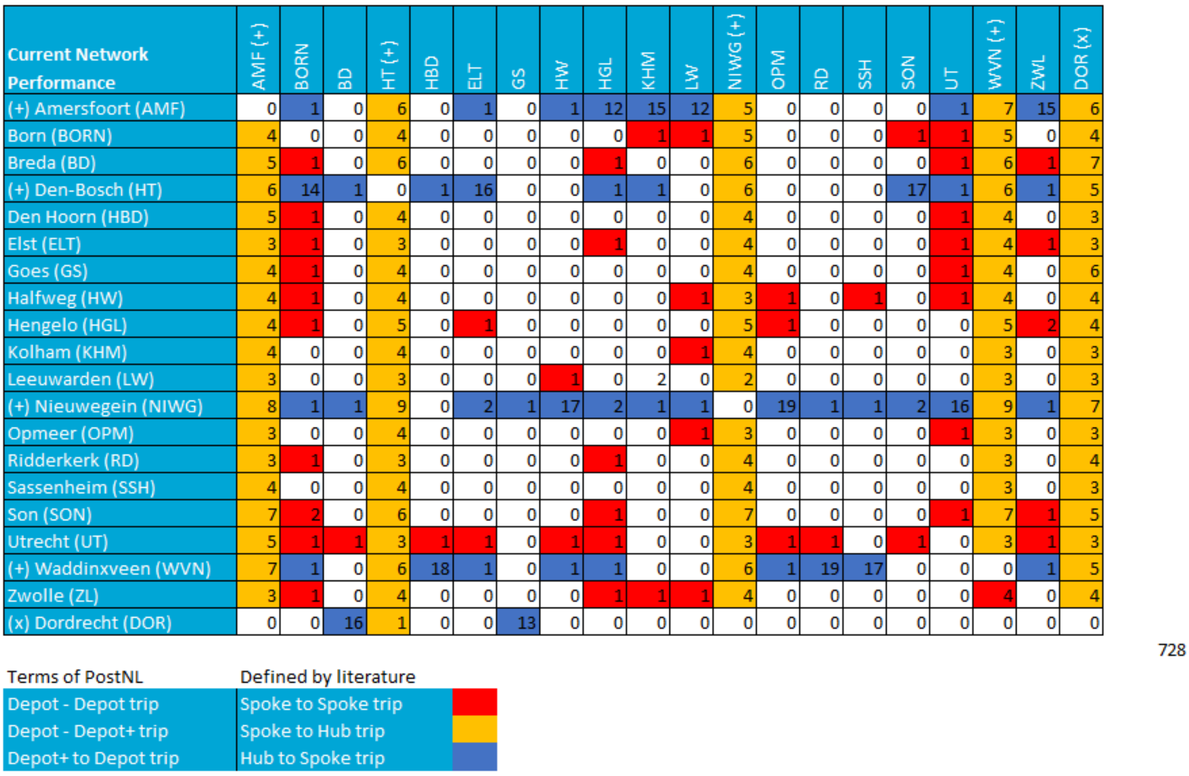
Measurements with regard to the network structure showed some remarkable facts. First of all, the measured trips between depots are not in balance. Although the total number of trips attracted is the same as the total number of trips produced, there is no sign of trip balance at depot level. The lack of trip balance at this level could be explained by two reasons. First, the number of trips between depots is on average based on 79 measurements. By using averages instead of one single measurement, it could be possible that the trips at the depot will be out of balance. The second reason why this occurs is the mix of owned trucks and trucks of third parties. For owned trucks, it is sure that trips will go back towards the origin. However, trips performed by third party trips (scope 3) could originate from a different location, like their own home base. This ensures that a truck just appears without the registering an inward trip. The second remarkable fact is the number of trips between depots which does not meet the network design. Figure 5.6 shows the difference between the network design (left) relative to the trips as measured (right). First of all, the web structure as intended by PostNL does not make use of single allocation. Most of the nodes are served by more than one hub (Depot+ in terms of PostNL). Besides, there are a lot of spoke-to-spoke trips without involving transhipment at a hub. To make this difference more clear and visual, figure 5.5 is developed to analyse the current situation in relation to the design. The difference in trips could be explained by a couple of reasons.

First, it could be possible that a depot generates enough volume for only one destination that the planning department decided to send the parcels from origin to destination without transhipment at a depot+. Secondly, it could be due to ad-hoc decision making of the planning department. Taking a look at figure 5.5, there can be noticed that the number of trucks allocated on design links is significantly higher than the number of trucks allocated to non-design links. Demand, time and truck availability could be reasons to take a certain ad-hoc decision into account. Besides, for the Planning department fuel saving plays also an important role for the purpose of cost minimisation. Thirdly, it is possible that the main goal of the trip between depots is not focused on the transportation of parcels but on other purposes like empty containers, waste, export or relocation of trucks for other depot shifts. By using the first assumption during data collection as discussed in section 4.2, it was intended to filter these kinds of trips out of the data. However, when these trips have at least one depot shift, which could be 1 RC to 48, these trips were taken into account. This resulted in the conclusion that on average 728 trucks are driving through the network based on the average number of trips between locations. These trips make use of 184 different links/routes from i to j.



Network Design	AMF (+)	BORN	BD	HT (+)	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG (+)	OPM	RD	SSH	SON	UT	WVN (+)	ZWL	DOR (x)
(+) Amersfoort (AMF)				🟧					🟦	🟦	🟦	🟧						🟧	🟦	🟧
Born (BORN)	🟧			🟧								🟧						🟧		🟧
Breda (BD)	🟧			🟧								🟧						🟧		🟧
(+) Den-Bosch (HT)	🟧	🟦				🟦						🟧				🟦		🟧		🟧
Den Hoorn (HBD)	🟧			🟧								🟧						🟧		🟧
Elst (ELT)	🟧			🟧								🟧						🟧		🟧
Goes (GS)	🟧			🟧								🟧						🟧		🟧
Halfweg (HW)	🟧			🟧								🟧						🟧		🟧
Hengelo (HGL)	🟧			🟧								🟧						🟧		🟧
Kolham (KHM)	🟧			🟧								🟧						🟧		🟧
Leeuwarden (LW)	🟧			🟧								🟧						🟧		🟧
(+) Nieuwegein (NIWG)	🟧			🟧				🟦					🟦				🟦	🟧		🟧
Opmeer (OPM)	🟧			🟧								🟧						🟧		🟧
Ridderkerk (RD)	🟧			🟧								🟧						🟧		🟧
Sassenheim (SSH)	🟧			🟧								🟧						🟧		🟧
Son (SON)	🟧			🟧								🟧						🟧		🟧
Utrecht (UT)	🟧			🟧								🟧						🟧		🟧
(+) Waddinxveen (WVN)	🟧			🟧	🟦							🟧		🟦	🟦					🟧
Zwolle (ZL)	🟧			🟧								🟧						🟧		🟧
(x) Dordrecht (DOR)			🟦				🟦													

(a) Network design



Current Network Performance	AMF (+)	BORN	BD	HT (+)	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG (+)	OPM	RD	SSH	SON	UT	WVN (+)	ZWL	DOR (x)
(+) Amersfoort (AMF)	0	🟦 1	0	🟧 6	0	🟦 1	0	🟦 1	🟦 12	🟦 15	🟦 12	🟧 5	0	0	0	0	🟦 1	🟧 7	🟦 15	🟧 6
Born (BORN)	🟧 4	0	0	🟧 4	0	0	0	0	0	🟥 1	🟥 1	🟧 5	0	0	0	🟥 1	🟥 1	🟧 5	0	🟧 4
Breda (BD)	🟧 5	🟥 1	0	🟧 6	0	0	0	0	🟥 1	0	0	🟧 6	0	0	0	0	🟥 1	🟧 6	🟥 1	🟧 7
(+) Den-Bosch (HT)	🟧 6	🟦 14	🟦 1	0	🟦 1	🟦 16	0	0	🟦 1	🟦 1	0	🟧 6	0	0	0	🟦 17	🟦 1	🟧 6	🟦 1	🟧 5
Den Hoorn (HBD)	🟧 5	🟥 1	0	🟧 4	0	0	0	0	0	0	0	🟧 4	0	0	0	0	🟥 1	🟧 4	0	🟧 3
Elst (ELT)	🟧 3	🟥 1	0	🟧 3	0	0	0	0	🟥 1	0	0	🟧 4	0	0	0	0	🟥 1	🟧 4	🟥 1	🟧 3
Goes (GS)	🟧 4	🟥 1	0	🟧 4	0	0	0	0	0	0	0	🟧 4	0	0	0	0	🟥 1	🟧 4	0	🟧 6
Halfweg (HW)	🟧 4	🟥 1	0	🟧 4	0	0	0	0	0	0	🟥 1	🟧 3	🟥 1	0	🟥 1	0	🟥 1	🟧 4	0	🟧 4
Hengelo (HGL)	🟧 4	🟥 1	0	🟧 5	0	🟥 1	0	0	0	0	0	🟧 5	🟥 1	0	0	0	0	🟧 5	🟥 2	🟧 4
Kolham (KHM)	🟧 4	0	0	🟧 4	0	0	0	0	0	0	🟥 1	🟧 4	0	0	0	0	0	🟧 3	0	🟧 3
Leeuwarden (LW)	🟧 3	0	0	🟧 3	0	0	0	🟥 1	0	2	0	🟧 2	0	0	0	0	0	🟧 3	0	🟧 3
(+) Nieuwegein (NIWG)	🟧 8	🟦 1	🟦 1	🟧 9	0	🟦 2	🟦 1	🟦 17	🟦 2	🟦 1	🟦 1	0	🟦 19	🟦 1	🟦 1	🟦 2	🟦 16	🟧 9	🟦 1	🟧 7
Opmeer (OPM)	🟧 3	0	0	🟧 4	0	0	0	0	0	0	🟥 1	🟧 3	0	0	0	0	🟥 1	🟧 3	0	🟧 3
Ridderkerk (RD)	🟧 3	🟥 1	0	🟧 3	0	0	0	0	🟥 1	0	0	🟧 4	0	0	0	0	0	🟧 3	0	🟧 4
Sassenheim (SSH)	🟧 4	0	0	🟧 4	0	0	0	0	0	0	0	🟧 4	0	0	0	0	0	🟧 3	0	🟧 3
Son (SON)	🟧 7	🟥 2	0	🟧 6	0	0	0	0	🟥 1	0	0	🟧 7	0	0	0	0	🟥 1	🟧 7	🟥 1	🟧 5
Utrecht (UT)	🟧 5	🟥 1	🟥 1	🟧 3	🟥 1	🟥 1	0	🟥 1	🟥 1	0	0	🟧 3	🟥 1	🟥 1	0	🟥 1	0	🟧 3	🟥 1	🟧 3
(+) Waddinxveen (WVN)	🟧 7	🟦 1	0	🟧 6	🟦 18	🟦 1	0	🟦 1	🟦 1	0	0	🟧 6	🟦 1	🟦 19	🟦 17	0	0	0	🟦 1	🟧 5
Zwolle (ZL)	🟧 3	🟥 1	0	🟧 4	0	0	0	0	🟥 1	🟥 1	🟥 1	🟧 4	0	0	0	0	0	🟥 4	0	🟧 4
(x) Dordrecht (DOR)	0	0	🟦 16	🟧 1	0	0	🟦 13	0	0	0	0	0	0	0	0	0	0	0	0	0

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Terms of PostNL	Defined by literature	
Depot - Depot trip	Spoke to Spoke trip	🟥
Depot - Depot+ trip	Spoke to Hub trip	🟧
Depot+ to Depot trip	Hub to Spoke trip	🟦

(b) Measured trips between locations

Figure 5.5: Trips between depots according to the network design (5.5a) relative to the trips in reality (5.5b). Orange cells shows the trips from depot to depot+, blue from depot+ to depot and finally red cells trips from depot to depot.

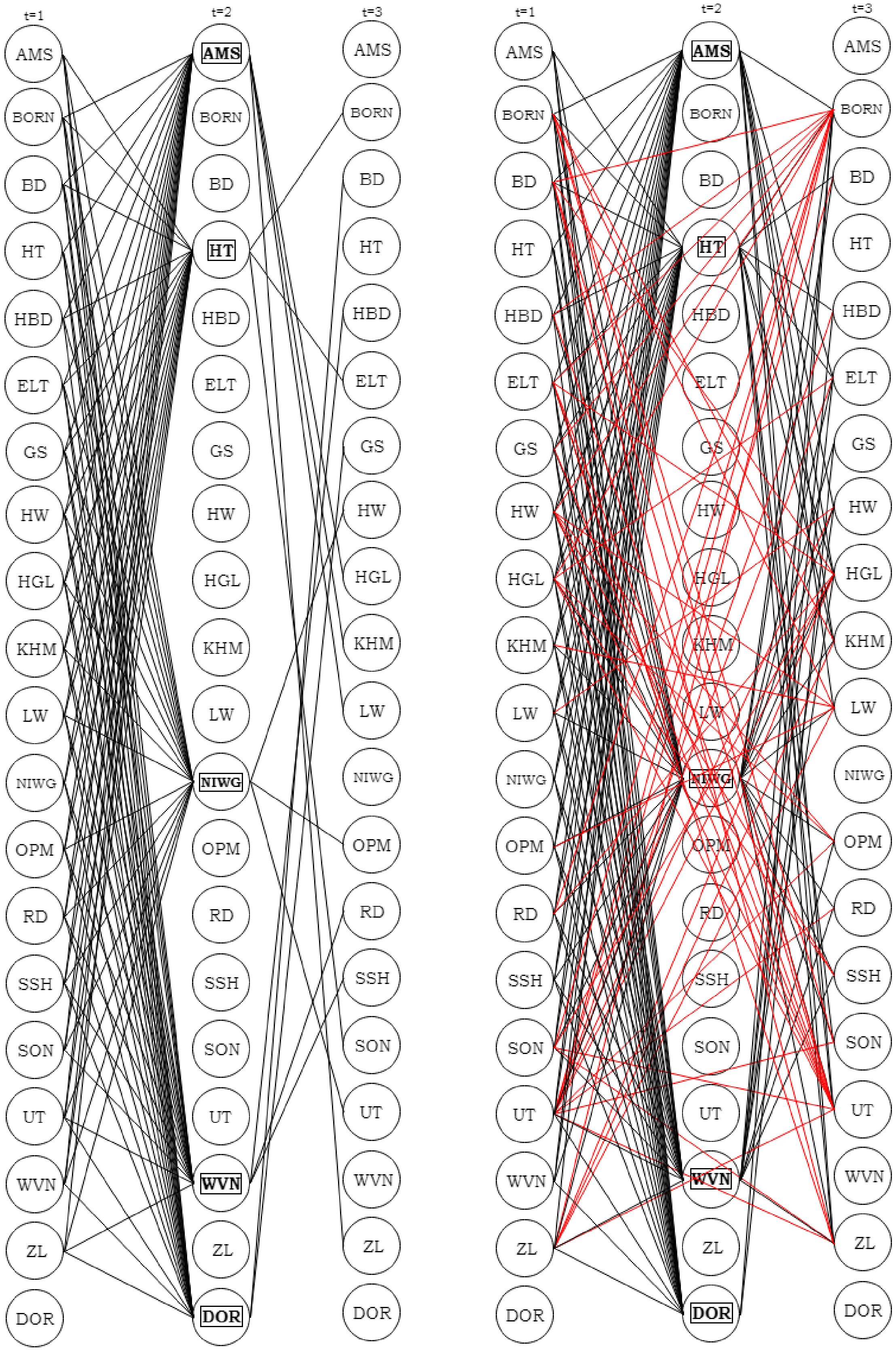

Figure 5.6: Time-space representation from t=1 until t=3 of the network design (left) in relation to the measured state (right). The black lines represent spoke-to-hub trucks or hub-to-spoke trips while the red lines define the measured spoke-spoke trips. Current hubs are defined with bold location names.

To say more about the reliability of the assumed 728 trips per day, a comparison can be made in relation to the confidence interval as shown in table 5.3. This 95% confidence interval is calculated by the equation $\bar{X} \pm t_{n-1,\alpha} \frac{s}{\sqrt{n}}$ based on total number of trips per day instead of the number of trips between locations per day.

Table 5.3: Confidence interval total number of trips per day

sample mean	sample deviation	sample size	$t_{0.05,78}$	95% Confidence interval
733	143	79	1.99	[703 , 763]

Since the average number of 728 is within the range of [703,763], it can be concluded that the used figure 5.5b should be reliable enough in relation to the sample of table 5.3. Using the number of trips between locations from figure 5.5 in combination with the total distance between locations as shown in figure E.1 of Appendix E, it can be said that 64,788 kilometres are travelled on average per day concerning transportation between depots.

Validation: As becomes clear from table 5.3, the deviation in the number of trips per day is significant. Comparing the values as analysed in this subsection with the assumed rule of thumb used by PostNL, could be helpful to say more about the correctness in order of magnitude. According to Peter van Soest (Strategic planner transport PostNL), a parcel will be transported by 1.66 trucks from origin to destination depot. In this way, the transport of 863,395 items as calculated in section 5.1 will result in 1,433,236 single parcel movements. However, by using trucks loaded with RCs which have a combined capacity of 1776 items per truck, this would suggest that 807 trucks are needed to transport the demand through the network. This result of 807 trucks is higher than the measured state of 728 trucks. Although this differs in value, the measured value of 728 trips will be used. First, because this value is based on a sample which should be large enough to say more about the population. Secondly, the deviation of table 5.3 shows that the amount of trips per day fluctuates a lot over the days. Finally, the rule of thumb used by PostNL and the number of trips are based on assumptions and averages which could change in time.

Conclusion: It is expected that the current state performs 728 trips in total as distributed in figure 5.5b by using 184 routes. This means that on an average day, the total amount of distance travelled comes down to 64,788 kilometres.

5.3. Truck utilisation

Due to the fact that this report is focused on the vision of Physical Internet, utilisation of trucks during transportation plays an important role. As described in chapter 3, Montreuil (2011) defines that empty travelling is one of the symptoms that contributes to an inefficient and unsustainable definition of today's road transportation networks. Concentrating on the current state concerning empty travelling, it can be concluded from figure 5.7 that there is quite some fluctuation in empty kilometres per day. Furthermore, figure 5.7 shows a clear relation between the number of empty trips and amount of empty kilometres: the more empty trips the more empty kilometres driven. Figure 5.7 does not show any days with fewer empty trips in combination with a high amount of empty kilometres. In other words, it can be concluded that when an empty trip occurs it drives as little kilometres as possible kilometres. Taking the average concerning empty trips per day, it can be concluded that there are 28 empty trips which travel 2,411 kilometres on a daily base. Besides empty trips, the statement by Montreuil (2011) concerns the utilisation of single parcels, as discussed in section 5.1.2, as well as the utilisation of trucks. From the data set concerning trip registration, measured between 2nd of January until the 4th of April, the number of RCs that are transported relative to the capacity of 48 RC per truck can be outlined. Figure 5.8 shows the average truck utilisation per day by using dots for trips related to a depot shift and with a max of 48 RCs loaded. Trips with more roll cages loaded, for example during distribution of empty containers which could be stacked, are not taken into account. The average of these daily averages shows that a truck is loaded for 84% as a horizontal line in figure 5.8.

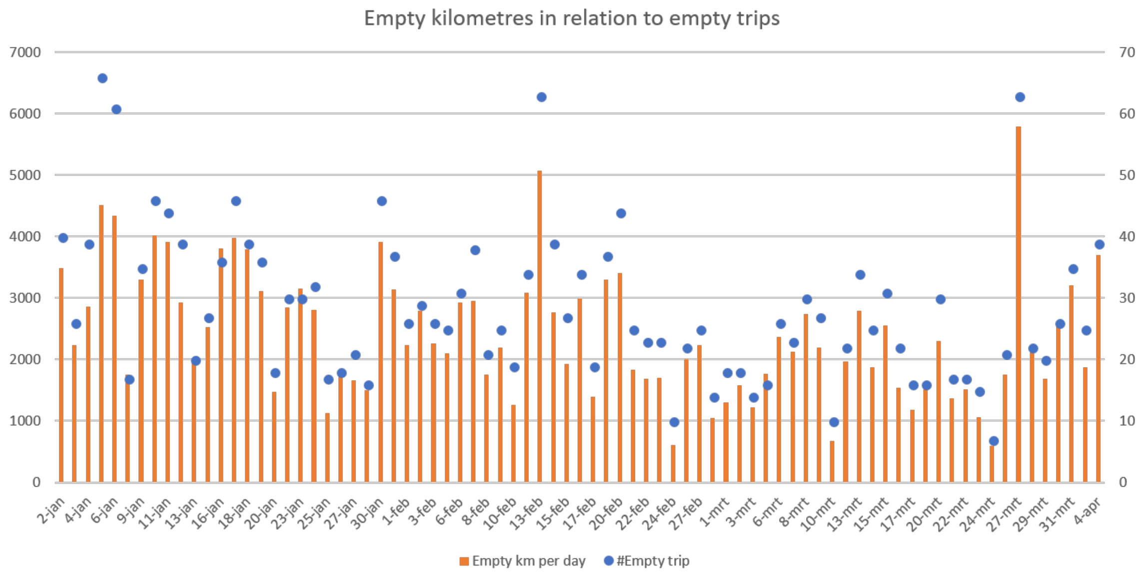

Figure 5.7: Empty kilometres on average per day (left axis) in relation to the amount of empty trips per day (right axis) between 2 January and 4 of April

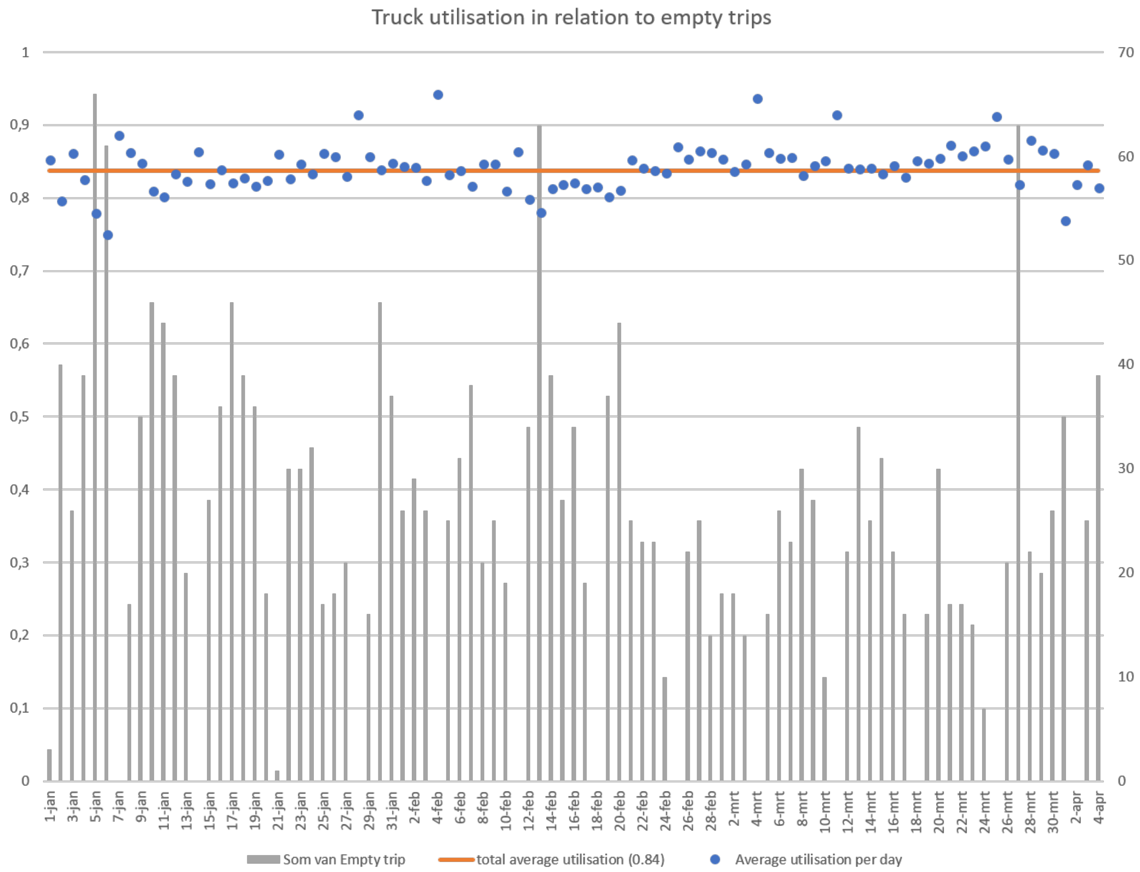

Figure 5.8: Calculated truck utilisation on average per day (left axis) in relation to the number of empty trips per day (right axis) between 2 January and 4 of April

At the first sight, a total average of 0.84 (or 84%) seems quite high. Especially in combination with the number of empty trips during the day. One of the most important reasons is that the planning department tries to plan the transportation as efficient as possible with regard to driven kilometres. Where this report is focused on emitting as little CO_2 as possible, the planning department is mainly focused on financial interest. The fewer kilometres driven, the less costs in terms of fuel, truck and driver costs. Although most of the dots seem quite close to the average line, there are also some outliers. To show the reason of these outliers in utilisation, it is interesting to add the number of empty trips per day as grey column in figure 5.8. An empty trip is defined as a trip between two locations with less than 1 RC loaded. This could occur, for example, when there are more trips towards a depot than outwards from this depot. This means that when a certain trip is done, it could be possible that trucks are planned empty towards other depots or back to the origin. Concerning the last case, when on a certain route a fully loaded truck travels from A to B and it has to go back empty to A, the utilisation on that specific route for that day is on average $1 + 0 = 0.5$. Finally, it is important to mention that this truck utilisation is based on the number of RCs per truck. It does not say anything about the utilisation of a single RC.

Validation: According to Peter van Soest (Strategic planner transport PostNL), the average utilisation of a truck is around 86-87%. This means that the result of 84% comes quite close to the mentioned statement by Peter van Soest. In addition, he mentioned that forecast has to play an important role in planning trips on a short-term on a dynamic network. The earlier PostNL knows which RC has to go from origin A to destination B the better and more efficient they can plan trips between depots.

Conclusion: The average utilisation of trucks on a day is around 84%-87%. It can be concluded that the number of empty trips plays a very important role in the average daily truck utilisation. Almost all peaks in figure 5.8 are accompanied by low utilisation on a daily base. A higher utilisation is only possible when forecasting performs better.

5.4. Fleet characteristics

In section 4.3 measurements are shown concerning PostNL's MAN and Renault trucks for the first 14 weeks of 2018. This measurement covers 121 out of 151 23-t trucks. Because most of the transport between hubs is done by 23-t trucks, it is assumed that the total fleet of PostNL consists of max 151 trucks. Analysing the fuel consumption of the known 121 trucks as data set, it can be concluded that the average fuel consumption per truck is defined as 26.9 L per 100 kilometres. Figure 5.9 shows the different measurements per truck type and the average overall as a horizontal line.

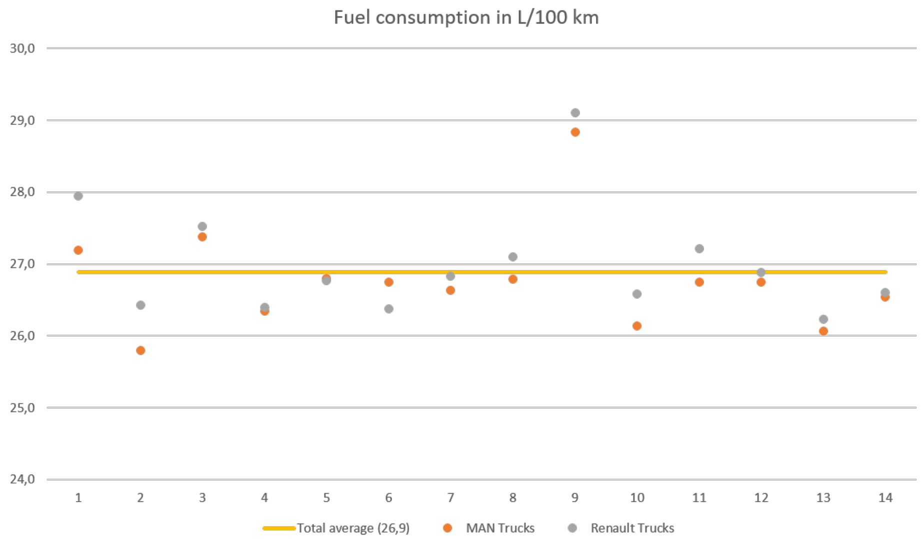

Figure 5.9: Calculated average fuel consumption for MAN and Renault trucks

As mentioned before, the measurements from figure 5.9 are taken within the first fourteen weeks of 2018. Most of the data points are close to the average level of 26.9 L/100 km which means that the standard deviation is quite small. One of the outliers, like the measurement of week 9, can be explained by weather characteristics.

Table 5.4: Confidence interval concerning fuel consumption in L/100 km

Sample mean	Sample deviation	Sample size	$t_{0.05,80}$	95% Confidence interval
26.9	0.75	28	2.05	[26.60, 27.17]

It is assumed in this report that the average speed of a truck is around 71 kilometres an hour based on the following assumption: First, the real speed on highways will be close to the maximum speed of 85-90 km/h since most of the trips will be during the night which means less dense traffic. Secondly, the first and last mile to/from the highway ensures a lower average speed with regard to the maximum speed. A commonly used assumption by the strategic transport planning department at PostNL (Peter van Soest), is that a single trip for inter depot transport is around 89 kilometres and takes 75 minutes. This means that on average, a truck drives 71.2 kilometres an hour. Combining this statement with the less dense traffic during the night, it should be likely to assume that a truck drives 71 km/h on average.

Conclusion: Transportation of parcels will only take place by 23-t trucks with an average fuel consumption of 26.9L/100 km per truck driving 71 km/h.

5.5. Environmental impact

This section shows the average amount of CO_2 emitted per day based on the average number of trips between locations. This amount of CO_2 is calculated for two cases. First, the amount of CO_2 emitted by all 748 trips as measured. In this way, the total amount of emitted CO_2 can be compared with the amount of CO_2 according to Ecofys and calculations by PostNL. Secondly, the amount of CO_2 will be calculated related to trips with at least one depot shift loaded, 728 trips in total. In this way, the performance of improvements in further chapters in terms of CO_2 can be compared. The following assumptions are used to calculate the environmental impact per day:

1. The distance between hubs as given in table E.1
2. The average number of trips as given in table E.2
3. The average number of depot shift related trips as given in table 4.2
4. The average fuel consumption of 26.9L/100 km as analysed in section 5.4
5. A conversion factor of 2.6502 kgCO_2/L diesel determined by Hill et al. (2017)
6. There are 306 working days and 59 Sun- or holidays
7. The amount of emitted emissions on Sun- or holidays will be the same for both cases
8. 40% of the daily trips are performed by trucks op PostNL (S1, S2) against 60% outsourced (S3)

The distance between hubs is based on data from Google Maps. For this report, it is assumed that the distance from A to B is the same as the distance from B to A. To convert the amount of used fuel to emitted kgCO_2, the same conversion factor as used by PostNL is used which is based on research and analysis by the Department for Environment Food and Rural Affairs and the Department for Business, Energy and Industrial Strategy in Great Britain (Hill et al., 2017). This department developed different conversion factors, also called DEFRA factor, to report greenhouse gas emissions related to the consumption of different kind of fuels. With regard to diesel fuel, this DEFRA factor is 2.6502 kgCO_2/L Diesel TTW[1] (Scope 1). To make the calculation comparable with emissions calculated by PostNL or Ecofys, all days of the year have to be covered. As mentioned before, trips from section 4.2 are only focused on working days, which means Mondays to Saturdays. Based on 2017, it is expected that there are 306 working days and 58 Sun- holidays. Concerning the Sun- and holidays, a sample from the data is taken as shown in Appendix E. However, since the fact that this amount of CO_2 is quite small relative to working days and mostly performed for a small part of the demand, it is assumed to be equal for both cases. Finally, to distribute the emitted emissions performed by trucks of PostNL (scope 1) and trips performed by other carriers (scope 3), a common distribution key by PostNL is used as supplied by Peter van Soest (Strategic planner transport PostNL). According to him, 40% of the performed trips are carried out by trucks of PostNL against 60% by other carriers. Table 5.5 shows for both cases the average amount of CO_2.

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[1] See Appendix C

Table 5.5: Inter depot transportation related emissions

Emission in tCO_2	All inter depot trips	Depotshift related trips
Emission per working day	47.49	46.19
# Working days	306	306
Emission per Sun- and holiday	3.86	3.86
# Sun- and holidays	58	58
Amount of CO_2 per year (S1,S2,S3)	14,755	14,357
Amount of CO_2 per year (S1,S2)	5,902	5,743
Amount of CO_2 per year (S3)	8,853	8,614

To say more about the reliability of the calculated amount of CO_2 concerning depot shift related trips, a 95% confidence interval is used regarding the amount of CO_2 per day. For 79 days, the amount of CO_2 emitted per day is determined by multiplying the number of trips between depots per day, the distance between depots and emission related factors. Table 5.6 shows the results of using a sample with 79 measurements.

Table 5.6: Confidence interval total number of trips per day

Sample mean	Sample deviation	Sample size	$t_{0.05,78}$	95% Confidence interval
46.09	8.39	79	1.99	[44.21,47.97]

Since 46.19 lies within the range of [44.21,47.97], there can be concluded that the used assumptions as mentioned before should be reliable enough concerning the total amount of emitted CO_2 per day.

Validation: Concerning the validation of the presented amount of emitted CO_2 two sources can be used. First, there is the amount of emissions calculated by Ecofys, as presented in section 1.2, and secondly the amount of emission calculated by the reporting department of PostNL. Table 5.7 shows the results of both sources concerning heavy trucks at PostNL division parcels divided into two layers: First there are emissions calculated by Ecofys and PostNL which concerns all the trips (collection and inter depot) driven by heavy trucks that can be assigned to parcel transportation. The second layer is the trip based variant as calculated by this report. In relation to the results of Ecofys and PostNL, this amount of CO_2 concerns only transportation of trucks between depots. Concerning the values of table 5.7, it can be concluded that there is a remarkable difference in absolute terms. First, it will be discussed how the different values are established. Further, the validation of the assumed emitted emission per working day as shown in table 5.5 will be discussed.

Table 5.7: Emission comparison table between different methods with regard to heavy transport at PostNL parcels

Collection and interdepot transportation			
Emission Heavy Trucks (tCO2)	Ecofys (2017)	PostNL CO2 calculatie tool (2017)	Trip based calculations
Per year (S1,S2)	18,201	13,232	-
Per year (S3)	24,996	21,254	-
Per year (S1,S2,S3)	43,197	34,486	-
Interdepot transportation			
Emission Heavy Trucks (tCO2)	Ecofys (2017)	PostNL CO2 calculatie tool (2017)	Trip based calculations
Per year (S1,S2)	-	-	5,743
Per year (S3)	-	-	8,614
Per year (S1,S2,S3)	-	-	14,755

Because most of the input for Ecofys' results were coming from PostNL, the emissions according to the PostNL's CO_2 emission tool will be taken into account first. This tool, drawn up by the reporting department of PostNL, shows the total amount of emitted CO_2 by the divisions mail and parcels. The reason why this tool shows the emissions for both divisions is because of two reasons. First, to create comparability and secondly due to the mix of data which is also one of the uncertainties of the results. In fact, emissions emitted by heavy trucks are coming from the total amount of fuel consumed. This amount is used for all kind of trips (e.g.

collection, empty trips, depot shifts, idle, retour shift, entry- or exit trips, Sundays, shipments concerning time-based network etc.) for both divisions, mail and parcels. To make a distribution of emission between both divisions, a conversion factor is used based on the SLA ratio[2] which result in the 24(mail)/76(parcel) rule. To summarise,by using this method the total amount of emitted CO_2 by heavy trucks with regard to parcels is 76% of the total amount of consumed fuel. Concerning the total amount of emitted CO_2 of outsourced trips by third parties, two types of information are considered: the amount of driven kilometres or the amount of driven kilometres that should be driven in case of a PostNL trucks. In both cases, the total amount of CO_2 will be calculated by using an average fuel consumption and DEFRA factor. The results by using this method is shown in the second column of table 5.7.

The other party that calculated the emitted emissions is Ecofys. Their calculation is mainly based on the fuel consumption values coming from PostNL. However, their emissions are higher than the results of PostNL. The first reason for this remarkable fact is that the calculations of Ecofys are based on WTW emissions instead of PostNL's results which are based on TTW. According to Antwan Wiegerinck, Quantitative support consultant at PostNL, the differences between these approaches should be around 18%. Moreover, with regard to scope 3 emissions, Ecofys takes more scope 3 factors into account which are transportation related. Both reasons result in a higher amount of emission than calculated by the emission tool of PostNL.

By using the input and method as used in the case of Ecofys and the calculation tool, it is hard to conclude the validation of the results as shown in table 5.5. Nonetheless, using the average trip distance of 89 kilometres a day as assumed by PostNL (Interview in Appendix I), makes it possible to say more about the validation concerning CO_2. When 728 trips drive 89 kilometres per day on average, the total amount of CO_2 emitted per day is 46.19 tonnes which is exactly the same as shown in 5.5.

Conclusion: With regard to inter depot transportation with at least one RC loaded with parcels, it can be concluded that 46.19 tCO_2 will be emitted on an average working day. This number is based on average trips between depots, average fuel consumption and a constant distance between depots. Although this calculation is hard to validate with the calculations by Ecofys and PostNL, it should be valid enough by using assumptions developed by the strategic transportation planning department of PostNL.

5.6. Performance Indicators

To evaluate the performance of a Physical Internet based service network, performance indicators have to be defined. These indicators as shown in table 5.8 are based on analysis of previous sections. For this report, a service network design performs better when the same demand is transported with less amount of CO_2 emitted. The amount of emitted CO_2 will be the Key Performance Indicator to compare different designs. However, the other columns in table 5.8 show the degree of efficiency and hence the reduction in unsustainable logistics as defined by Montreuil (2011).

Table 5.8: Performance Indicators current state. The total amount of emitted CO_2 will be defined as Key Performance Indicator (KPI).

Network design case study PostNL	Trips (#)	Total distance (km)	Empty trips (#)	Empty kilometres (km)	Avg. Utilisation	tCO_2 per day
Current state	728	64,788	28	2,411	0.84	46.19

5.7. Conclusion

Analyses of PostNL's current state, as measured in chapter 4, make it possible to say more about the current state performance as well as to create a reference for further designs. Besides, used assumptions are argued based on measurement and PostNL's validation. First of all, this chapter concludes that the average volume per parcel is 0.0227 m^3 which result in a capacity per RC of 37 items. However, reduction up til 10% should be possible as shown by the analysis of Coolblue's parcel output after the implementation of a new packaging machine. With regard to the network as described in chapter 2.2, this chapter concludes that the network as currently used does not match with the network design. Instead of a single allocated web structure, also multi-allocation and direct connections are common. On average, it can be said that 728 trips perform the transportation of the demand with a total travelled distance of 64,788 kilometres. However, not all of these trucks are completely loaded. In fact, 28 of the 728 trips are completely empty with a total travelled distance

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[2] Service Level Agreement used by PostNL to calculate intern costs

of 2,411 kilometres. Since the fact that the capacity of a truck is 48 RCs, it can be said that the other trucks are responsible for the demanded transportation with an average utilisation of 0.84. As analysed further in this chapter, a truck consumes 26.9L/100 km in combination with an average speed of 71 km/h. This chapter concludes by answering the following sub-question:

How does the current logistical process of parcels at Post NL perform concerning their environmental impact in terms of CO_2 ?

Based on the average number of trips between locations in combination with substantiated assumptions, it can be concluded that the transportation of parcels between depot locations is responsible for 46.19 tCO_2 per day. Currently, 728 trips are measured between different locations to make distribution of parcels from origin to destination possible. With a total travelled distance of 64,788 kilometres, it must be said that 2,411 kilometres are performed without any load which has a negative influence on the performance of the current process with regard to CO_2. With regard to fuel consumption, PostNL tries to improve their performance by measuring the amount of time-related to cruise control, idle and roll-out time. In this way, PostNL tries to measure and improve the current state depending on the results.

IV

Design

6

Network design optimisation model

This chapter shows a service network design model including the characteristics of Physical Internet logistics. Section 6.1 introduce an inter depot network design for two types of networks. First, the requirements, objective and constraints will be discussed in general. Further this section, the characteristics of a parcel delivery network design will be discussed and complemented by relevant elements of Physical Internet logistics. The section concludes with the used assumptions. Secondly, section 6.2 will translate the defined model into a mathematical model to determine the performance of a PI based service network design. Thirdly, the implementation of the model will be discussed in section 6.3 by making use of CPLEX as a solver. After this, the model will be verified and validated in section 6.4 and 6.5. A graphical overview of this chapter's structure is shown in figure 7.1.

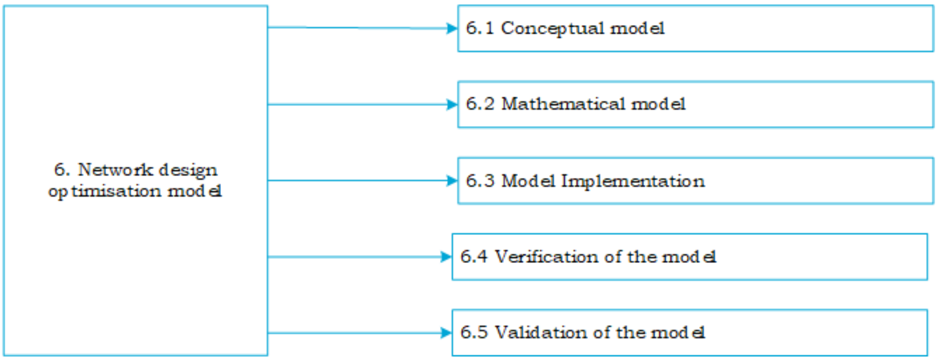


Figure 6.1: Structural overview of chapter 6

6.1. Conceptual model

In this section, the development of a service network design will be discussed with regard to the parcel delivery industry including characteristics of Physical Internet Logistics. First, requirements and constraints concerning a service network design will be discussed. Further, the model will be described with regard to the network design and physical internet elements.

6.1.1. Requirements

A service network in the parcel delivery industry is designed to transport a certain demand from origin to destination locations within a time period. The model as used for this report must be able to allocate a fleet on a network to transport the demand within the given time period. Elements of Physical Internet will be tested by changing the network, vehicle and demand characteristics.

6.1.2. Objective

In most cases, the objective is to perform a service against a minimum in terms of costs. These costs are mainly based on fuel costs, which depends on the used route, and fixed costs consisting of the cost of using an asset. When the fixed costs of using an asset is comparatively higher than the costs of using a route, it is not uncommon that an asset travels empty to perform another service instead of the allocation of another asset. For example, An asset performs a transportation from A to B. It could be possible that this same asset goes from B to C empty to perform a service from C to A, instead of allocating a different asset to do this C-A job. Since this report is focused on the minimisation of the emitted amount of CO_2 instead of costs, the objective is expressed in minimisation of the emitted amount of CO_2 without a fixed element. CO_2 emissions depends on the three elements as introduced in section 5.5: 1) total driven distance; 2) fuel consumption and 3) DEFRA conversion factor. Because minimisation of costs in terms of money is mainly based on 1) total driven distance; 2) Price per litre fuel and 3) fuel consumption per kilometre, this formulation can be modified from price per litre to CO_2 emissions per litre.

6.1.3. Constraints

An element that plays an important role in fleet allocation on a parcel delivery network, is 'time'. For shippers, it is beneficial to deliver their orders at carrier as late as possible while the parcel will be delivered as soon as possible. This means that the time window of delivery should be as short as possible. For carriers, like PostNL, it is the other way around. The longer they have to transport the demand the more beneficial it is in terms of costs or efficiency. Distance, speed, earliest departure time, latest arrival time and (un)loading time are the factors that influence the time element. The model assumes that the allocation is only possible between the earliest departure time and latest arrival time. Another hard constraint of the model is that transhipment of demand can only take place at hubs, not at spokes. The third constraint is focused on truck balancing. This means that the total amount of trucks that arrives at a node is the same as the amount of truck that leaves. The final constraint is focused on capacity. Every truck has the same capacity. The demand transported by a truck could be lower or equal to the capacity. besides, the transported demand cannot be negative.

6.1.4. Model description

With regard to this report, a distribution network is taken into account with two types of nodes: spokes and hubs. Both locations are able to produce and attract demand. However, at hubs also transhipment is possible. Concerning a network with hubs and spokes, different designs are possible. This model takes two network designs into account where the PI characteristics will be implemented. The difference between both designs is the number of hubs where transhipment of shipments can take plays. The first design, consist of some hubs and is mainly based on a multiple allocation web structure design like figure 6.2 in the middle. All the spokes (origins as well as destinations) are connected with all the hubs. This design is called 'hub network design' and allows only spoke-hub-spoke paths. The second design is called 'open network design' of which all the nodes act as a hub like figure 6.2 on the right. This means that at every hub transhipment is possible and results in two kinds of paths: spoke-spoke and spoke-hub-spoke. The reason why this report is willing to analyse both designs has to do with the time of implementation. From the point of view of PI, an open network would be ideal. However, it is expected that a company in the parcel delivery industry is not able to transform every depot location to perform transhipment overnight.

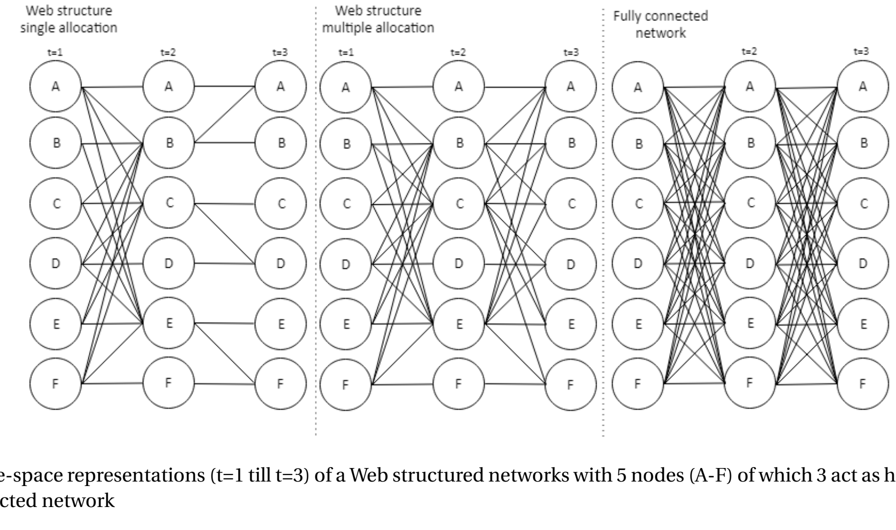


Figure 6.2: Time-space representations (t=1 till t=3) of a Web structured networks with 5 nodes (A-F) of which 3 act as hub (B,C,E) relative to a fully connected network

Despite the fact that Physical Internet logistics is mainly focused on a collaborative open network between different carriers, there are some elements which could be applied for network design at a carrier in the parcel delivery industry. Taking the key characteristics as mentioned in section 3.2 into account, the following elements are taken into account: Encapsulation of demand, an open-multi segment intermodel network design and finally individualisation of paths.

First of all, parcels will be transported into encapsulated containers, like roll cages as currently applied. Secondly, The network will be based on an open distributed multi-segment intermodal network. The combination of the characteristics 'open', 'multi-segment' and 'intermodal', result in the absence of path restrictions. Destinations can be served by different hubs. In the ideal PI network, it is assumed that every node could act as a hub where transhipment of load is possible. The network will look like a fully connected network, as shown in figure 6.2, with two kinds of paths between origin and destination: Spoke (origin)-to-spoke (destination) and spoke (origin)-to-hub-to-spoke (destination). This 'open' character will mainly be applied to the 'open network design'. Furthermore, it is assumed that a truck is only allocated to a single segment. This means, just like figure 3.5, that every individual truck performs only a service on the same route between nodes instead of touring. It is expected that more trucks are necessary but result in a reduction in the amount of empty kilometres. Another advantage is that trucks return to the origin. With regard to the driver, it is convenient to end at the origin for practical reasons. However, drivers could experience it as boring. To counteract this, truck drivers should be planned for different links every day. The third element of PI which is implementable for the parcel delivery industry is the individualisation of the demand between origin and destination. By segmentation of the network and individualisation of roll cages, different paths can be created based on different routes between origin and destination. In this way, different roll cages could follow different paths separately through the network between the same origin and destination like sketched in figure 6.3. On top of figure 6.3, the demand from A to F is concentrated on path A-B-F. By using the individualisation of roll cages focused on the objective to minimise the total amount of CO_2, it could be possible that the optimisation model results in a distribution of demand A-F on path A-B-F, A-C-F and A-D-F batched with other pairs as shown in figure 6.3 below.

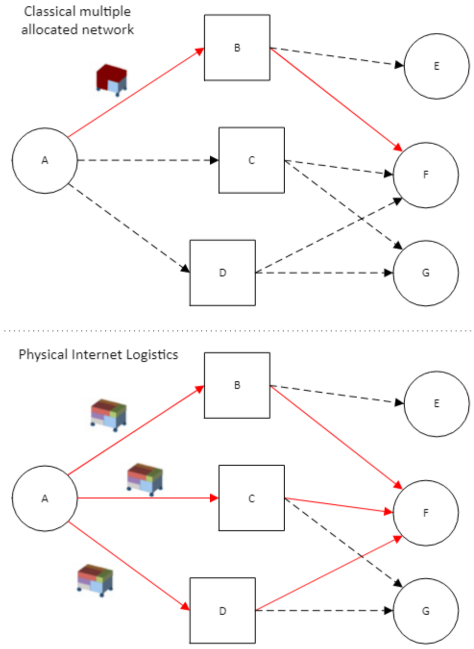


Figure 6.3: Demand transportation concentrated on a specific path (top) in relation to individual paths for encapsulated demand (down).

6.1.5. Model assumptions

To conclude this section, some assumptions are outlined to complete the conceptual design. In combination with the requirements, objective, constraints and model description the conceptual model can be translated to a mathematical model in the next section. The following assumptions are made for this report:

- The demand is known and is constant in advance.
- The demand is transported in roll cages.
- Origin-destination pairs are splittable, roll cages itself are not.
- There is an infinite supply of trucks.
- A truck has a constant and given speed and capacity.
- The amount of emitted CO_2 is only based on fuel consumption and travelled distance. Pavement or geographical characterises are not taken into account since the absence of extreme height differences in the Netherlands. Also, the influence of utilisation on fuel consumption is not assumed.
- A truck drives only between 2 nodes.
- For the distribution of shipments, it is assumed that transportation has to be completed within three periods like shown in figure 6.2.

6.2. Mathematical model

A mathematical optimisation model as used in this report is based on the given asset management model as discussed in section 3.3. The optimisation model results in a certain set of decision variables based on given sets, parameters, decision variables, constraints and objective. However, some modifications of the model have to be applied since the unique characteristics of a service network in the parcel delivery industry in relation to other consolidation-based freight networks as mentioned in section 6.1.

In addition to Andersen et al. (2009), an extra set of nodes is added. This set, in mathematical terms expressed as set H, will represent a set of hubs. At these hubs transhipment of load is possible between routes. Taking a look at a web structure network as shown in figure 6.2, only nodes B, C, E are an element of H. Concerning a fully connected network like the suggested open network, all nodes of the network are an element of H. Secondly, the model as used in this report made some modifications concerning costs in relation to the suggested mode by Andersen et al. (2009). Since this model is focused on the minimisation of CO_2, the costs are based on emission related factors. Also, Where the model of Andersen et al. (2009) makes use of a service frequency with a lower and upper bound, this model does not force assets to perform if a service is not necessary. This also results that there is no fixed schedule used between nodes. However, time boundaries are added related to the earliest departure time as well as the latest arrival time.
To define the used model as expressed by Andersen et al. (2009) in combination with the applied modifications, the following tables 6.1, 6.2 and 6.3 will present the used sets, parameters and decision variables with regard to freight carriers in the parcel delivery industry. Formulation and explanation of the objective will be shown in equation 6.1 followed by the used constraints in equation 6.2 till 6.11.

6.2.1. Sets

Table 6.1: Sets for a service network design in the parcel delivery industry

N'	Set of physical nodes $i' \in N'$
$N \subseteq N'$	Set of nodes $i \in N$ at time $t \in T$
A'	Set of physical arcs $(i', j') \in A'$
$A \subseteq A'$	Set of arcs $(i', j') \in A$ at time $t \in T$
$H' \subseteq N'$	Set of physical hubs $i' \in H'$
$H \subseteq N$	Set of depots+ $i \in H$ at time $t \in T$
$N^+(i) = \{j \in H : (i, j) \in A\}$	Set of predecessor nodes
$N^-(i) = \{j \in H : (j, i) \in A\}$	Set of successor nodes
L^p	set of paths $l \in L^p$
T	Set of time periods $T = \{t\} = \{1, .., T_{MAX}\}$
V	Set of vehicles $v \in V$

The mathematical model make use of different sets as presented in table 6.1. The operation of a parcel carrier is defined as the transportation of a certain demand w^p_{ij} from origin $i' \in N'$ to destination $j' \in N'$ within a certain time window by using a fleet $v \in V$ with a standard capacity u_{ij} per truck on a network. The physical nodes $i' \in N'$ are connected by undirected[1] arcs $(i', j') \in A'$ (called routes before) and forms a static network represented by graph $G' = (N', A')$. As mentioned before, to create a network with hubs consistent of the set of nodes, there are some nodes from the set N' labelled as hub $H' \subseteq N'$. The mathematical model is expressed in terms op possible paths $l \in L^p$ from origin to destination for commodity p. Moreover, since time characteristics play a very important role in the establishment of the logistical process in the parcel delivery industry, the scheduled length is divided into a set of periods $T = \{t\} = \{1, .., T_{MAX}\}$. For every time period $t \in T$, the graph of nodes and arcs is represented by $G = (N, A)$ in which nodes $i \in N$ represent the nodes $i' \in N'$ from the static network.

6.2.2. Parameters

Table 6.2: Parameters for a service network design in the parcel delivery industry

w_p	volume to be transported from origin to destination concerning commodity $p \in P$
a^l_{ij}	Binary value if arc $i, j \in A$ belongs to path $l \in L^p$ for commodity p
u_{ij}	Capacity associated with a service on arc from i to j
d_{ij}	distance of arc $(i', j') \in A'$
e_v	emission-factor in gram CO_2 per kilometre of vehicle $v \in V$
s_v	Speed in kilometres per hour of vehicle $v \in V$
tl_i	(un)loading time at a node $i \in N$
E_i	Earliest departure time at origin $i \in N$
A_i	Latest arrival time at destination $j \in N$

Concerning the transportation of a certain amount of demand w^p from origin to destination, there are some parameters as presented in table 6.2 that determine the final value of the total emitted amount of CO_2. Parameters which influence the flow through the network, are the demand w^p, arc availability a^l_{ij} and the capacity per truck u_{ij}. The constraints, as further discussed in this section, show how these parameters limit the number of possibilities. Costs are expressed in terms of CO_2 depending the emission-factor e as well as on the distance of a certain arc d_{ij}. Speed s_v in kilometres an hour, (u)loading time tl_i at node i in minutes play an important role for the moment of transport within the earliest E_i departure and latest A_j arrival time between node i and $j \in N$.

---

[1] Flow is possible in both directions

6.2.3. Decision variables

Table 6.3: Decision variables for a service network design in the parcel delivery industry

δ_v	Binary,whether the vehicle is used (1) or not (0)
h^l	The flow on path $l \in L^p$ for commodity p
y_{ijv}	If vehicle v is used for design arc i to j
EUT_{ij}	Earliest unloading time at hub $j \in H$ for transferring on arc i to j
LLT_{ji}	Latest loading time at hub $j \in H$ for transferring on arc i to $j \in A$

The variables as shown in table 6.3 will be varied to find the optimal solution with regard to the given objective. Most of the elements of table 6.3 are in line with the given variables by Andersen et al. (2009). A binary decision variable δ_v is introduced by Andersen et al. which is equal to 1 if vehicle v is utilised. Another binary variable, which indicates that a certain service is selected or not, is defined as y_{ijv}.Flow of commodity p on path l is defined by variable h^l. However, to deal with the given parameters concerning earliest departure and latest arrival time, EUT_{ij} and LLT_{ji} are introduced to define the earliest and latest loading time at a certain hub for transferring a certain demand on arc $(i,j) \in A$. The way these variables are expressed, is explained in equation 6.2 and 6.3.

6.2.4. Objective

$$min \sum_{(i,j)\in A} \sum_{v\in V} d_{ij} * e_v * y_{ijv} \tag{6.1}$$

Equation 6.1 has the intention to minimise the total emitted CO_2, which is calculated by the summation of trucks y_{ijv} travelling distance d_{ij} from node i to node j times the emission factor e. This result in an optimal way of allocation to minimise the amount of CO_2.

6.2.5. Constraints

The first considered constraints are related to the time window where transportation between nodes is possible. This window is fixed in constraint 6.4 between the earliest unloading time in equation 6.2 and the latest loading time in equation 6.3.

$$EUT_{ij} = tl_j * + E_i + 60 * d_{ij}/s_v \quad \forall (i,j) \in A, i \in N, j \in H, v \in V \tag{6.2}$$

As equation 6.2 shows, there are three important elements that determine the earliest unloading at a certain hub $j \in H$ coming from origin $i \in N$: 1) unloading time at hub $j \in H$; 2) earliest departure time at origin $i \in N$ and 3) transportation time on arc $(i,j) \in A$. This moment in time, express the first moment that load could be available at hub $j \in H$ if there is an arc $i, j \in A$. To make sure that this same truck goes back on time, this will be forced by equation 6.3 as the latest unloading time.

$$LLT_{ji} = A_i - tl_j - 60 * d_{ji}/s_v \quad \forall (i,j) \in A, i \in N, j \in H, v \in V \tag{6.3}$$

Latest loading time at a hub $j \in H$ is the last moment to get the vehicle back toward the origin $i \in N$. This moment depends on 1) the latest arrival time back at node $i \in A$; 2) the loading time at hub $j \in H$ and 3) the total travel time on arc $(j,i) \in A$. Both equation 6.2 and 6.3 enforce that a vehicle is only able to operate between EUT_{ij} and LLT_{ji} trough constraint 6.4.

$$\sum_{(i,j)\in A: EUT_{ij} \le t \le LLT_{ji}} y_{ijv} - \delta_v = 0 \quad \forall t \in T, v \in V \tag{6.4}$$

Besides the time window boundary of operating between EUT_{ij} and LLT_{ji}, equation 6.4 shows that each time period when an asset is utilised, it should be engaged in one activity only.

$$\sum_{j\in N^+(i)} y_{ijv} - \sum_{j\in N^-(i)} y_{jiv} = 0 \quad \forall i \in N, v \in V \tag{6.5}$$

constraint 6.5, is an equation that enforces two things. First, the equation makes sure that there is an equal in-and-out degree of open arcs. Although this is not measured in the current situation as explained in chapter 5, this constraint will be used in this report to become more realistic. After all, chapter 5 discuss an average on several measurements and this model disuse the transportation of a given demand on a daily level. Secondly, since the set of predecessor nodes and successor nodes of node i only take nodes $j \in H$ into account, this constraint enforces that there is only a connection between spoke i and hub j. To make sure that that asset v travels from i to j and backwards j to i on the same arc, equation 6.6 is introduced.

$$y_{ijv} - y_{jiv} = 0 \quad \forall (i,j) \in A, v \in V \tag{6.6}$$

$$\sum_{l \in L^p} h^l = w^p \quad \forall p \in P \tag{6.7}$$

Constraint 6.7 sets the flow conversation of the model. For each commodity p, the sum of flows through different paths must be the same as the demand w^p between origin and destination.

$$\sum_{p \in P} \sum_{l \in L^p} a^l_{ij} h^l - \sum_{v \in V} u_{ij} y_{ijv} \leq 0 \quad \forall (i,j) \in A \tag{6.8}$$

Capacity constraint is defined by equation 6.8 which enforces that the flow h^l on an arc $(i,j) \in A$ part of path l is not able to transport more than the capacity u_{ij} using an asset y_{ijv}. Furthermore, variable type are determined by constraint 6.9, 6.10 and 6.11.

$$h^l \geq 0 \quad \forall (i,j) \in A, p \in P \tag{6.9}$$

$$y_{ijv} \in \{0,1\} \quad \forall (i,j) \in A, v \in V \tag{6.10}$$

$$\delta_v \in \{0,1\} \quad \forall v \in V \tag{6.11}$$

6.3. Model implementation

To implement the suggested decision model as shown in section 6.2, CPLEX as solver is used to optimise the case at PostNL with regard to Physical Internet characteristics. CPLEX uses an Optimisation Programming Language (OPL) developed by IBM. Other computer programming software could be Matlab or Python. Implementation of the defined model in section 6.2 is done by modification of a standard OPL Model concerning a Trucking problem. The first reason why this solver and model is used is because of experience acquired during lectures given by Maknoon (2017). Secondly, because of the fact that the presented trucking model by IBM is practically the same as the mathematical model presented in section 6.2 and makes it possible to use the available data from PostNL. The trucking model takes a shipping company into account concerning a hub and spoke network. Shipments in terms of volume, have to be delivered from a certain origin to a specific destination within a given time window. According to the trucking problem, as defined by IBM, there are different trucks with each its own capacity, costs and emission. The model has the objective to minimise the total amount of costs and meet the volume requirement of origin-destination transportation. Besides, there is a minimum departure time and maximum arrival time at every node. By modifying the standard OPL trucking model towards the defined model in section 6.2, it is implementable for the case at postNL. Table G.1 shows the conversion of the mathematical formulation as discussed section 6.2 into the Trucking Problem by IBM CPLEX. Solving the mathematical problem is done by using CPLEX' dynamic search algorithm. This search method is based on Branch & Cut, an exact method which solves series of continuous sub-problems as explained in Appendix G. The output of running CPLEX will be as follow: 1) Value of the objective; 2) Volume inbound hub per trip (origin, hub, destination), 3); volume outbound hub per trip (origin, hub, destination) and 4) number of trucks allocated to route (i,j). However, there must be said that volume inbound gives the same value as the volume outbound due to the balancing constraint.

The optimisation model is performed on a Personal Computer including an Intel Core i7-2600k CPU with 3.40GHz clock speed. Moreover, the installed memory is 8.00 GB.

6.4. Verification

This section shows the verification of the used computerised CPLEX model which is defined as the substantiation that the implemented CPLEX model represents the conceptual model as defined in chapter 6 within limits (Schlesinger et al., 1979). The implemented model will be checked according to the specifications of the mathematical model by performing different test cases based on real-life situations. The output of the different cases will be compared with expected outputs by hand. In this way, the model can be verified based on analytic results. First, an outbound run is performed in subsection 6.4.1 to see the output of the model using extreme values. Further, subsection 6.4.2 is focused on an increase in demand in terms of items. In subsection 6.4.3 verification is focused on a decrease in volume per parcel. The last case concerning verification is shown in subsection 6.4.4 which is focused on increasing capacity per trailer. For the verification, the following configuration is used based on the case study at PostNL:

- A network of 20 nodes with attraction and/or production of demand.
- Two designs:
    - Network design with 5 of 20 nodes act as a hub, called '5 Hub Network'
    - Network design with 20 of 20 nodes act as a hub, called 'Open Network'
- Graph characteristics based on PostNL's locations as shown in table E.1.
- Demand based on measurement at PostNL as discussed in section 5.1.
- Trucks with a capacity of 48 roll cages per truck travelling 71 kilometres an hour.
- 713 gram of CO_2 emitted per kilometre travelled.
- time-window of 450 minutes between earliest departure time and latest arrival time

6.4.1. Case 1 - Extreme values

As this section introduces, verification of a computerised model checks if the implemented computerised model is right according to the specifications as given in the conceptual model. For this report, the conceptual mathematical model including its specifications is presented in section 6.1 followed by the computerised model as introduced in section 6.2. This subsection is focused on input values concerning extreme cases to verify the correctness of the used model. First, a situation is sketched where the amount of CO_2 emitted per kilometre (parameter e) is 0. In real-life, this could be the case if a fleet with only electrical vehicles is used. However, when no emissions are emitted there is nothing to optimise since the objective will always be 0. The hand calculation will be as follow:

Hand calculation

The objective as defined in section 6.2, is focused on the minimisation of the total costs based on the elements distance per route d_{ij}, Emission-factor e and vehicle allocation y_{ijv} to route i,j.

$$min \quad Z \sum_{(i,j)\in A} \sum_{v\in V} 2 * d_{ij} * e * y_{ijv} \tag{6.12}$$

When e is 0, it is expected that Z would also be 0 for both designs.

Table 6.4 shows for both designs that the hand calculation, expected value and CPLEX result meet each other with the same value. A case that could not be submitted to a real-life situation, is a capacity per truck of 0. When this occurs, the model should not give any output besides an error. Taking a look at the formulation as shown in section 6.2, the same can be concluded:

Hand calculation

Constraint 6.8 in section 6.2, as used below, enforce that the flow h^ltransported on path is always lower than the capacity u_{ij}.

$$\sum_{p\in P} \sum_{l\in L^p} a^l_{ij} h^l - \sum_{v\in V} u_{ij} y_{ijv} \leq 0 \quad \forall (i,j) \in A \tag{6.13}$$

When the capacity is 0, equation 6.13 would be larger than 0 or no demand would be transported. Since this constraint will enforce something that is not possible, the output of this model will give an error for both designs.

No sollution occured af changing the capacity of a truck to 0 in the used CPLEX model. This means that the computerised model is in line with the hand calculation as expected. Table 6.4 summarises the verification of the two used cases in this subsection. With regard to more realistic situations, subsection 6.4.2, 6.4.3 and 6.4.4 show 3 other cases where parameters are changed based on realistic assumption, trends or innovations.

Table 6.4: verification of the used model by using extreme values

Network design	Emission per km = 0				Capacity $u_{ij} = 0$			
	Hand calculation	Expected	Result CPLEX	Status	Hand calculation	Expected	Result	Status
5 hub network	Z = 0	Z = 0	Z = 0	Pass	No solution	No solution	No solution	Pass
Open Network	Z = 0	Z = 0	Z = 0	Pass	No solution	No solution	No solution	Pass

6.4.2. Case 2 - Increase in terms of items demand

As introduced in section 1.2, the parcel delivery is rising in terms of volume. Concerning the volume growth of PostNL, it can be concluded that there was an increase of 17,2% in 2017 (202 million items) relative to 2016. Also for the upcoming years, it is expected that this growth, mainly focused on the B2C and C2X, will continue. Intern forecast publications by PostNL, prepared by the Strategy & Development department of PostNL, shows that the total number of transported items will increase to 244 million items in 2018 and 401 million items in 2023. These values, concern a base scenario based on the following assumptions:

- known volume forecast for the period 2017-2022
- Volume growth after 2022 based on a Compound Annual Growth Rate (CAGR) of 11%
- Having a stable market in combination with a consistently marketshare

Since this report is focused on reduction potentials of a new network design on a short-term, like the target of 2023, it would be interesting to verify the model by using the expected increase in demand. Assuming a demand as measured in chapter 4 is a sample of the population 2018 with 244 million items, it can be concluded that the same volume growth on a daily base as used for a yearly base between 2018 and 2023 is expected. This volume growth is +64% in 2023 relative to 2018 and applied to the item matrix as presented in figure 4.1. To verify if the CPLEX computerised model will result within the expected limits, an estimate by hand is made.

Hand calculation

After combination and simplification of equation 6.7 and 6.8 with the objective 6.1, the total amount of emissions emitted during the transportation of a certain demand D from i to j, can in general be expressed as follow:

$$Total_{Emission1} = \frac{Demand}{capacity_{pertruck}} * Emission_{pertruckonroute(i,j)} \tag{6.14}$$

If the demand increase with 64%, the total amount of emissions will be as follow:

$$Total_{Emission2} = \frac{\frac{41}{25}Demand}{capacity_{pertruck}} * Emission_{pertruckonroute(i,j)} \tag{6.15}$$

$$Total_{Emission2} = \frac{41}{25} * Total_{Emission1} \tag{6.16}$$

$$Increase \quad Factor = \frac{41}{25} = 1.64 \quad or \quad 64\% \tag{6.17}$$

When the demand increase with 64%, the amount of emitted CO_2 should also increase with 64%.

By using the hand calculation as shown in the given frame, it is expected that the total amount of CO_2 will increase from 43.21 tCO_2 to 70.86 tCO_2 concerning a 5 hub network. For the open network, it is calculated by hand that the daily amount of CO_2 will increase from 38.90 to 63.80 tCO_2. Although it is expected that the computerised model will give the same order of magnitude outputs, it is not expected that it will be exactly the same. The main reason is that the model deals with integer values of allocating vehicles. For example, when the demand that has to be transported from i to j is 48 RCs, exactly one truck is used with a capacity of 48. When this demand increase with 64%, the number of RCs that have to be transported will increase to 79. Since truck allocation is an integer value, the number of allocated vehicles increase with 100 % which will result in a much higher objective than the growth of 64%. However, this situation could also occur the other way around. Where in the 2018 situation only 1 truck is allocated for the transportation of 20 RCs, this single truck is also able to transport the 2023 situation with 33 RCs. To deal with this phenomenon, it is expected that the CPLEX result shall be in the range of -2% and +2% of the hand calculation. To compare the hand calculation with the expected as well as CPLEX result, table 6.5 is created.

Table 6.5: Verification computerised model with regard to demand increase

Increase demand with 64%				
Network Design	Hand calculation	Expected	Result CPLEX	Status
5 hub Network	Z = 70.86	69.45 <Z <72.28	Z = 69.97	Pass
Open Network	Z = 63.80	62.52 <Z <65.07	Z = 62.59	Pass

As expected, the results of CPLEX are between the given limits. In fact, the absolute value of the computerised model is lower than the hand calculation, which means that CPLEX is able to create a more optimal solution than expected. Finally, there can be concluded that CO_2 emissions are almost directly proportional to volume growth. This is explained by the fact that when you have to transport more demand you have to drive more and so emit more CO_2.

6.4.3. Case 3 - Reduction in volume per parcel

This subsection presents a verification case focused on a volume reduction per parcel. As discussed in the introduction of this report, a lot of companies, stakeholder organisations and governments are looking for measures to reduce the environmental impact of transportation. One of these organisations is Topsector Logistiek, an cooperative organisation in the Netherlands consisting of companies, government and universities focused on sustainable and economic growth of the transport sector. Besides issues as market competition and contribution maximisation to the economy, the organisation deals with subjects related to climate change. As a consequence, the organisation is looking for effective measures that reduce the footprint of transportation. One of them is a research by Gerard Peeters (2017), performed on behalf of Topsector Logistiek. This research was focused on packaging, the volume per parcel and the amount of air that is involved. Reason for this research was the observed box size relative to the actual content of the parcel. Something which is also noted by Montreuil (2011), as discussed in section 3.2. Research by Gerard Peeters (2017) shows many facts concerning inefficient packaging. On average, Gerard Peeters (2017) concludes that 30 to 40% of a parcel box consists of air. This amount of air could be used as product security. However, Most of the time this amount of air has no purpose. Since this research took parcels into account coming from the segments E-commerce, Retail, E-fulfilment and production companies, it is hard to say how much reduction is possible for the parcel delivery industry focused on B2C. Besides, Gerard Peeters (2017) concludes that it is hard to achieve a reduction of 30-40% since protection of the content is a must. Still, there is a way to see a fair reduction potential in the parcel delivery industry. As discussed in section 5.1.2, Coolblue as one of the largest shippers with regard to parcels in the Netherlands, implemented a packaging machine which makes tailored boxes for every parcel. When the compare the values of figure 5.4, there can be concluded that the average volume per parcel decreased with 9%. When this reduction is used as a starting point, the model can be verified by calculating the effects of a reduction in volume by using the following assumptions:

- The potential of volume reduction per parcel is up to 10% based on results at Coolblue table 5.4.
- As a result, the capacity per roll cage increases as shown in table 6.6.
- Based on capacity per roll cage, the number of roll cages is calculated for transportation the demand as shown in the attached excel file.

Concerning this case, the computerised model will be verified using a volume reduction of 10% per parcel.

As mentioned before, the reduction in volume per parcel will be applied to an increase per RC as shown in table 6.6.

Table 6.6: Capacity single RC with regard to volume reduction

Volume reduction per parcel (%)	0	1	2	3	4	5	6	7	8	9	10
Volume per parcel (L)	22.7	22.5	22.2	22.0	21.8	21.6	21.3	21.1	20.9	20.6	20.4
Volume per parcel (m3)	0.0227	0.0225	0.0222	0.0220	0.0218	0.0216	0.0213	0.0211	0.0209	0.0206	0.0204
Capacity Gray container (Items/RC)	29.1	29.4	29.7	30.0	30.3	30.6	30.9	31.3	31.6	32.0	32.3
Capacity Parcel container (Items/RC)	45.4	45.9	46.3	46.8	47.3	47.8	48.3	48.8	49.3	49.9	50.4
Capacity RC Equivalent (Items/RC)	37.2	37.6	38.0	38.4	38.8	39.2	39.6	40.0	40.5	40.9	41.4
Capacity growth wrt base (0%)	0%	1%	2%	3%	4%	5%	6%	8%	9%	10%	11%

The capacity growth as shown in the last row of table 6.6 is the percentage relative to 0% reduction in volume per parcel and based on the capacity RC equivalent. As could be noticed, this capacity is noted with one decimal place despite the fact that an item is an integer number. However, it is expected that there is such a large demand in combination with a random distribution of volume per parcel that the capacity on average will be 37.2 items/RC (base state). In contrast to this, an integer value is used for the demand in terms of items and RC. With the knowledge of table 6.6 that a reduction of 10% in volume per parcel will result in a capacity increase per RC of 11%, the verification of this case is performed concerning a hand calculation.

Hand calculation

After combination and simplification of equation 6.7 and 6.8 with the objective 6.1, the total amount of emissions emitted during the transportation of a certain demand D from i to j, can in general be expressed as follow:

$$Total_{Emission1} = \frac{Demand_{RC1}}{capacity_{pertruck}} * Emission_{pertruckonroute(i,j)} \tag{6.18}$$

$$Demand_{RC1} = \frac{Demand_{items}}{capacity_{perRC1}} \tag{6.19}$$

Increasing the capacity per RC with 11% result in the following total amount of emissions:

$$Total_{Emission2} = \frac{Demand_{RC_2}}{capacity_{pertruck}} * Emission_{pertruckonroute(i,j)} \tag{6.20}$$

$$Demand_{RC2} = \frac{Demand_{items}}{capacity_{perRC2}} = \frac{Demand_{items}}{\frac{111}{100} capacity_{perRC1}} \tag{6.21}$$

$$Demand_{RC2} = \frac{100}{111} * \frac{Demand_{items}}{capacity_{perRC1}} \tag{6.22}$$

$$Total_{Emission2} = \frac{100}{111} * Total_{Emission1} \tag{6.23}$$

$$Reduction \quad Factor = \frac{100}{111} \approx 0.90 \quad or \quad 10\% \tag{6.24}$$

Decreasing the volume per parcel with 10 % result in a capacity per RC 11%. This increase in capacity should result in a decrease of 10 % in the amount of emitted CO_2.

As presented in the hand calculation, a reduction of 10 % volume per parcel will result in approximately

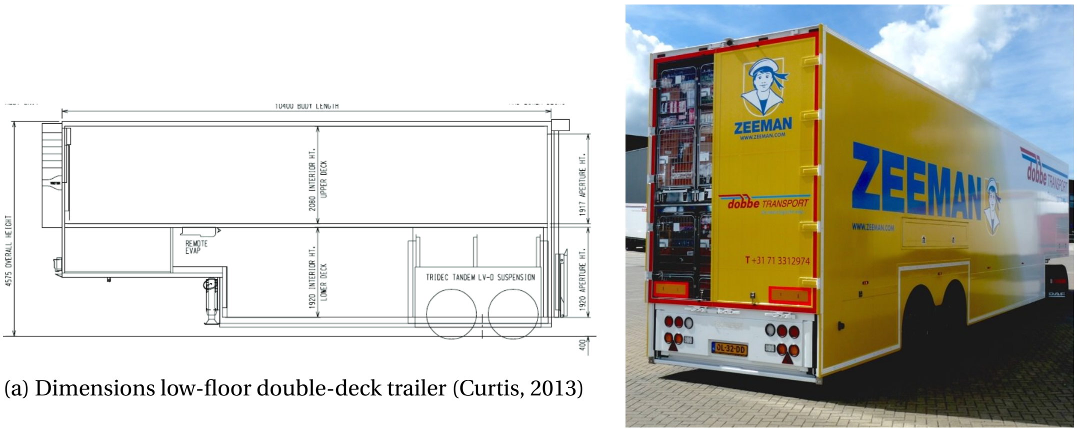
10% less CO_2 per day. This means that using a 5 hub network, the total amount of CO_2 per day will decrease from 43.21 tonnes to 38.89 and concerning an open hub network from 38.90 tonnes to 35.01 CO_2 per day. For the verification of the computerised model, the demand with a reduction in volume per parcel is used as shown in the attached excel file. Due to the fact that fleet allocation deals with its integer characteristic, as discussed in section 6.4.2, the same range (-2%; +2%) of expected output is used. The results of the verification focused on the reduction per parcel in terms of volume, are shown in table 6.7. It can be concluded that also in this case the computerised model passes.

Table 6.7: Verification computerised model with regard to an decrease in volume per parcel

Volume reduction per parcel 10%				
Network Design	Hand calculation	Expected	Result CPLEX	Status
5 hub network	Z = 38.89	38.11 <Z <39.67	Z = 38.63	Pass
Open network	Z = 35.01	34.31 <Z <35.71	Z = 34.85	Pass

6.4.4. Case 4 - Increase capacity

The third case with regard to the verification of the computerised model is focused on an increase in capacity per trailer or truck. From expert interview, as shown in section I.6, it became clear that companies as Action or Jumbo (active in the retail) take advantage of double deck trailers. Research which is focused on this topic is done by Curtis (2013). Figure 6.4 shows an impression of a double deck trailer including its dimensions.



(a) Dimensions low-floor double-deck trailer (Curtis, 2013)

(b) Double-deck trailer for the transportation of standardised RCs (Burgersgroup B.V., 2018)

Figure 6.4: Example an implemented double-deck trailer

According to Curtis (2013), a double deck trailer is able to transport 60% more volume in relation to a conventional trailer, like PostNL's. However, due to its increase in dimensions, the fuel consumption will also increase. For this report, an increase in fuel consumption will be taken into account of 10% relative to a conventional trailer based on research by Curtis (2013). The following hand calculation will be used as a basis of comparison to verify the computerised model.

Hand calculation

After combination and simplification of equation 6.8 with the objective 6.1, the total amount of emissions emitted during the transportation of a certain demand D from i to j, can in general be expressed as follows:

$$Total_{Emission1} = \frac{Demand}{capacity_{pertruck}} * Emission_{pertruckonroute(i,j)} \tag{6.25}$$

Increasing the capacity with 60% in combination with an fuel consumption increase of 10%, the total amount of emissions will be as follows:

$$Total_{Emission2} = \frac{Demand}{\frac{8}{5} * capacity_{pertruck}} * \frac{11}{10} * Emission_{pertruckonroute(i,j)} \tag{6.26}$$

$$Total_{Emission2} = \frac{5}{8} * \frac{11}{10} * Total_{Emission1} \tag{6.27}$$

$$Reduction \quad Factor = \frac{5}{8} * \frac{11}{10} = 0.6875 \quad or \quad 31.25\% \tag{6.28}$$

When the capacity of a trailer increase with 60 %, the amount of emitted CO_2 should decrease by 31.25%.

As shown by the hand calculation, the total amount of CO_2 should decrease by 31.25% when the conventional trailer will be replaced by double-deck trailers with a capacity increase of 60%. To verify the computerised model, the capacity increase should be implemented by an increase in capacity per truck. 60% increase means a capacity of 76.8 RC per truck. Due to the fact that CPLEX only works with integer values, it is assumed that the capacity will be 76 RCs, which is a decrease of 58%. An emissions increase of 10 % result in 784.3 tCO_2 instead of 713 tCO_2. For the implemented model 784 tCO_2 is used which is an increase of around 10 %. Combining this, this means that a 5 hub network will reduce their impact from 43.21 tCO_2 to 30,02 and an open network design will emit 27.03 tCO_2 instead of 38.90 tonnes. Besides an increase in capacity and emissions, also the (un)loading time increased by 60% from 25 minutes to 40 minutes. Mainly due to the increase in (un)loading time, it is expected that the result of CPLEX will be higher than the calculations by hand. Due to the variant in output since the optimisation of the model, we will make use of the same expectation range of -2% and +2% as used before. The results are shown in table 6.8.

Table 6.8: Verification computerised model with regard to an decrease in volume per parcel

Increase trailer capacity with 60%				
Network Design	Hand calculation	Expected	Result CPLEX	Status
5 hub network	Z = 30.02	29.42 <Z <30.62	Z = 30.31	Pass
Open network	Z = 27.03	26.48 <Z <27.57	Z = 27.28	Pass

Comparing the calculations by hand with the results generated by CPLEX of table 6.8, it can be concluded that the result is higher for both designs.

6.5. Validation

To analyse the model's fit regarding the situation in the real world, the model has to be validated. The validation will be based on the comparison between the 5 hub design, as presented in section 6.4, with the measured and analysed situation as discussed in chapter 4 and 5. The reason why this 5 hub design is used, is because of the multiple allocation [2] characteristics of the current state as observed in figure 5.6. Moreover, it is better to verify the model by using a hub design instead of an open network design in relation to the measured state since the difference in transhipment possibilities. Concerning the open hub design, transhipment is possible at every location while the hub design takes only the hubs into account where shipment is possible just like the current/measured situation. Another reason why a 5 hub design is used for validation is that measurement shows that trips from origin to a hub are loaded with all kind of destinations. It can be concluded that currently path individualisation is applied on a small scale just as used by the Physical Internet based model. When the same hubs are used concerning a hub design as used in the measured state, validation is possible. However, it is expected that both results won't be equal. First of all, because of the difference in trip types. In the current state, besides spoke-hub-spoke trips also spoke-to-spoke trips are measured. In the used design model, there are only spoke-hub-spoke trips possible. The second reason which could lead to a difference in result is the way of routing. The routing as used for this model is based on the allocation

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[2] A destination is served by multiple hubs

of single trucks to single roads A to B and back. In the real world, it could occur that a truck drives from A to B loaded, from B to C empty and loaded again from C to A. With these mentioned differences but the same parameters based on the current state as analysed in chapter 5, it is expected that the measured state will be higher but of the same order of magnitude.
As input, a network of 20 nodes is used, 20 origins/destinations of which 5 can act as a hub where transhipment is possible. Demand, speed, capacity per truck, costs per kilometre in terms of CO_2 and used arrival/destination times are based on measurement. The comparison between the output of the used network design relative to the measured state is presented in table 6.9.

Table 6.9: Validation table model based on a hub network design in relation to the measured state at case study PostNL

Network design case study PostNL	Trips (#)	tCO2 per day
Current state	728	46.19
hub network design	736	43.21

As expected, the amount of emitted CO_2 is higher for the current state than given by the model. However, the result of the model is on the same scale and differs only 6.45% from the measured state. Moreover, the number of used trips is higher concerning the design model as in the measured state. Also, this was expected due to the constraint that trucks could only be allocated to a single route. To the author's knowledge, the difference between the measured state as well as the 5 hub state as a representation of reality is sufficiently small that the model is valid enough to use.

7

Model application

With the knowledge that the suggested model is defined, verified and validated in chapter 6, the model can be applied for a case study at PostNL. This chapter discusses the outcomes with regard to a hub design as well as an open network design as introduced in section 6.1. First, section 7.1 discuss the application of the network design model with regard to the case of PostNL. Specific values are introduced based on measurements and analyses from chapter 4 and 5. Further, the experimental results concerning a case study at PostNL will be shown and analysed in section 7.2 for a hub network design and in section 7.3 for an open hub network design. The presented results will be focused on the defined indicators concerning fleet allocation, empty trips, utilisation and the total amount of emitted CO_2. Further, the sensitivity of different parameters will be discussed in section 7.4 to show possible potentials with regard to reduction in terms of CO_2. The structure of this chapter is graphically shown in figure 7.1.

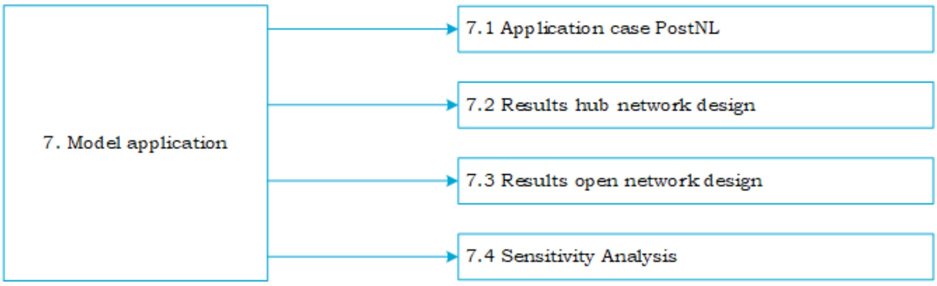
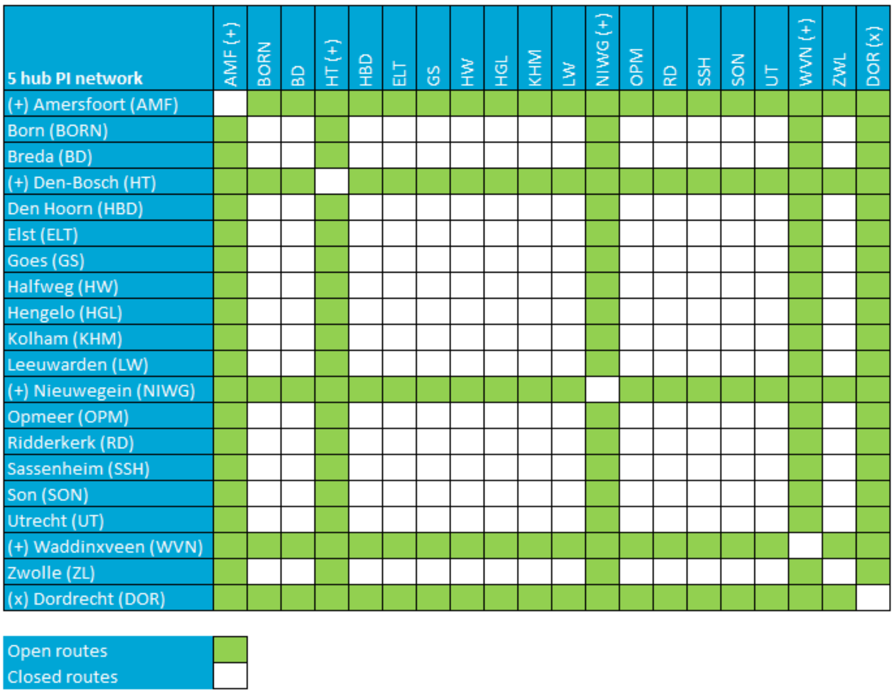


Figure 7.1: Structural overview of chapter 7

7.1. Application case PostNL

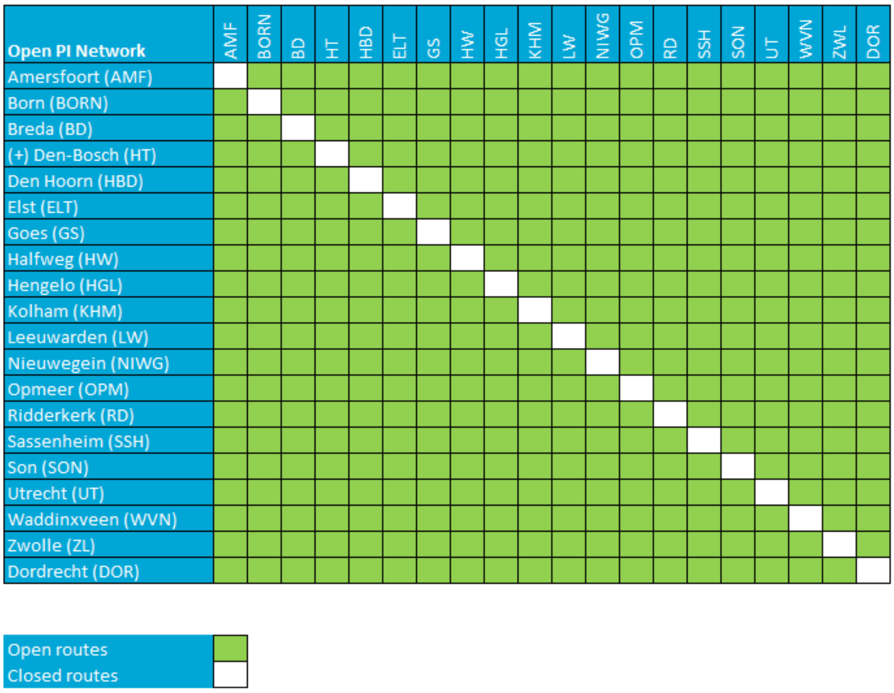
To analyse the performance of the suggested design networks in further sections, a case study at PostNL is used. The used nodes as defined before will be represented by the 20 spoke locations (depot in terms of PostNL) as discussed in section 2.2. Since PostNL make use of 5 hubs (in terms of PostNL Depot+) where transhipment is possible, the hub design model as introduced before will make use of the same 5 hubs as defined by PostNL. In this way, the effects of PI characteristics can be shown while making use of the same locations where transhipment of demand is possible. Regarding the open network design, all the nodes are able to support transhipment. With the defined spokes and hubs for both networks, path possibilities arise between origins and destinations. The main differences is in the number of route possibilities, as shown by figure 7.2 and figure 7.3 with green boxes. For a hub network design, paths are only possible to and from the allocated hubs by making use of 170 route possibilities. This means that origin-destination pairs have to make use of the locations Amersfoort, Den-Bosch, Dordrecht, Nieuwegein or Waddinxveen. Concerning an open hub design, spoke-spoke and spoke-hub-spoke paths are possible by using 380 different routes/links.



5 hub PI network	AMF (+)	BORN	BD	HT (+)	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG (+)	OPM	RD	SSH	SON	UT	WVN (+)	ZWL	DOR (x)
(+) Amersfoort (AMF)	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Born (BORN)	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	🟩	⬜	🟩
Breda (BD)	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	🟩	⬜	🟩
(+) Den-Bosch (HT)	🟩	🟩	🟩	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Den Hoorn (HBD)	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	🟩	⬜	🟩
Elst (ELT)	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	🟩	⬜	🟩
Goes (GS)	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	🟩	⬜	🟩
Halfweg (HW)	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	🟩	⬜	🟩
Hengelo (HGL)	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	🟩	⬜	🟩
Kolham (KHM)	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	🟩	⬜	🟩
Leeuwarden (LW)	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	🟩	⬜	🟩
(+) Nieuwegein (NIWG)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Opmeer (OPM)	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	🟩	⬜	🟩
Ridderkerk (RD)	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	🟩	⬜	🟩
Sassenheim (SSH)	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	🟩	⬜	🟩
Son (SON)	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	🟩	⬜	🟩
Utrecht (UT)	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	🟩	⬜	🟩
(+) Waddinxveen (WVN)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	🟩	🟩
Zwolle (ZL)	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	🟩	⬜	🟩
(x) Dordrecht (DOR)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜

Open routes	🟩
Closed routes	⬜

Figure 7.2: 170 possible routes from node i (first column) to node j first row with regard to a 5 hub network design. The green box shows if a route is possible or not.



Open PI Network	AMF	BORN	BD	HT	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG	OPM	RD	SSH	SON	UT	WVN	ZWL	DOR
Amersfoort (AMF)	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Born (BORN)	🟩	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Breda (BD)	🟩	🟩	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
(+) Den-Bosch (HT)	🟩	🟩	🟩	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Den Hoorn (HBD)	🟩	🟩	🟩	🟩	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Elst (ELT)	🟩	🟩	🟩	🟩	🟩	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Goes (GS)	🟩	🟩	🟩	🟩	🟩	🟩	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Halfweg (HW)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Hengelo (HGL)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Kolham (KHM)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Leeuwarden (LW)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Nieuwegein (NIWG)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Opmeer (OPM)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Ridderkerk (RD)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	🟩	🟩	🟩	🟩	🟩	🟩
Sassenheim (SSH)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	🟩	🟩	🟩	🟩	🟩
Son (SON)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	🟩	🟩	🟩	🟩
Utrecht (UT)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	🟩	🟩	🟩
Waddinxveen (WVN)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	🟩	🟩
Zwolle (ZL)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	🟩
Dordrecht (DOR)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜

Open routes	🟩
Closed routes	⬜

Figure 7.3: 380 possible routes from node i (first column) to node j first row concerning an open network design. The green box shows if a route is possible or not.

Specific values with regard to the case of PostNL have to be taken into account for the use of the mathematical model. These values are shown in table 7.1 including references to chapters before. Concerning the process at postNL, the demand w^p is defined in terms of roll cages (RC) that have to be transported from origin to destination through the network. The required number of RCs between origin and destination are determined as follow: First, the total number of items/individual parcels is determined as shown in table 4.1.

Further, from section 5.1.1 there can be concluded that 1 RC is able to transport 37 items based on the average volume per parcel. Combining these givens results in the number of RCs that have to be transported between origin and destination as presented in the attached excel file of this report. Transportation will be performed by only one type of transportation asset: a truck with a constant capacity of 48 RCs and an average speed of 71 kilometres an hour. Concerning a 5 hub network design, only a spoke-hub-spoke path is possible. The open network design makes use of spoke-hub-spoke paths as well as spoke-spoke paths. Emissions emitted by using an arc are based on the measured distance in combination with an emission factor of 713 gram CO_2 per kilometre as a result of the average fuel consumption in L/km times the DEFRA Factor. Since the fact that sorting of the collected demand starts around 15:30h, it is expected that the batch that arrives at 22:00h will be small relative to the batches that arrive during the afternoon. It is assumed that the sorting process ends at 23:00h whereafter 30 minutes (23:30h) the earliest moment arises that a truck can leave the origin spoke. The latest moment that a truck is allowed to arrive at the destination is at 07:00h (An hour earlier than currently is used), which is 480 minutes later than the starting moment. Since CPLEX as solver is used for the mathematical model, a limited number of trucks per path available was considered of 151. This value is consistent with the number of trucks that PostNL owns. However, by using this model it is possible that more trucks will be allocated on the network than the given limit per path. In this way, the model is able to find the most environmentally friendly combination of decision variables. This fits the reality since PostNL is able to hire third parties.

Table 7.1: Specific values for the case at PostNL including references

w^p	volume to be transported in terms of RC	Given in attached excel file
u_{ij}	Loading capacity of 48 RCs per truck on arc from i to j	Concluded in section 5.1.1
d_{ij}	distance of arc $(i', j') \in A'$	Given in table E.1
e	emission-factor of 713 gram CO_2 per kilometre	Concluded in section 5.5
s	Speed of 71 kilometres per hour	Concluded in section 5.4
tl_i	(un)loading time of 25 minutes at a node $i \in N$	Concluded in section 4.2
E_i	23:30h (30 minutes after start) is the earliest departure time at origin $i \in N$	Concluded in section 2.2
A_i	07:00h (480 minutes after start) is the latest arrival time at destination $j \in N$	Concluded in section 2.2

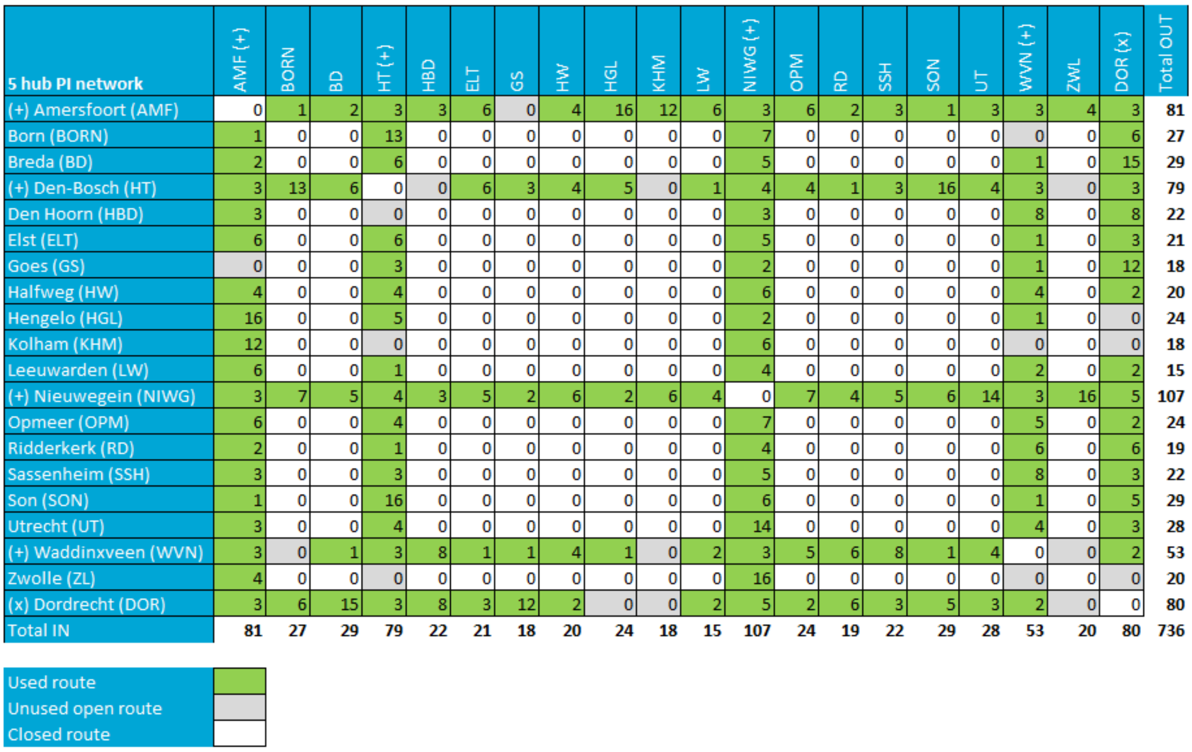
7.2. Results hub network design

The performance of a hub network as given in chapter 6 will be analysed in this section. As input, this design makes use of the specific values for the case at PostNL as shown in table 7.1. With regard to this design, the same 5 hubs as currently used by PostNL have been adapted. The solution of the 5 hub network design (Amersfoort, Den-Bosch, Nieuwegein, Waddinxveen and Dordrecht) is generated with a MIP gap of 1.20 % after a running time of 3600 seconds. The meaning of this MIP gap is discussed in Appendix G. First, the structure and fleet allocation of a 5 hub network will be discussed relative to the current (measured) state at case study PostNL. Moreover, the performance will be presented concerning utilisation and emitted amount of CO_2. The different paths of demand from origin to destination through a hub are shown in the attached excel file.

7.2.1. Structure & fleet allocation hub network design

After a running time of 3600 seconds, CPLEX came up with a network structure and fleet allocation as given in figure 7.4. From the first view on figure 7.4, it can be concluded that the mathematical model worked properly since the vehicles are only allocated to routes from spoke-to-hub or from hub-to-spoke. Moreover, the design balance constraint made sure that the total number of trucks from i to j is equal to the number of trucks from j to i. With regard to the output of the solver, there are a couple of interesting conclusions to make in relation to figure 7.2. First, there is observed that 151 out of 170 possible routes are used for the transportation of the given demand relative to 184 used routes in the current state as analysed in section 5.2. However, this difference is mainly because of the number of spoke to spoke trips. Where in the current state paths are measured from spoke to spoke or spoke-hub-spoke, the 5 hub design makes only use of spoke-hub-spoke trips as presented in the attached excel file. when spoke to spoke trips are not taken into account, the current state used 137 routes between spokes and hubs. As expected, the application of PI results in more used routes (151>137). In addition, the total number of trips that take place increased by 8 extra trips from 728 to 736. However, when the total amount of driven kilometres is calculated by using table E.1 from Appendix

E, it can be concluded that the total distance travelled of a 5 hub network design is 60,610 kilometres relative to 64,788 as analysed in section 5.2.



5 hub PI network	AMF (+)	BORN	BD	HT (+)	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG (+)	OPM	RD	SSH	SON	UT	WVN (+)	ZWL	DOR (x)	Total OUT
(+) Amersfoort (AMF)	0	1	2	3	3	6	0	4	16	12	6	3	6	2	3	1	3	3	4	3	**81**
Born (BORN)	1	0	0	13	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	6	**27**
Breda (BD)	2	0	0	6	0	0	0	0	0	0	0	5	0	0	0	0	0	1	0	15	**29**
(+) Den-Bosch (HT)	3	13	6	0	0	6	3	4	5	0	1	4	4	1	3	16	4	3	0	3	**79**
Den Hoorn (HBD)	3	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	8	0	8	**22**
Elst (ELT)	6	0	0	6	0	0	0	0	0	0	0	5	0	0	0	0	0	1	0	3	**21**
Goes (GS)	0	0	0	3	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	12	**18**
Halfweg (HW)	4	0	0	4	0	0	0	0	0	0	0	6	0	0	0	0	0	4	0	2	**20**
Hengelo (HGL)	16	0	0	5	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	**24**
Kolham (KHM)	12	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	**18**
Leeuwarden (LW)	6	0	0	1	0	0	0	0	0	0	0	4	0	0	0	0	0	2	0	2	**15**
(+) Nieuwegein (NIWG)	3	7	5	4	3	5	2	6	2	6	4	0	7	4	5	6	14	3	16	5	**107**
Opmeer (OPM)	6	0	0	4	0	0	0	0	0	0	0	7	0	0	0	0	0	5	0	2	**24**
Ridderkerk (RD)	2	0	0	1	0	0	0	0	0	0	0	4	0	0	0	0	0	6	0	6	**19**
Sassenheim (SSH)	3	0	0	3	0	0	0	0	0	0	0	5	0	0	0	0	0	8	0	3	**22**
Son (SON)	1	0	0	16	0	0	0	0	0	0	0	6	0	0	0	0	0	1	0	5	**29**
Utrecht (UT)	3	0	0	4	0	0	0	0	0	0	0	14	0	0	0	0	0	4	0	3	**28**
(+) Waddinxveen (WVN)	3	0	1	3	8	1	1	4	1	0	2	3	5	6	8	1	4	0	0	2	**53**
Zwolle (ZL)	4	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	**20**
(x) Dordrecht (DOR)	3	6	15	3	8	3	12	2	0	0	2	5	2	6	3	5	3	2	0	0	**80**
Total IN	**81**	**27**	**29**	**79**	**22**	**21**	**18**	**20**	**24**	**18**	**15**	**107**	**24**	**19**	**22**	**29**	**28**	**53**	**20**	**80**	**736**

Used route	🟩
Unused open route	▨
Closed route	☐

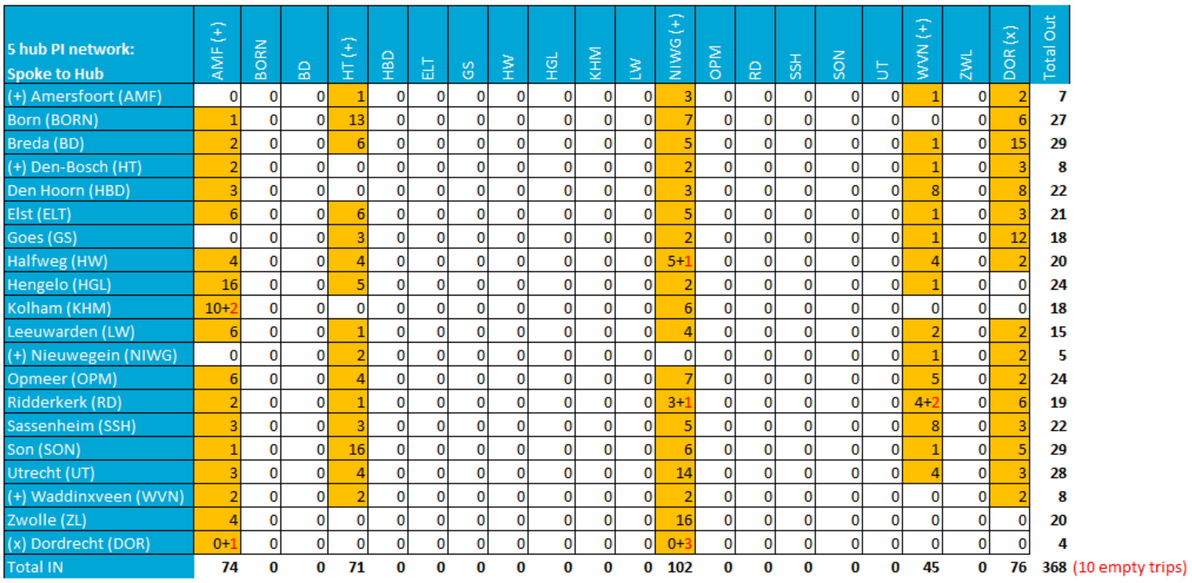
Figure 7.4: Used routes and the amount of allocated trips between i (first column) to node j (first row) concerning 5 hub network design.

Although it is hard to compare the number of trips as measured in the current state with the allocated trips by CPLEX since the lack of trip balancing in the measured state, it can be concluded that Nieuwegein (NIWG) attracts more trips in the design model than in the measured state. Most of these trips are allocated to Waddinxveen (WVN) in the measured state. Another thing that could influence the decrease in total amount of kilometres is the fact that, concerning a 5 hub network design, every spoke is able to connect with every hub and vice versa. With regard to the current network design by PostNL, every origin (spoke) is able to connect with every hub but every hub is not connected with every destination (spoke) as described in section 2.2. However, as measured in the current state PostNL broke this rule and serve destinations by more than one hub. Still, it is observed that the decision model uses the multi allocation characteristic more than currently measured at PostNL. The reallocation of trips from WVN to NIWG in combination with the lack of spoke-to-spoke trips and compulsory path restriction in the current process could be helpful to decrease to the total amount of driven kilometres.

7.2.2. Utilisation hub network design

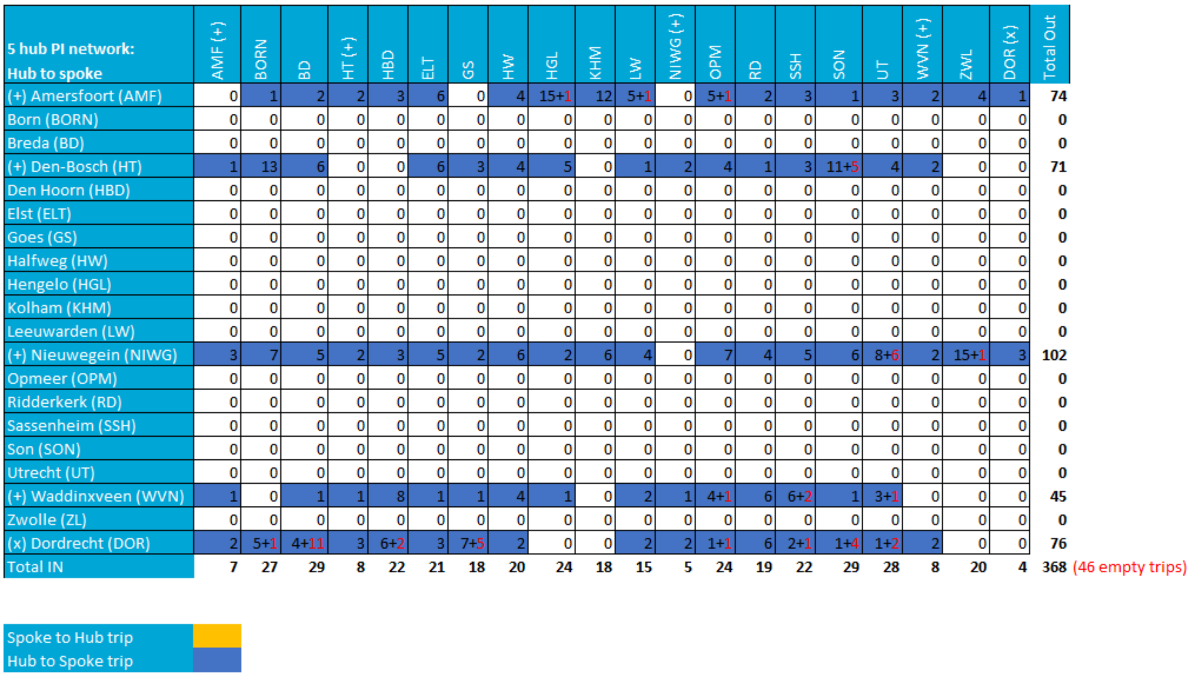
Th utilisation of trips plays a very important role concerning the vision of Physical Internet logistics. As mentioned by Montreuil (2011), carriers are shipping air and empty travelling is the trend of the day. To say more about the effects of Physical Internet concerning utilisation of trucks and empty trips, analysis has to be performed concerning the trips from spoke-to-hub and from hub-to-spoke. First, the number of loaded and empty trips between spokes and hubs will be analysed as shown in figure 7.5. Secondly, conclusions are made focused on the utilisation as presented in figure 7.6.

The fleet allocation according to the design model resulted in 736 trips, of which 368 spoke to hub and 368 from hub to spoke, to transport the total number of demand from i to j. Moreover, the total number of fully empty trips is 56 as shown in figure 7.5a (10 empty trips) and figure 7.5b (46 empty trips) in red numbers relative to 28 empty trips as measured in the current state. Remarkable are the empty trips returning backwards to the origin, especially coming from Dordrecht. The main reason is the lack of demand production in Dordrecht. However, demand intended for Belgium is attracted by Dordrecht.



5 hub PI network: Spoke to Hub	AMF (+)	BORN	BD	HT (+)	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG (+)	OPM	RD	SSH	SON	UT	WVN (+)	ZWL	DOR (x)	Total Out
(+) Amersfoort (AMF)	0	0	0	1	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	2	7
Born (BORN)	1	0	0	13	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	6	27
Breda (BD)	2	0	0	6	0	0	0	0	0	0	0	5	0	0	0	0	0	1	0	15	29
(+) Den-Bosch (HT)	2	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	3	8
Den Hoorn (HBD)	3	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	8	0	8	22
Elst (ELT)	6	0	0	6	0	0	0	0	0	0	0	5	0	0	0	0	0	1	0	3	21
Goes (GS)	0	0	0	3	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	12	18
Halfweg (HW)	4	0	0	4	0	0	0	0	0	0	0	5+1	0	0	0	0	0	4	0	2	20
Hengelo (HGL)	16	0	0	5	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	24
Kolham (KHM)	10+2	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	18
Leeuwarden (LW)	6	0	0	1	0	0	0	0	0	0	0	4	0	0	0	0	0	2	0	2	15
(+) Nieuwegein (NIWG)	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	5
Opmeer (OPM)	6	0	0	4	0	0	0	0	0	0	0	7	0	0	0	0	0	5	0	2	24
Ridderkerk (RD)	2	0	0	1	0	0	0	0	0	0	0	3+1	0	0	0	0	0	4+2	0	6	19
Sassenheim (SSH)	3	0	0	3	0	0	0	0	0	0	0	5	0	0	0	0	0	8	0	3	22
Son (SON)	1	0	0	16	0	0	0	0	0	0	0	6	0	0	0	0	0	1	0	5	29
Utrecht (UT)	3	0	0	4	0	0	0	0	0	0	0	14	0	0	0	0	0	4	0	3	28
(+) Waddinxveen (WVN)	2	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	8
Zwolle (ZL)	4	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	20
(x) Dordrecht (DOR)	0+1	0	0	0	0	0	0	0	0	0	0	0+3	0	0	0	0	0	0	0	0	4
Total IN	74	0	0	71	0	0	0	0	0	0	0	102	0	0	0	0	0	45	0	76	368 (10 empty trips)

(a) Trips from spoke (first column) to hub (first row) concerning a 5 hub network design.



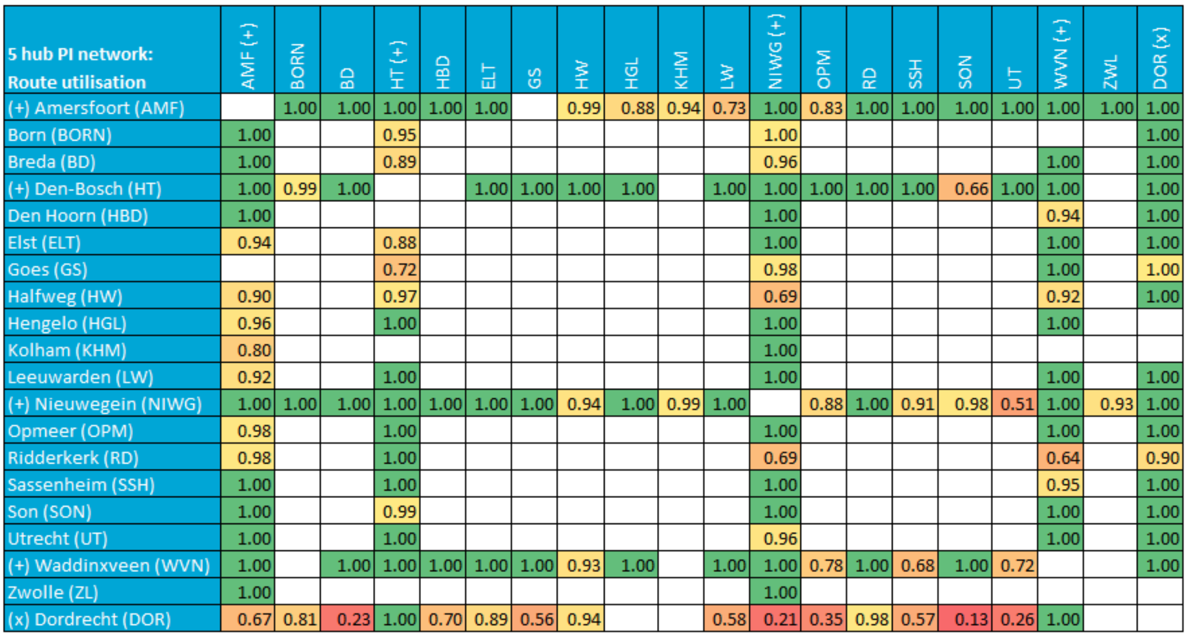
5 hub PI network: Hub to spoke	AMF (+)	BORN	BD	HT (+)	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG (+)	OPM	RD	SSH	SON	UT	WVN (+)	ZWL	DOR (x)	Total Out
(+) Amersfoort (AMF)	0	1	2	2	3	6	0	4	15+1	12	5+1	0	5+1	2	3	1	3	2	4	1	74
Born (BORN)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Breda (BD)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(+) Den-Bosch (HT)	1	13	6	0	0	6	3	4	5	0	1	2	4	1	3	11+5	4	2	0	0	71
Den Hoorn (HBD)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elst (ELT)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Goes (GS)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Halfweg (HW)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hengelo (HGL)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kolham (KHM)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leeuwarden (LW)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(+) Nieuwegein (NIWG)	3	7	5	2	3	5	2	6	2	6	4	0	7	4	5	6	8+6	2	15+1	3	102
Opmeer (OPM)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ridderkerk (RD)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sassenheim (SSH)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Son (SON)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Utrecht (UT)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(+) Waddinxveen (WVN)	1	0	1	1	8	1	1	4	1	0	2	1	4+1	6	6+2	1	3+1	0	0	0	45
Zwolle (ZL)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(x) Dordrecht (DOR)	2	5+1	4+11	3	6+2	3	7+5	2	0	0	2	2	1+1	6	2+1	1+4	1+2	2	0	0	76
Total IN	7	27	29	8	22	21	18	20	24	18	15	5	24	19	22	29	28	8	20	4	368 (46 empty trips)

Spoke to Hub trip	🟨
Hub to Spoke trip	🟦

(b) Trips from hub (first column) to spoke (first row) concerning a 5 hub network design.

Figure 7.5: Spoke-to-hub (7.5a) and hub-to-spoke (7.5b) trip matrix concerning a 5 hub network design optimised by the introduced model in chapter 6.1. The number of empty trips are indicated by red numbers.

Since it is interesting to compare the total amount of empty kilometres instead of the absolute number of trips from an environmental perspective, the total distance travelled with empty trips is calculated by using the distance matrix as shown in table E.1. Where section 5.3 shows that the total amount of empty kilometres is around 2,411 kilometres on a daily base currently, the 5 hub network design results in 3,363 empty kilometres which is an increase of 39% relative to the current state. Although this is not in line with the principles of the Physical Internet as defined by Montreuil (2011), it could be explained by two reasons. First, the hub network design requires that a truck always travels back towards the spoke on the same route. It could occur that there is much more demand from spoke A to hub B than vice versa. In this way, not all the number of trucks from B to A travel back loaded. Secondly, Montreuil (2011) takes an open and fully connected network into account in which transhipment is possible at every node. The hub design limits this principle by the number of restricted hubs. In this way, some paths make unnecessary use of a hub which can result in empty kilometres. To determine the utilisation of the used routes, the amount of volume that is transported during a certain trip has to be analysed. Besides the trip allocation as discussed before, also the quantity of load that is transported on a certain route/link i to j is given as result by CPLEX. This is presented in the attached excel file. Results of the utilisation per route are shown in figure 7.6, of which can be concluded that the average utilisation is 0.92 relative to 0.84 in the measured state. As expected, empty trips have a decent impact on the utilisation of routes which can be concluded from the concentration of empty trips in figure 7.5a and 7.5b in combination with the utilisation of figure 7.6. Nevertheless, not all the trips are fully loaded. This is mainly because that demand between origin and destination is not in terms of the capacity of 48 RC. For example, when the demand between i and j is very low, a truck has to be allocated despite the low volume. Refusal of performing a service is not an option, which results in the allocation of a truck with a lower volume loaded. Also, it becomes clear that places with only attraction or production, like Dordrecht, result in very low utilized routes to or from these locations.



5 hub PI network: Route utilisation	AMF (+)	BORN	BD	HT (+)	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG (+)	OPM	RD	SSH	SON	UT	WVN (+)	ZWL	DOR (x)
(+) Amersfoort (AMF)		1.00	1.00	1.00	1.00	1.00		0.99	0.88	0.94	0.73	1.00	0.83	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Born (BORN)	1.00			0.95								1.00								1.00
Breda (BD)	1.00			0.89								0.96						1.00		1.00
(+) Den-Bosch (HT)	1.00	0.99	1.00			1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	0.66	1.00	1.00		1.00
Den Hoorn (HBD)	1.00											1.00						0.94		1.00
Elst (ELT)	0.94			0.88								1.00						1.00		1.00
Goes (GS)				0.72								0.98						1.00		1.00
Halfweg (HW)	0.90			0.97								0.69						0.92		1.00
Hengelo (HGL)	0.96			1.00								1.00						1.00		
Kolham (KHM)	0.80											1.00								
Leeuwarden (LW)	0.92			1.00								1.00						1.00		1.00
(+) Nieuwegein (NIWG)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	1.00	0.99	1.00		0.88	1.00	0.91	0.98	0.51	1.00	0.93	1.00
Opmeer (OPM)	0.98			1.00								1.00						1.00		1.00
Ridderkerk (RD)	0.98			1.00								0.69						0.64		0.90
Sassenheim (SSH)	1.00			1.00								1.00						0.95		1.00
Son (SON)	1.00			0.99								1.00						1.00		1.00
Utrecht (UT)	1.00			1.00								0.96						1.00		1.00
(+) Waddinxveen (WVN)	1.00		1.00	1.00	1.00	1.00	1.00	0.93	1.00		1.00	1.00	0.78	1.00	0.68	1.00	0.72			1.00
Zwolle (ZL)	1.00											1.00								
(x) Dordrecht (DOR)	0.67	0.81	0.23	1.00	0.70	0.89	0.56	0.94			0.58	0.21	0.35	0.98	0.57	0.13	0.26	1.00		

Figure 7.6: Utilisation of the routes between i (first column) and node j (first row) according to a 5 hub network design

To conclude, relative to the measured state a 5 hub network design has more empty kilometres but a higher truck utilisation. The increase empty kilometres are mainly due to the requirement of allocating a truck only to a single route. The higher utilisation is due to the greater use of multiple allocation.

7.2.3. Environmental impact hub network design

As discussed in the first chapter of this report, the parcel delivery industry is looking for solutions that reduce their environmental impact regarding CO_2. Using the number of allocated trips between nodes for a 5 hub network design, calculations can be made concerning the total amount of emitted CO_2 in combination with the same assumptions for fuel and CO_2 as used in section 5.5. Table 7.2 shows that the amount of emitted CO_2 will be 43.21 tCO_2 per day for a 5 hub network design relative to the current state of 46.19 tCO_2. As mentioned before, both networks are dealing with the same demand, locations and hubs. However, the decrease of 6.5% is reached by different and individualised routing of RCs between origin and destination as shown in the attached excel file. For example, 78 RCs have to be transported from Amersfoort to Born. From the output of CPLEX it becomes clear that 38 RCs took a path from Amersfoort to Born directly combined with other origins, while the remaining 40 RC go Born via Nieuwegein.

Table 7.2: Total amount of emitted CO_2 concerning a 5 hub network design based on a case study at PostNL

Network	Amount of tCO_2 per day
Current state (trip measurement)	46.19
5 hub network	43.21

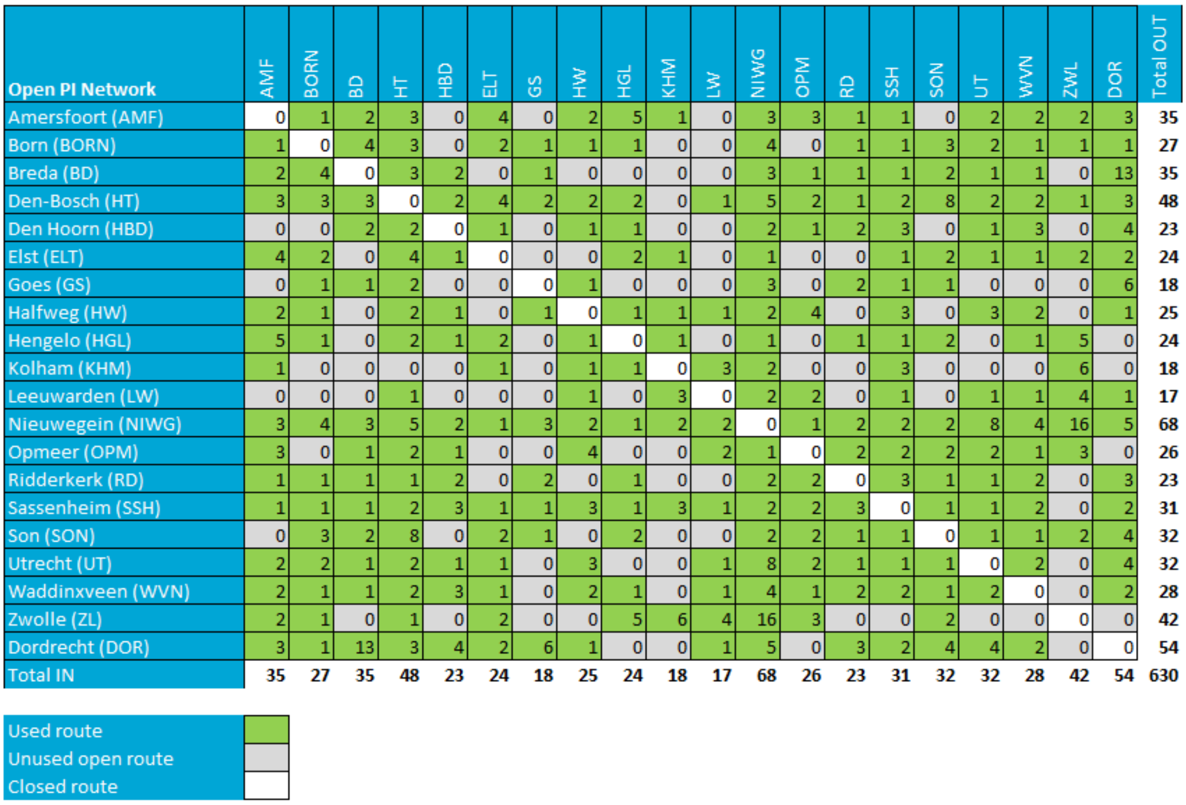
7.3. Results open network design

This section shows the performance of a completely open network design by using the case at PostNL. This means that, in relation to a hub network design, transhipment can take place at every node and also direct spoke to spoke paths are allowed. This section will have the same structure as section 7.2: First the focus will be on the network structure and fleet allocation followed by an analysis with regard to utilisation and the design's performance regarding emissions. By using CPLEX as solver, decision variables were generated after a running time of 3000 seconds and a MIP GAP of 2.19 %. The running time was 600 seconds shorter than performed during the hub network model since the used computer was running out of memory. Moreover, the MIP GAP of 2.19 % is larger in relation to the 5 hub design. This means that there is more room for improvement concerning this design when a computer is used with better calculation characteristics. However, the gap of 2.19% is accepted in this report to show the differences.

7.3.1. Structure & fleet allocation open network design

Figure 7.7 presents the fleet allocation as generated by the decision model. This figure shows the number of trips from node i (first column) to node j (first row) which distribute the total demand. By comparing figure 7.7 with the measured state like figure 5.5b, it can be concluded that there are a lot of routes used in the open network design in relation to the current state. Where chapter 5 concludes that currently 184 routes are used, an open network design as shown in figure 7.7 makes use of 274 out of 380 available routes, an increase of 49%. These routes, concerning the current state as well as the open network design, can be part of two type of paths: spoke-to-spoke or spoke-hub-spoke. An increase in the number of used routes/links is one of the principles that should be a result of implementing Physical Internet Logistics.

Concerning the total number of used trips, a big difference between the current (measured) state with 736 trips in total and the open network design with 630 trips in total is observed. The total distance travelled by these 630 trips comes down to 54,560 kilometres, a decrease of 16% relative to the current state. In addition, these 630 trips are more distributed over different routes than the 736 trips in the current state. In general, routes are less occupied in relation to the 5 hub network since the absence of path restriction. Remarkable from figure 7.7 is that Nieuwegein (NIWG), which is a hub in the current state, still maintains its link with every other node in the network. From this observation it can be concluded that the Nieuwegein is a great location to have a hub when a service network makes use of a hub-and-spoke network design. With regard to the design balance it is observed that the constraints worked correctly since the total number of vehicles out is the same as the total number of vehicles in.



Open PI Network	AMF	BORN	BD	HT	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG	OPM	RD	SSH	SON	UT	WVN	ZWL	DOR	Total OUT
Amersfoort (AMF)	0	1	2	3	0	4	0	2	5	1	0	3	3	1	1	0	2	2	2	3	**35**
Born (BORN)	1	0	4	3	0	2	1	1	1	0	0	4	0	1	1	3	2	1	1	1	**27**
Breda (BD)	2	4	0	3	2	0	1	0	0	0	0	3	1	1	1	2	1	1	0	13	**35**
Den-Bosch (HT)	3	3	3	0	2	4	2	2	2	0	1	5	2	1	2	8	2	2	1	3	**48**
Den Hoorn (HBD)	0	0	2	2	0	1	0	1	1	0	0	2	1	2	3	0	1	3	0	4	**23**
Elst (ELT)	4	2	0	4	1	0	0	0	2	1	0	1	0	0	1	2	1	1	2	2	**24**
Goes (GS)	0	1	1	2	0	0	0	1	0	0	0	3	0	2	1	1	0	0	0	6	**18**
Halfweg (HW)	2	1	0	2	1	0	1	0	1	1	1	2	4	0	3	0	3	2	0	1	**25**
Hengelo (HGL)	5	1	0	2	1	2	0	1	0	1	0	1	0	1	1	2	0	1	5	0	**24**
Kolham (KHM)	1	0	0	0	0	1	0	1	1	0	3	2	0	0	3	0	0	0	6	0	**18**
Leeuwarden (LW)	0	0	0	1	0	0	0	1	0	3	0	2	2	0	1	0	1	1	4	1	**17**
Nieuwegein (NIWG)	3	4	3	5	2	1	3	2	1	2	2	0	1	2	2	2	8	4	16	5	**68**
Opmeer (OPM)	3	0	1	2	1	0	0	4	0	0	2	1	0	2	2	2	2	1	3	0	**26**
Ridderkerk (RD)	1	1	1	1	2	0	2	0	1	0	0	2	2	0	3	1	1	2	0	3	**23**
Sassenheim (SSH)	1	1	1	2	3	1	1	3	1	3	1	2	2	3	0	1	1	2	0	2	**31**
Son (SON)	0	3	2	8	0	2	1	0	2	0	0	2	2	1	1	0	1	1	2	4	**32**
Utrecht (UT)	2	2	1	2	1	1	0	3	0	0	1	8	2	1	1	1	0	2	0	4	**32**
Waddinxveen (WVN)	2	1	1	2	3	1	0	2	1	0	1	4	1	2	2	1	2	0	0	2	**28**
Zwolle (ZL)	2	1	0	1	0	2	0	0	5	6	4	16	3	0	0	2	0	0	0	0	**42**
Dordrecht (DOR)	3	1	13	3	4	2	6	1	0	0	1	5	0	3	2	4	4	2	0	0	**54**
Total IN	**35**	**27**	**35**	**48**	**23**	**24**	**18**	**25**	**24**	**18**	**17**	**68**	**26**	**23**	**31**	**32**	**32**	**28**	**42**	**54**	**630**

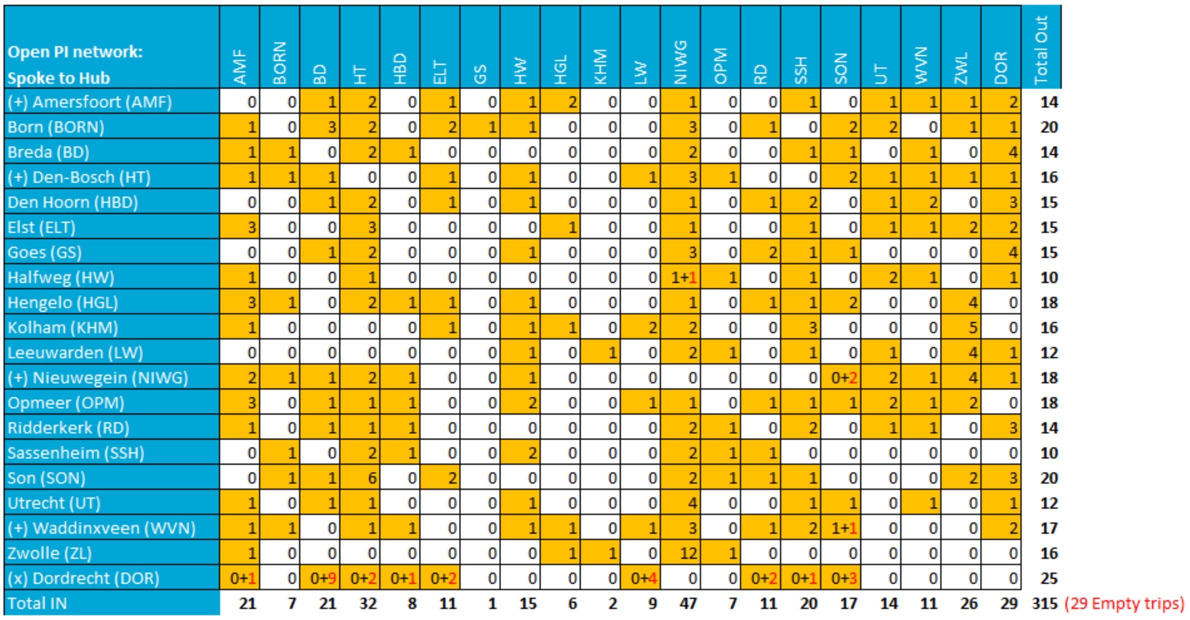
Used route	🟩
Unused open route	⬜
Closed route	☐

Figure 7.7: Used routes and the number of allocated trips between i (first column) to node j (first row) concerning an open network design

7.3.2. Utilisation of an open network design

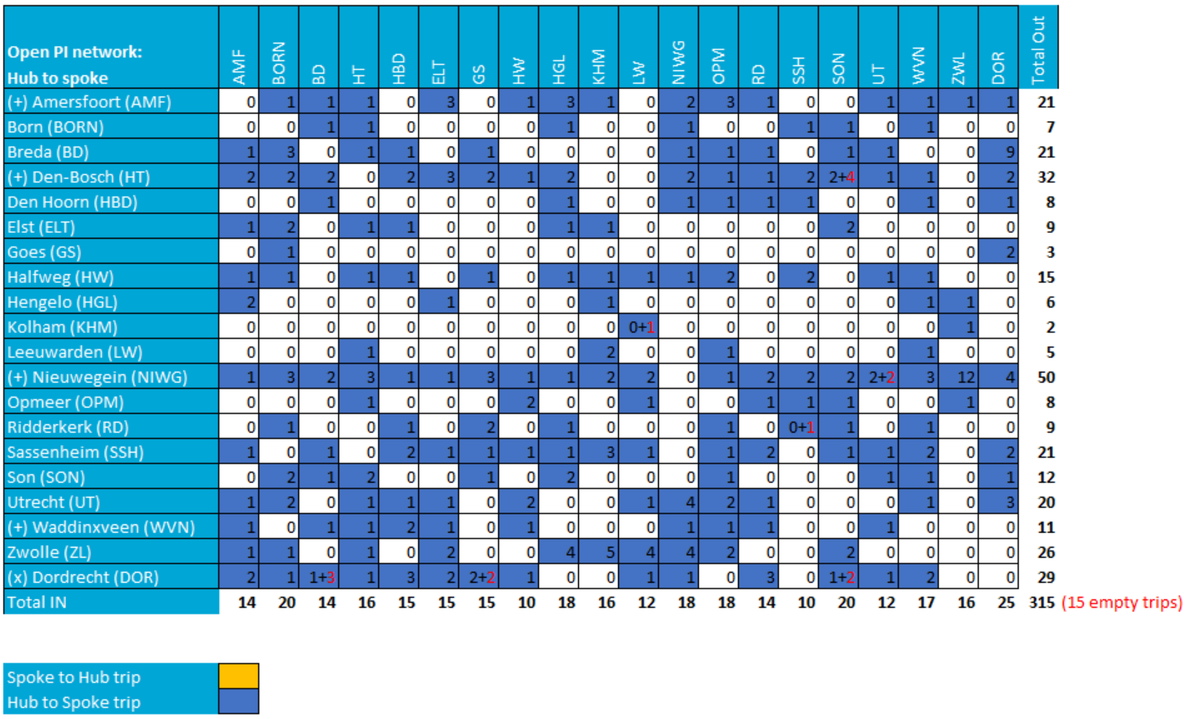
Earlier this section it became clear that an open network for the case at PostNL consists of fewer vehicles and less kilometres but more used routes relative to the current state. Since an open network design is more in line with the vision of Physical Internet, it is interesting to take a look at the number and distribution of empty trips in figure 7.8. In combination with the transported quantity, some conclusions can be made concerning the average utilisation per route as shown figure 7.9.

As mentioned before, there are two kinds of paths concerning an open network: spoke A to spoke B and spoke A to hub C to spoke B. Since a trip can consists of one of both kind of paths, the trips were split up in inbound (spoke to hub trips) in figure 7.8a and outbound (hub to spoke trips) in figure 7.8b. However, it could be possible that this 'hub' is actually the destination of an RC and so should be defined as spoke instead of a hub. Concerning the number of empty trips, the fleet allocation according to CPLEX results in 44 empty trips of which 29 trips could be defined as inbound and 15 as outbound in figure 7.8a and 7.8b with red numbers. Also in this network design, the number of empty trips is mainly concentrated to and from the location of Dordrecht since this location only attracts demand without any production. Although this is a decrease of 12 empty trips relative to a 5 hub design, 44 trips is still an increase of 16 trips relative to the measured state. However, the amount of empty kilometres is significantly lower with 2,141 kilometres per day in relation to a 5 hub network design (3,363 kilometres) or the measurement of the current state (2,411 kilometres). It can be concluded that an open network design results in a more efficient fleet allocation in terms of empty kilometres than the current network design concerning 5 hubs as expected by Montreuil (2011).



Open PI network: Spoke to Hub	AMF	BORN	BD	HT	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG	OPM	RD	SSH	SON	UT	WVN	ZWL	DOR	Total Out	
(+) Amersfoort (AMF)	0	0	1	2	0	1	0	1	2	0	0	1	0	0	1	0	1	1	1	2	14	
Born (BORN)	1	0	3	2	0	2	1	1	0	0	0	3	0	1	0	2	2	0	1	1	20	
Breda (BD)	1	1	0	2	1	0	0	0	0	0	0	2	0	0	1	1	0	1	0	4	14	
(+) Den-Bosch (HT)	1	1	1	0	0	1	0	1	0	0	1	3	1	0	0	2	1	1	1	1	16	
Den Hoorn (HBD)	0	0	1	2	0	1	0	1	0	0	0	1	0	1	2	0	1	2	0	3	15	
Elst (ELT)	3	0	0	3	0	0	0	0	1	0	0	1	0	0	1	0	1	1	2	2	15	
Goes (GS)	0	0	1	2	0	0	0	1	0	0	0	3	0	2	1	1	0	0	0	4	15	
Halfweg (HW)	1	0	0	1	0	0	0	0	0	0	0	1+1	1	0	1	0	2	1	0	1	10	
Hengelo (HGL)	3	1	0	2	1	1	0	1	0	0	0	1	0	1	1	2	0	0	4	0	18	
Kolham (KHM)	1	0	0	0	0	1	0	1	1	0	2	2	0	0	3	0	0	0	5	0	16	
Leeuwarden (LW)	0	0	0	0	0	0	0	1	0	1	0	2	1	0	1	0	1	0	4	1	12	
(+) Nieuwegein (NIWG)	2	1	1	2	1	0	0	1	0	0	0	0	0	0	0	0+2	2	1	4	1	18	
Opmeer (OPM)	3	0	1	1	1	0	0	2	0	0	1	1	0	1	1	1	2	1	2	0	18	
Ridderkerk (RD)	1	0	1	1	1	0	0	0	0	0	0	2	1	0	2	0	1	1	0	3	14	
Sassenheim (SSH)	0	1	0	2	1	0	0	2	0	0	0	2	1	1	0	0	0	0	0	0	10	
Son (SON)	0	1	1	6	0	2	0	0	0	0	0	2	1	1	1	0	0	0	2	3	20	
Utrecht (UT)	1	0	1	1	0	0	0	1	0	0	0	4	0	0	1	1	0	1	0	1	12	
(+) Waddinxveen (WVN)	1	1	0	1	1	0	0	1	1	0	1	3	0	1	2	1+1	0	0	0	2	17	
Zwolle (ZL)	1	0	0	0	0	0	0	0	1	1	0	12	1	0	0	0	0	0	0	0	16	
(x) Dordrecht (DOR)	0+1	0	0+9	0+2	0+1	0+2	0	0	0	0	0+4	0	0	0+2	0+1	0+3	0	0	0	0	25	
Total IN	21	7	21	32	8	11	1	15	6	2	9	47	7	11	20	17	14	11	26	29	315	(29 Empty trips)

(a) Trips from spoke (first column) to hub (first row) concerning an open network design.



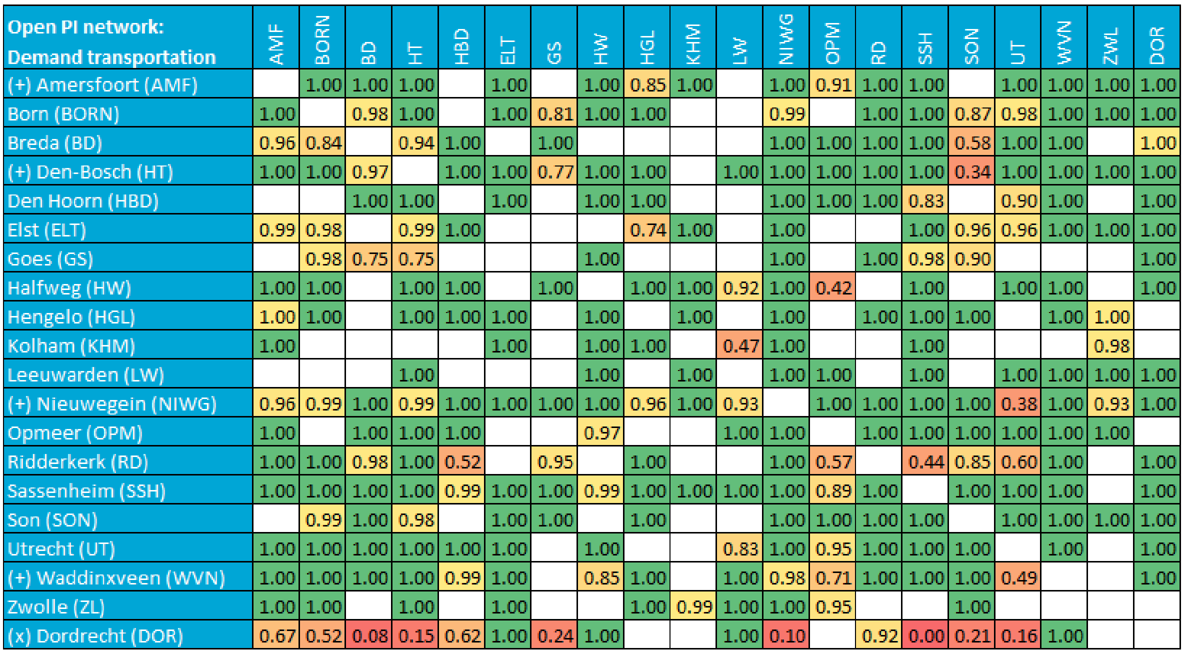
Open PI network: Hub to spoke	AMF	BORN	BD	HT	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG	OPM	RD	SSH	SON	UT	WVN	ZWL	DOR	Total Out	
(+) Amersfoort (AMF)	0	1	1	1	0	3	0	1	3	1	0	2	3	1	0	0	1	1	1	1	21	
Born (BORN)	0	0	1	1	0	0	0	0	1	0	0	1	0	0	1	1	0	1	0	0	7	
Breda (BD)	1	3	0	1	1	0	1	0	0	0	0	1	1	1	0	1	1	0	0	9	21	
(+) Den-Bosch (HT)	2	2	2	0	2	3	2	1	2	0	0	2	1	1	2	2+4	1	1	0	2	32	
Den Hoorn (HBD)	0	0	1	0	0	0	0	0	1	0	0	1	1	1	1	0	0	1	0	1	8	
Elst (ELT)	1	2	0	1	1	0	0	0	1	1	0	0	0	0	0	2	0	0	0	0	9	
Goes (GS)	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	
Halfweg (HW)	1	1	0	1	1	0	1	0	1	1	1	1	2	0	2	0	1	1	0	0	15	
Hengelo (HGL)	2	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	1	0	6	
Kolham (KHM)	0	0	0	0	0	0	0	0	0	0	0+1	0	0	0	0	0	0	0	1	0	2	
Leeuwarden (LW)	0	0	0	1	0	0	0	0	0	2	0	0	1	0	0	0	0	1	0	0	5	
(+) Nieuwegein (NIWG)	1	3	2	3	1	1	3	1	1	2	2	0	1	2	2	2	2+2	3	12	4	50	
Opmeer (OPM)	0	0	0	1	0	0	0	2	0	0	1	0	0	1	1	1	0	0	1	0	8	
Ridderkerk (RD)	0	1	0	0	1	0	2	0	1	0	0	0	1	0	0+1	1	0	1	0	0	9	
Sassenheim (SSH)	1	0	1	0	2	1	1	1	1	3	1	0	1	2	0	1	1	2	0	2	21	
Son (SON)	0	2	1	2	0	0	1	0	2	0	0	0	1	0	0	0	1	1	0	1	12	
Utrecht (UT)	1	2	0	1	1	1	0	2	0	0	1	4	2	1	0	0	0	1	0	3	20	
(+) Waddinxveen (WVN)	1	0	1	1	2	1	0	1	0	0	0	1	1	1	0	0	1	0	0	0	11	
Zwolle (ZL)	1	1	0	1	0	2	0	0	4	5	4	4	2	0	0	2	0	0	0	0	26	
(x) Dordrecht (DOR)	2	1	1+3	1	3	2	2+2	1	0	0	1	1	0	3	0	1+2	1	2	0	0	29	
Total IN	14	20	14	16	15	15	15	10	18	16	12	18	18	14	10	20	12	17	16	25	315	(15 empty trips)

Spoke to Hub trip	🟨
Hub to Spoke trip	🟦

(b) Trips from hub (first column) to spoke (first row) concerning an open network design.

Figure 7.8: Spoke-to-hub (7.8a) and hub-to-spoke (7.8b) trip matrix concerning an open network design optimised by the introduced model in chapter 6.1. The number of empty trips are indicated by red numbers.

With a reduction of total trips and empty trips in combination with the same demand as used before, it is expected that the utilisation of trucks is higher than analysed at the 5 hub network design or the current state. To determine this utilisation, the number of RCs that has been transported from node i to node j needs to be analysed. This quantity is based on the different paths that make use of the connection between certain nodes as presented in the attached excel file. Combining the fleet allocation from figure 7.7 with the quantity of carried roll cages makes it possible to calculate the utilisation per route by dividing the total quantity of transported RCs by the total number of used vehicles on a specific route. Figure 7.9 shows in a detailed way the utilisation per route. It can be concluded that the utilisation slightly improved (0.94) in comparison with a 5 hub network design (0.92). In relation to the current state (0.84), the utilisation increased with 12% which is a positive effect of implementing PI based elements. Also for this design, the 'low utilised routes' are concentrated to and from Dordrecht due to the lack of demand production. Nevertheless, most of the routes have an utilisation of 1 or slightly lower, something which is desirable.



Open PI network: Demand transportation	AMF	BORN	BD	HT	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG	OPM	RD	SSH	SON	UT	WVN	ZWL	DOR
(+) Amersfoort (AMF)		1.00	1.00	1.00		1.00		1.00	0.85	1.00		1.00	0.91	1.00	1.00		1.00	1.00	1.00	1.00
Born (BORN)	1.00		0.98	1.00		1.00	0.81	1.00	1.00			0.99		1.00	1.00	0.87	0.98	1.00	1.00	1.00
Breda (BD)	0.96	0.84		0.94	1.00		1.00					1.00	1.00	1.00	1.00	0.58	1.00	1.00		1.00
(+) Den-Bosch (HT)	1.00	1.00	0.97		1.00	1.00	0.77	1.00	1.00		1.00	1.00	1.00	1.00	1.00	0.34	1.00	1.00	1.00	1.00
Den Hoorn (HBD)			1.00	1.00		1.00		1.00	1.00			1.00	1.00	1.00	0.83		0.90	1.00		1.00
Elst (ELT)	0.99	0.98		0.99	1.00				0.74	1.00		1.00			1.00	0.96	0.96	1.00	1.00	1.00
Goes (GS)		0.98	0.75	0.75				1.00				1.00		1.00	0.98	0.90				1.00
Halfweg (HW)	1.00	1.00		1.00	1.00		1.00		1.00	1.00	0.92	1.00	0.42		1.00		1.00	1.00		1.00
Hengelo (HGL)	1.00	1.00		1.00	1.00	1.00		1.00		1.00		1.00		1.00	1.00	1.00		1.00	1.00	
Kolham (KHM)	1.00					1.00		1.00	1.00		0.47	1.00			1.00				0.98	
Leeuwarden (LW)				1.00				1.00		1.00		1.00	1.00		1.00		1.00	1.00	1.00	1.00
(+) Nieuwegein (NIWG)	0.96	0.99	1.00	0.99	1.00	1.00	1.00	1.00	0.96	1.00	0.93		1.00	1.00	1.00	1.00	0.38	1.00	0.93	1.00
Opmeer (OPM)	1.00		1.00	1.00	1.00			0.97			1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	
Ridderkerk (RD)	1.00	1.00	0.98	1.00	0.52		0.95		1.00			1.00	0.57		0.44	0.85	0.60	1.00		1.00
Sassenheim (SSH)	1.00	1.00	1.00	1.00	0.99	1.00	1.00	0.99	1.00	1.00	1.00	1.00	0.89	1.00		1.00	1.00	1.00		1.00
Son (SON)		0.99	1.00	0.98		1.00	1.00		1.00			1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00
Utrecht (UT)	1.00	1.00	1.00	1.00	1.00	1.00		1.00			0.83	1.00	0.95	1.00	1.00	1.00		1.00		1.00
(+) Waddinxveen (WVN)	1.00	1.00	1.00	1.00	0.99	1.00		0.85	1.00		1.00	0.98	0.71	1.00	1.00	1.00	0.49			1.00
Zwolle (ZL)	1.00	1.00		1.00		1.00			1.00	0.99	1.00	1.00	0.95			1.00				
(x) Dordrecht (DOR)	0.67	0.52	0.08	0.15	0.62	1.00	0.24	1.00			1.00	0.10		0.92	0.00	0.21	0.16	1.00		

Figure 7.9: Utilisation of the routes between i (first column) and node j (first row) according to an open network design

7.3.3. Environmental impact open network design

Since this report is focused on the amount of emitted CO_2 with regard to the transportation of parcels by using a certain network design, calculations have to be made focused on the total amount of CO_2 to say more about its performance. By using the total number of trips between nodes as presented in figure 7.7 in combination with the distance between nodes of table E.1 and the emission assumptions as used in section 5.5, it can be concluded that the total amount of CO_2 is 16% lower for an open network in relation to the current state at PostNL. Where section 5.5 shows that the current state is responsible for 46.19 tCO_2, CPLEX shows that an open network will emit 38.90 tCO_2 as presented in table 7.3. Mainly the different way of trip distribution makes this decrease possible.

Table 7.3: Total amount of emitted CO_2 concerning an open network design based on Physical Internet elements using a case study at PostNL

Network	Amount of tCO_2 per day
Current state (trip measurement)	46.19
Open network	38.90

7.4. Sensitivity analysis

During the verification phase of the used model, it became clear that some of the used parameters have a stronger influence on the objective than others. By making use of a sensitivity analyse it is possible to determine the sensitivity of a given parameter. However, focusing on the mathematical formulation of section 6.2, it can be concluded that most of the parameters are directly proportional to the objective equation 6.1 as will be discussed in subsection 7.4.1. Moreover, it turns out during the analysis of the measurement that the 95% confidential range of the parameters is relatively small as shown in table 7.4. To say more about the parameters with regard to CO_2 reduction in terms of sensitivity, this section discuss them based on scenarios as outlined in subsection 7.4.2. Further, the sensitivity of some Physical Internet characteristics will be discussed as far as possible in subsection 7.4.3.

Table 7.4: Used parameters including their 95% confidental range as analysed in chapter 5

Parameter	Mean	Range	Increment
Demand (items)	863,395	[830588, 896200]	-4%, +4%
Volume per parcel (L)	22.68	[22.58, 22.78]	-1%, +1%
Fuel Consumption (L/100km)	22.69	[22.60, 27.17]	-1%. +1%

7.4.1. Parameters

Focusing on the parameters as shown in table 6.2, four types of parameters can be determined: demand, capacity, vehicle and time.

Demand. The demand expressed in items is an increasing parameter for the upcoming years as suggested by the Strategy & Development department of PostNL. As discussed in section 6.4.2, an increase in demand in combination with a constant volume per parcel will result in a directly proportional increase in tCO_2 per day. Nevertheless, demand is a combination of items as well as volume. As introduced by section 6.4.3, volume reduction per parcel could be effective with regard to fleet allocation focused on CO_2 minimisation. As figure H.1 presents, the amount of emitted CO_2 decreases linearly per decrease in average volume per parcel with regard to fleet allocation. In fact, when the volume per parcel decreases a truck is able to transport more items. In this way, the model allocates the trucks differently and the total amount of emitted CO_2 decreases.

Capacity. When the capacity of a truck increases, it is expected that the amount of CO_2 per day will decrease in a directly proportional way just as discussed in the paragraph before. However, as already sketched in section 6.4, in real life an increase in capacity is often accompanied by an increase in fuel consumption. Concerning the case of a double deck trailer with an increased capacity of 60%, the fuel consumption increases with 10 % (Curtis, 2013). The ratio as defined by Curtis (2013) is used in this report.

vehicle. The fuel consumption is directly proportional to the amount of CO_2 emitted per day as outlined by the objective equation 6.1. Efficient trucks, driver training, platooning or other kinds of truck-related measures are directly proportional to the objective. Moreover, different types of fuel will have the same directly proportional ratio due to fuel characteristics. These characteristics are presented in table 4.4 based and on research by Balm et al. (2013); Verbeek and van Zyl (2014).

Time. These parameters are supplied in fours ways: (Un)loading time, speed, earliest and departure time. The model converts these times into a time window where transportation is possible. Concerning a case study at PostNL, the total time window between earliest departure and latest arrival time was set on 450 minutes (7.5h). Increasing the latest departure time did not have any effect on the fleet allocated focused on the objective. The same effect occurred with decreasing until the limit of 360 minutes. When the window between earliest departure time and latest arrival time got below 360 minutes, the model results in an error. With regard to this used model, it can be concluded that time does not have any influence in the total amount of CO_2 per day when it is larger than 360 minutes. Case to a carrier as PostNL to make sure that this won't happen. Morning traffic or roadworks should be taken into account on a daily base.

7.4.2. What if Scenarios

As can be observed, fleet allocation is mainly based on the demand and available capacity. The performance of this fleet allocations depends on its characteristics like fuel consumption or speed and may be seen as constant as discussed before. Focusing on demand and capacity, a sensitivity analyses of the model can be performed by using 6 scenarios with regard to the design 5 hub network and open network. The scenarios are varying the following parameters:

- Demand for 2018/2020/2023.
- Volume reduction per parcel of 0% or 10%.
- Small or large trailer.

An increase in demand will be based on forecasting by PostNL with regard to the total volume transported per year. It is expected by PostNL that the total number of parcels will increase from 244 million in 2018 to 325 million in 2020 and 401 million in 2023. However, it is important to mention that this forecast by PostNL is focused on a growth of the total volume. This means that ratio between origins and destinations stays constant for every year. The increase in demand of 33% and 64% can be compared for the implementation of different measures. As discussed before in this section, a volume reduction per parcel has a positive effect in terms of CO_2 reduction. Regarding trucks, section 6.4.4 introduces double deck trailers with a capacity increase of 60% in combination with a fuel consumption increase of 10%. The different effects of measures on different networks are shown in table 7.5. The top of table 7.5 shows the performance of the specific design in terms of CO_2. The bottom part presents the per cent difference relative to the base scenario: demand 2018 with 0% volume reduction which makes use of small trailers.

Table 7.5: Performance of an optimised 5 hub network and open network for different scenarios with regard to CO_2

Absolute Emissions in tCO2	5 hub network			Open network		
Scenario	Demand 2018	Demand 2020 (+33%)	Demand 2023 (+64%)	Demand 2018	Demand 2020 (+33%)	Demand 2023 (+64%)
Volume reduction 0% /small trailer	43.21	56.74	69.97	38.9	50.86	62.59
Volume reduction 10% / small trailer	38.63	51.17	63.22	34.85	45.96	56.51
Volume reduction 0% / large trailer	30.31	39.89	48.78	27.28	35.69	44.09
Volume reduction 10% / large trailer	27.28	35.63	43.99	24.49	32.13	39.43
Relative difference with base scenario	5 hub Network			Open Network		
Scenario	Demand 2018	Demand 2020 (+33%)	Demand 2023 (+64%)	Demand 2018	Demand 2020 (+33%)	Demand 2023 (+64%)
Volume reduction 0% /small trailer	0%	31%	62%	0%	31%	61%
Volume reduction 10% / small trailer	-11%	18%	46%	-10%	18%	45%
Volume reduction 0% / large trailer	-30%	-8%	13%	-30%	-8%	13%
Volume reduction 10% / large trailer	-37%	-18%	2%	-37%	-17%	1%

From table 7.5 it can be concluded that a volume reduction in combination with large trailers is the most effective. Moreover, the directly proportional characteristics of the parameters regarding the objective is noticeable within limits. A consequence of an optimal fleet allocation is that there is no space for taking care of fluctuations in demand or other external factors. This means that these factors must be predicted with a certain reliability. Otherwise, it is expected that the network is not able to fix them which result in a much higher amount of emitted CO_2.

7.4.3. Sensitivity of Physical Internet characteristics

This subsection is focused on the applied characteristics of Physical Internet and its influence on the total amount of emitted CO_2. As mentioned before, there are four characteristics of Physical Internet used in the model: Openness of the network, path individualisation, encapsulation and single allocation of trucks. The effect of openness is already shown by the difference in total amount of emitted CO_2 with regard to a 5 hub and open network. Path individualisation depends partly on the openness of a network as well as encapsulation. Effects of encapsulation and path individualisation will be discussed by means of demand in combination with roll cages. As discussed before, the demand that has to be transported is based on the capacity of a roll cage and a truck. By individualisation of demand to item level, the effects of individualisation and encapsulation can be determined. The other way around is also taken into account. Batching the demand in terms of the truck capacity result in less individualised but more encapsulated paths. Unfortunately, the effects regarding Physical Internet's single allocation of trucks is not taken into account in the sensitivity analysis due to the limitations of the used model. For further research, this effect should be analysed by the implementation of tours performed by trucks. The results of individualisation and batching are shown in table 7.6.

Table 7.6: Effects of encapsulation and path individualisation

CO_2 emissions	5 hub network	open network	Demand (#RC)
Path individualisation (RC level)	43.21	38.90	20,052
Path individualisation (item level)	43.34	38.62	20,076
Path batching (round demand)	43.37	38.90	20,352
Path batching (round up demand)	60.69	54.00	28,512

The second row of table 7.6 shows the amount of emitted CO_2 when the demand expressed in items is converted into roll cages, just as used in section 7.2 and section 7.3. The third row of table 7.6 is the result of demand individualisation on item level defined as 'Path individualisation (item level)'. By expressing the demand and truck capacity in terms of items, path individualisation is applied on a more detailed level. The truck capacity is calculated by using the capacity in items per roll cage and the capacity in roll cages per truck. This results in a capacity of 1786 items per truck. The fourth and fifth row of table 7.6 show the amount of emitted CO_2 when the demand is expressed in truck capacity called 'Path batching'. For example, the demand from A to B is 50 roll cages. The fourth row converts and rounds this to a demand of 1 truck between A and B since the capacity of 48 roll cages per truck. Using the same capacity per truck, the firth row converts and rounds a demand of 50 roll cages up into a demand of 2 trucks between A and B. For both cases, the capacity per truck is expressed in 1 truck. The difference due to rounding is significant, 8160 roll cages. There can be concluded from table 7.6 that the level of encapsulation and path individualisation slightly influence the total amount of CO_2. Mainly the difference in openness (hub network or open network) results in a significant difference in emissions emitted per day.

V

Evaluate

8

Feasibility case study PostNL

This chapter discusses the feasibility of the results as performed in this report regarding the case study at PostNL. The structure as shown in figure 8.1 will be as follow: First, section 8.1 comes up with implementation suggestions to realise measures with regard to CO_2 reduction for the case at PostNL. Further, section 8.2 discusses the expected effects of a Physical Internet based network design in comparison with the current situation and the science based targets in line with the Climate Change Agreement as determined by van de Brug et al. (2018) in section 1.2. Moreover, the effects of the two mentioned reduction measures as discussed in section 7.4 will be taken into account. The sub-question which is central to this chapter will be as follow:

SQ5: What is the potential of the suggested implementation?

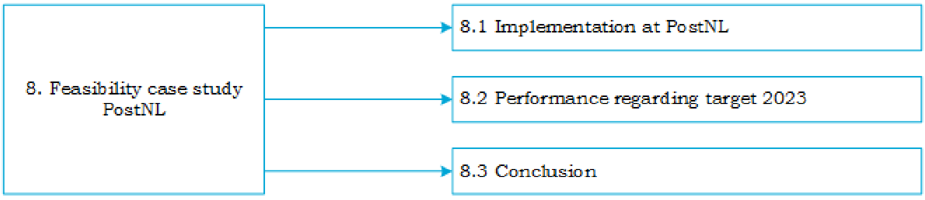


Figure 8.1: Structural overview of chapter 8

8.1. Implementation at case study PostNL

Since the fact that the results of a Physical Internet based network design sounds promising with regard to CO_2 reduction, the vision has to be translated into an implementation plan. This section discusses this implementation including their challenges and possible shortcomings.

8.1.1. Network & planning related

Implementation of the two suggested network designs requires rebuilding of current locations. The advantage of the suggested 5 hub design is that transhipment will only take place at locations which are currently defined as a hub. There should be enough space currently at PostNL to perform this since the characteristics of the current network. The number of trips to serve is almost the same, however, the number of locations to serve increased. Warehouse layout must be changed to process transhipment in an efficient way to serve more locations than currently occurs. Regarding an open network, warehouse designs of all the current spokes should change to be able to perform transhipment.

The challenge for PostNL is mainly focused on the planning and allocation of trips. The deterministic and static assumptions of the used model require ad-hoc decision-making regarding fleet allocation. Moreover, optimisation results in a very static solution without any space for taking care of fluctuations. The dynamic and stochastic environment of the demand is normalised by PostNL using forecasting as explained in section 5.1 in combination with a network design as shown in section 2.2. A Physical Internet based network design means that a standard network structure will disappear and forecasting in combination with real-time information will play a more important role for allocation.

After all, only a reliable prediction of the demand makes an open network possible. Three factors which play an important role can be defined:

- Expectation
- Communication
- Time

The *expectation* factor is just like forecasting as currently occurs at PostNL. For example, historical data or paydays will be used as input. *Communication* will play an important role between PostNL as a carrier and different shippers. By using IoT, demand expectations of different shippers can be communicated to PostNL which result in a fleet allocation plan. The earlier PostNL the demand knows the better. PostNL, on the other hand, could communicate to the shipper where supply is desirable within a certain distance to the shipper. The opener a network is the more different drop-off locations could be allocated by PostNL. This concerns in particular large shippers (B2B or B2C). Small shippers, like C2X, can be rewarded by making use of IoT. By using the PostNL app a shipper can be rewarded when he/she notify any shipments with regard to origin, destination and drop off day. The last factor is *time*. PostNL could use different 'latest arrival moments' linked to different locations where demand drop off is possible. For the case at PostNL, sensitivity in section 7.4 shows that different time frames do not have any influence on the performance of the transport planning when the window is reasonable with regard to distance, speed and (un)loading time. 360 minutes (6h) should be enough to distribute the parcels over the country. This means that demand should be delivered before 01:00h instead of the current applied 22:00h at spokes or 03:00h at hubs. By implementation of different latest drop-off moments for different locations, PostNL creates more flexibility for shippers but also time for themself to plan trips. Finally, as mentioned in section 7.4, stochastic variables as traffic jams in the morning or roadworks should be taken into account.
Nevertheless, the assumed demand in this report as discussed in section 5.1 is in general higher than measured on a daily base. This means that the allocation by the optimisation model takes a higher demand into account while the total amount of CO_2 emitted is lower than currently measured. By this assumption, some flexibility is created to cover the demand fluctuations over the days. Besides, application of larger trailers could have its potential to flatten peaks on hour level.

8.1.2. Asset & driver related

Implementation of Physical Internet Logistics means that truck drivers will only be allocated to single connections. Tours via different locations belong to the past. As mentioned before, it is expected that this can be experienced as boring by the drivers. This could be fixed by allocating the driver to different connections per week. Taking a look at the suggested measures with regard to volume reduction per parcel and double deck trailer it can be concluded that double deck trailers are the easiest to implement by PostNL. In fact, an investment in double-deck trailers is a decision which could be made by PostNL itself. The design of the (un)loading docks does not have to get changed since double deck trailers are equipped with a tailgate including exterior lifting system (Burgersgroup B.V., 2018). When a truck is positioned just in front of a dock, the lifting system is able to load and unload the truck. However, circumstances like rain, snow, cold or wind could have a bad influence on the load and the process. Besides, a lot of heating energy escapes from inside when a dock-door is open without any truck close to it. A recess in the building floor where the lifting door is able to move vertically could be a solution to solve the coming problems of a double deck trailer. It is expected that such a reconstruction of the (un)loading door/floor will be quite expensive. Regardless, when more than two small trailers with a capacity of 2 times 48 roll cages have been allocated to a route, it could be interesting to use double deck trailers instead of the currently used trailers. Considering the measured state as shown in figure 4.2, only 86 connections are performed by one or two trucks. Performing the other routes with large trailers, which contains a capacity of 76 roll cages per truck, results in less amount of emitted emissions as presented in table 8.1.

Table 8.1: Implementation of larger trailers

	Current state	Large trailer scenario
Small trailer trips	728	86
Large trailer trips	0	448
Total amount of tCO_2	46.19	37.45

A decrease of 19% in tCO_2 could be realised when larger trucks are allocated. However, in reality this reduction would be smaller due to the time-related characteristics of a parcel delivery carrier. Most of the time the number of trucks do not departure at the same time. When for example three trucks are allocated to a connection A-B, it could be possible that they departure with a 2 hours interval. The disadvantage of larger trucks are the larger holding times of demand at the nodes due to longer (un)loading time. Moreover, double-deck trailers need more space for turning due to their size.

8.1.3. Policy related

With regard to volume reduction per parcel, effects are only visible when customers of PostNL are aware of the environmental related effects of a volume reduction per parcel. Marketing focused on the advantages of air reduction in terms of packaging saving or fuel saving could be a way to affect the market. Another way of forcing the market to reduce the amount of air is volume based pricing or also called 'Dimensional Weight Pricing' as suggested by Gerard Peeters (2017). This way of pricing, which is common for years in the air transportation sector, is based on the ratio of volume per parcel and its weight. Currently, most of the carriers use a fixed price focused on a maximum in volume and weight. With the implementation of volume based pricing, a lack of attention in packaging with regard to volume could result in a significant impact in the shipper's costs per shipment. Consequently, challenges for shippers are created to send their demand in an efficient and sustainable way. Despite the fact that this way of pricing has enough potentials without any investment costs, it is expected that it hard to implement such a policy. Shippers, irrespective if they are companies, authorities or individuals want to pay as less as possible. If PostNL decides to change the way of pricing, this should be focused on a reasonable standard. of course, when the price is much higher than competitors standard it is likely that PostNL will lose market share.

8.2. Performance regarding target 2023

Companies operating in all kinds of segments have to take action to reduce their environmental footprint. Focused on CO_2 emissions concerning the distribution of parcels, this report came up with two Physical Internet based network designs in combination with two potential measures. This section will compare the performance as discussed in chapter 7 with the CO_2 targets in line with the Climate Change Agreement of Paris as shown in table 1.1.

As already experienced in section 5.5, it is hard to compare CO_2 calculations from different sources with the trip based calculation as used in this report. In particular because the trip based calculations are focused on just one aspect of the process while the other sources make use of the total amount of consumed fuel, no matter the reason it was used for. To make a comparison with the targets by Ecofys and relevant conclusions about the effects of possible measures, some assumptions have to be made. Starting point are the results as shown in table 8.2 of which the second and third column are coming from table 5.5. First of all, the difference between all trips and depot shift trips (1.3 tCO_2) is also relevant for a 5 hub design as well as open hub design to determine the total amount of CO_2 per working day. This means that the emission per working day of table 7.2 and table 7.3 are summed with 1.3 tCO_2 as depicted in table 8.2 column four and five. Moreover, it is expected that the trips on Sun- and holidays are the same for the current (measured) state as well as the PI based network designs.

Table 8.2: Emissions with regard to intern depot transportation of parcels

	Current state		PI based network	
	All intern depot trips	Depotshift related trips	5 hub network design	Open network design
Emission per working day in tCO_2	47.49	46.19	44.51	40.20
# Working days	306	306	306	306
Emission per Sun- and Holiday	3.86	3.86	3.86	3.86
# Sun- and holidays	58	58	58	58
Amount of tCO_2 per year (S1,S2,S3)	14,755	14,357	13,844	12,525
Amount of tCO_2 per year (S1,S2)	5,902	5,743	5,538	5,010
Amount of tCO_2 per year (S3)	8,853	8,614	8,306	7,515

Besides transportation between depots, heavy trucks are also allocated to trips concerning the collection of parcels at shippers. This means that the results of table 8.2 are not enough to say more about the effects in relation to the targets. Some assumptions have to be made to compare the results. First of all, it is assumed that the results coming from Ecofys are the right ones. This assumption, of which the results are shown in the second column of table 5.7, is because the fact that the CO_2 targets with regard to the Climate Change Agreement of Paris are also based on and relative to these results. However, these results are based on WTW [1] emissions. As assumed by van de Brug et al. (2018), The difference between TTW and WTW is assumed to be 18 %. Secondly, There is assumed that the emissions per year as measured in the current state (14,755 tCO_2) are valid enough to allocate them to inter depot transport TTW. Combining these assumptions, it can be concluded that the current situation with regard to the collection is responsible for 21,853 tCO_2. Since the process of collection is the same for the designs and the current state, it is assumed that the total amount of CO_2 emitted during collection is also the same. Applications of the assumptions on the current state measurement as well as the suggested network designs come down to the results as presented in table 8.3.

Table 8.3: Emissions of heavy trucks per year of the measured state in relation to the PI network designs based on demand 2018

tCO_2 in 2018 (S1,S2,S3)	Current situation	5 hub network design	Open network design
Emission per working day interdepot transport	47.49	44.51	40.2
Emission per year interdepot transport	14,755	13,844	12,525
Emission per year collection transport	21,853	21,853	21,853
Total per year) TTW	36,608	35,697	34,378
Total per year WTW	43,197	42,122	40,566

It is expected that the demand in items will increase by 64 % as discussed in section 6.4.1. This growth is based on volume forecasting reports for the period 2017-2022 in combination with an expected volume growth after 2022 based on CAGR. To calculate the effects of a 64% volume growth with regard to CO_2 emissions, the results of section 6.4.1 are used. First the focus on inter depot transport. Concerning the current situation, it is expected that the amount of tCO_2 will increase by 64%. For the designs, it is assumed that the amount of CO_2 per day will increase by 62% for the 5 hub network design and with 61% for the open hub network design. Secondly, the assumption is made that emissions with regard to the collection will increase by 64% for the current situation and the network designs. The results for 2023 by making use of the mentioned assumptions are shown in table 8.4.

Table 8.4: Emissions of heavy trucks per year of the measured state in relation to the PI network designs based on demand 2023

tCO_2 in 2023 (S1,S2,S3)	Expected situation	5 Hub network design	Open hub network design
Emission per working day interdepot transport	77.88	72.11	64.72
Emission per year interdepot transport	24,198	22,704	20,541
Emission per year collection transport	35,838	35,401	35,183
Total per year TTW	60,037	58,105	55,724
Total per year WTW	70,843	68,564	65,754
Impact reduction related measures in tCO_2 WTW			
Introduction double-deck trailer	62,277	60,527	58,482
Volume reduction per parcel (10%)	63,799	65,885	63,330

Besides the amount of emissions for the expected situation as well as for the different designs, the possible impact of two kinds of measures with regard to inter depot transportation are shown in the last two rows of table 8.4. As discussed in section 7.4, the application of double-deck trailers has the potential to reduce the amount of CO_2 with 30 %. Moreover, a volume reduction per parcel is able to reduce the amount of emitted CO_2 by 10%. It is important to mention that measures and additional effect are only applied to the transportation between depots. To compare the expected situation as calculated in table 8.4 with SBT targets as introduced in table 1.1 a proportional reduction is applied like used by Ecofys. This means, as shown in table 8.5, that the emissions concerning own vehicles are allowed to grow with 12% relative to the measured state while emissions by outsourced trucks are allowed to grow with 3%.

Table 8.5: Targets with regard to heavy trucks based on table 1.1

Activity	Measured in tCO_2 WTW (2018)	Target in tCO_2 WTW (2023)
Own freight heavy trucks +12% (S1,S2)	18,201	20,385
Outsourced freight heavy trucks +3% (S3)	24,996	25,746
Science based target heavy trucks (S1,S2,S3)	43,197	46,131

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[1] Schematic overview relative to this definition is shown in Appendix C.

Despite the given effects by PI based network designs or reduction related measures, the amount of emitted CO_2 will not be lower than the target as shown in table 8.5. The main reason why this difference in value is still significant is because of the expected growth. While PostNL takes a growth into account of 64% in volume for 2023 in relation to 2018, Ecofys make use of an expected growth of 8% per year only based on CAGR. An expected growth of 8% per year results in an expected growth of 46% in 2023 relative to 2018. Since Science Based Targeting also takes the growth of a company and the sector into account, it can be concluded that a comparison is hard to make due to the different expectations in growth. In fact, the target set up by Ecofys is way too low in relation to the expected growth in volume for parcels. Despite the fact that it is hard to compare the target with results of table 8.4, is interesting to see the effects of growth as well as reduction related measures in one table.

8.3. Conclusion

This section will be concluded with the last sub-question as defined in section 1.6.

SQ5: What is the potential of the suggested implementation?

Concerning a case study at PostNL, the implementation of Physical Internet logistics have the potential to reduce the amount of CO_2 with 6% for a 5 hub network design and with 16% for an open network design when the fleet is allocated in the most optimal way. However, the dynamic and stochastic demand makes it hard to reach this optimal state. Nevertheless, it is expected that the more open a network is the more CO_2 can be reduced. Extra places for transhipment or direct connections will result in a more efficient distribution of parcels. Measures related to assets are mainly directly proportional. By the application of a double deck trailers, an optimal reduction of 30% could be reached. However, also this optimal solution is hard to reach since a carrier is not able to replace its fleet in one day. Implementation of larger trailers on routes where currently more than two trucks are allocated could result in a 19% reduction of CO_2. A reduction in average volume per parcel by 10% has the potential to reduce the emitted amount of CO_2 by 10% due to its directly proportional characteristics. However, a shipper has to be forced to decrease the volume per package. How to force shippers to decrease the volume per parcel is not taken into account in this report. However, a suggestion could be Volume Based Pricing where shippers have to pay for shipment based on the volume and weight ratio. It is expected that implementation of volume based pricing will deteriorate the position in the market. Implementation by the complete market could have its potential to reduce the environmental impact of shipping air.

9

Conclusion & Recommendation

In this final chapter, the findings of previous chapters will be outlined. As figure 9.1 shows, the chapter will start with the conclusion of this report. Secondly, recommendations and limitations as outline of this report will be prepared in section 9.2.

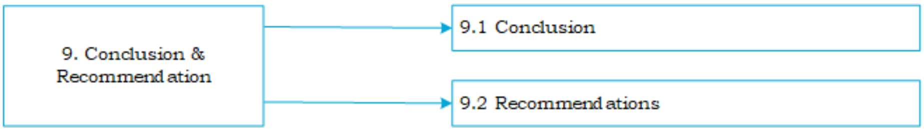

Figure 9.1: Structural overview of chapter 9

9.1. Conclusion

The conclusion of this report will be based on the research questions as defined in chapter 1.

1. **How is the parcel delivery market dealing with the environmental impact of their business?**
   The parcel delivery industry adopts a proactive stance in order to reduce their impact regarding CO_2 emissions. As defined by one of the market participants, DHL (2016), preservation of the industry can be divided into two principles: 1) burn less fuel and 2) burn cleaner fuel. The first principle is focused on the optimisation of network, services, fleet and buildings with the objective to burn as less fuel as possible. The burn clean principle is oriented to use fuel which is mainly based on renewable sources and multimodal transport.

2. **What does the current process of domestically parcel distribution at PostNL look like?**
   The outlet of PostNL is concentrated on the Netherlands. The country is divided into 19 regions with their specific collection and distribution area. The demand collected in or intended for that region, is centralised in a single spoke called a depot at PostNL. The 19 regions are connected with each other based on a single allocation web structure consisting of 20 locations: 15 spokes, 4 hubs (depot+ in terms of PostNL) and one extra hub without any outlet in terms of collection or distribution. With regard to the network structure, every spoke is connected with every hub but not every hub is connected with every spoke. Every hub serves only 3 to 4 other spokes during the distribution of which every spoke is served by only one hub. The logistical process goes as follows: First, the parcels are collected in every region and sorted at every spoke. After sorting, the parcels will be loaded onto roll cages after which they will be bundled with others. This bundling is based on the hub that serves the destination region. Further, the roll cages intended for the same hub will be loaded into a truck and transported. When the truck arrives at the hub, roll cages will be transferred to the truck allocated towards the destination. At the destination spoke, roll cages will be unloaded and sorted for further distribution.

3. **What are the main characteristics of Physical Internet Logistics with regard to the case study at PostNL?**
   Physical Internet Logistics as introduced by Montreuil (2011), is a concept to meet the challenges with

regard to sustainability in the logistical industry. Although the characteristics of Physical Internet vision are mainly focused on global shipments, there are some characteristics implementable for a domestic parcel delivery service. Mainly encapsulation of demand, individualisation of paths, segmentation of the routes, single allocation of trucks and network openness have potential. Concerning the encapsulation of demand, origin-destination pairs will be concentrated into standardised containers. These containers will follow their own route through the network. In the ideal vision of Physical Internet, this network consists of a fully connected structure where transhipment is possible at every node. Trucks are allocated to single links and drive only from A to B and back from B to A.

4. **How does the current logistical process of parcels at PostNL perform concerning their intended network design ?**
   The current situation differs from the network design. Although a web structure is observed, spokes are served by more than one hub (multiple allocation) instead of single allocation. Besides, direct spoke to spoke trips are also measured. With regard to the vision of Physical Internet, the demand is encapsulated into roll cages and follows two types of paths: spoke to spoke paths or spoke to a hub to spoke paths. Concerning this last one, most often only one single hub is used. It does not occur that equal origin-destination pairs differ from used hub location.

5. **What is the potential of the suggested implementation?**
   Based on a case study at PostNL, a carrier is able to reduce the daily environmental impact with 16% when a completely open network is applied. At every location, load transfer is possible and nodes are fully connected. However, it is expected that the reduction would be lower since the normalised characteristics as assumed. Besides, changing locations from spoke to hub could be a costly investment. When only the same hub locations are used as currently, a reduction of 6% is possible. Mainly the application of multi allocation spoke serving results in a reduction. Supporting measures as double deck trailers or volume reduction related policies are able to accelerate the reduction in emitted emissions. Optimal fleet allocation using double-deck trailers could result in a reduction of 30% CO_2 against 19% reduction when the double deck trailers are applied in the current situation. Volume reduction per parcel is able to reduce the environmental impact per per cent decrease.

How should the parcel delivery industry arrange their network to decrease the absolute CO_2 emissions?

The vision of physical Internet Logistics shows that a less restricted network results in less emissions of CO_2. Even when the same locations are defined as a hub as currently occurs, the openness of multi allocation results in a reduction in CO_2 emissions. The openness of an open hub network where transhipment is possible at every location results in the least amount of CO_2 emitted. This reduction is also reached due to the allowance of spoke-spoke trips in this network design. Besides, the more open a network design is the more path individualisation can be applied. However, sensitivity analysis shows that path individualisation has a small influence on the total amount of emitted CO_2. The single allocation makes sure that a truck driver always ends at his origin. In this way, it could be more interesting to perform more trips by a carrier itself than by an outsourced company.

9.2. Recommendations & Limitations

A limitation to this report is the deterministic and static assumptions based on averages regarding fuel consumption, demand, and latest time of departure. It is recommended for further research to take the stochastic and dynamic characteristics of the parameters into account. In this way, more realistic annual emissions could be calculated for comparison with targets from Paris. Secondly, this report is only focused on CO_2 minimisation to present the possible potential of Physical Internet Logistics. The limit is that transportation costs do play an important role which are not taken into account. Further research should take the costs per truck use into account. Thirdly, the sensitivity of truck allocation to single links is not analysed with the model in relation to multi allocation due to limitations of the used model. It is recommended for further research to analyse this characteristic and possible effects by allowing tours. The open character of a Physical Internet based network plays the most important role concerning CO_2 reduction, as can be concluded from this re-

search. For further research, it is recommended to take a look at the consequences of such an open network on warehouse level. When warehouses have to deal with more inward and outward streams, there will have to be some changes with regard to the layout. Further research should take a look at the consequences, application and boundaries of multiple allocation of streams.
With regard to the application of Physical Internet in the parcel delivery industry, there are some recommendations. First, this report shows that mainly an open network results in a reduction in CO_2. Although the fact that the opener a network is the easier path individualisation can be applied, individualisation results in a slight decrease. Openness can be created by connecting locations and redesign of locations from spoke to hub where transhipment is possible. Secondly, it is recommended for carriers in the parcel delivery industry to improve the reliability of the demand forecast. The sensitivity analysis of the model shows that demand is directly proportional to the amount of CO_2 emitted. However, when trucks are allocated to a network at a certain moment t but the demand changed in $t+1$, truck allocation will not be optimal anymore. Ad-hoc decision making plays an important role. It is recommended for carriers to create a reliable link with shippers concerning the supplied demand.

Concentrating on the case study at PostNL, there are a couple of recommendations from this report findings. First of all, PostNL should better report their emissions and its allocation with regard to fuel consumption. For example, emissions concerning heavy trucks for parcel transportation is based on the total used fuel by all the departments of PostNL in combination with the Service Level Agreement within PostNL. This result in inaccurate allocation of emissions within PostNL. In this way, it is hard to determine optimisation potentials concerning reduction. Segmentation and more specific allocation of emissions should give a better view of the current performance.
With regard to the used network, PostNL should apply the multi allocation characteristic as they do now. Although their network design is based on single allocation and measurements shows that multiple allocation is adapted, it is expected that this principle could be more adapted by PostNL. Moreover, it is recommended to upgrade more spokes into hubs. As the open network design shows in section 7.3, the more locations where transfer between trucks can take place the more efficient the network gets. Another recommendation concerning the current state is to avoid a location as Dordrecht where only attraction of demand takes place. As shown by both designs, a location as Dordrecht is a weak spot in the network concerning empty trips.
Also forecasting of demand and thus trips should be examined by PostNL. During a tour through one of the spokes of PostNL, it became clear that most of the predicted demand did not correspond to the real supplied demand. Concerning allocation, this will result over- or understaffing of trucks. This could be fixed by real-time demand prognoses by shippers or by shortening the latest moment of supplying. In this way, PostNL creates more time to plan the fleet allocation. However, this will result in a reduction of flexibility towards customers.
To accelerate the efficiencly of the logistical process, it is recommended to PostNL as a carrier to implement double-deck trailers. As shown by both designs, CO_2 emissions could be reduced with 19-30% when the current trailers will be replaced by double deck trailers. Since the capacity per truck is linked with the average volume per parcel, a reduction in volume results in a capacity increase per truck and so a reduction of the total process. By bundling the industries' interests together, as is done with Topsector Logistiek, Lean & Green and Connekt, volume based pricing could be introduced. This promising measure could force shippers to reduce their parcel. Every per cent reduction results in a directly proportional reduction in CO_2 with regard to inter depot transport.

VI

Appendix

A

Science Based Targets

The science based targets are developed by WWF on behalf of the Sciences Based Targets Initiative (SBTi) consisting of the following technical partners:

- International Council on Clean Transportation (ICCT)
- Partnership on Sustainable, Low Carbon Transport (SLoCaT)
- Smart Freight Centre (SFC)

And technical experts:

- Ecofys, a Navigant company
- International Energy Agency (IEA)

The next section will outline the different methods to define a Science Based Target.

A.1. Methods for Science Based Targets

The Absolute Approach. A method which dictates that every sector in the global economy should reduce by the same % as any climate based scenario that limits the global warming to 2°C.

The GEVA methodology. Is a methodology that is derived from the premise if all nations reduce their "GHG emissions per unit of GDP" by 5% per year, global GHG emissions will be 50% lower in 2050 than in 2010 as long as the global economy continues to grow at its historical rate of 3.5% per year. The method translates the suggested 5% per year decline into a corporate resolution to reduce corporate "GHG emissions per unit of value added" (GEVA) by 5% per year. The GEVA method only applies for scope 1 emissions, since only scope 1 emissions originate from operations that directly contribute to value added of a company.

The Sectoral Decarbonization Approach (SDA). This method is one of the most widely used methodologies. SDA divides the global carbon budget for limiting climate change to 1.5-2 °C in the largest emitting sectors. This budget originates from the International Energy Agency in Paris and is demonstrably in line with the Intergovernmental Panel on Climate Change's (IPCC) 1.5-2°C scenarios. The method divides the carbon budget by sector and allocates it to companies in that sector. By using this method, sectoral differences are taken into account in which sectoral emissions are expressed in sectoral activities, like gCO_2/ton.km.

A.2. Case PostNL

This section presents the different targets as defined by Ecofys (van de Brug et al., 2018).

Table A.1: Absolute emissions of PostNL for different divisions and activities under Scope 1,2 and 3 in 2017 (van de Brug et al., 2018)

Activity	Scope	Emissions (tCO_2)					
		Mail	Parcel	Germany	Italy	Spring	Total
Buildings							
Buildings (offices, DC's, Sorting centers)	Scope 1	5,395	1,759	1.58	555	308	9,597
Buildings (offices, DC's, Sorting centers)	Scope 2	28,993	8,868	3,003	1,742	526	43,132
Own transport							
Freight transport - 3 Ws	Scope 1 & 2	998	0	166	372	0	1,537
Freight transport - Light vehicles (<3.5t)	Scope 1 & 2	4,943	6,050	421	493	0	11,906
Freight transport - Heavy trucks (>15t)	Scope 1 & 2	5,748	18,201	0	0	0	23,949
Passenger transport - Light Road	Scope 1 & 2	3,798	976	25	534	0	5,332
Outsourced transport							
Freight transport - Light vehicles (<3.5t)	Scope 3	856	29,195	32,764	8,935	1,877	73,626
Freight transport - Heavy trucks (>15t)	Scope 3	7,893	24,996	0	0	4,94	37,829
Freight transport - Shipping	Scope 3	0	0	0	0	605	605
Freight transport - Air	Scope 3	0	0	0	0	105,849	105,849

Table A.2: Characteristics of PostNL's business for different divisions and activities under Scope 1,2 and 3 in 2017 (van de Brug et al., 2018) to calculated transportation related intensities.

Activity	Scope	Activity related characteristics						
		Mail	Parcel	Germany	Italy	Spring	Total	Unit
Buildings								
Buildings (offices, DC's, Sorting centers)	Scope 1	529,909	251,737	68,471	43,227	11,195	898,539	m^2
Own transport								
Freight transport - 3Ws	Scope 1&2	196,182	0	24,490	61,800	0	282,471	t.km
Freight transport - Light vehicles (<3.5t)	Scope 1&2	12,406,959	5,218,708	784.664	1,004,408	0	19,414,740	t.km
Freight transport - Heavy trucks (>15t)	Scope 1&2	55,845,6257	176,844,485	0	0	0	232,690,112	t.km
Passenger transport - Light Road	Scope 1&2	24,320,989	5,935,081	126,099	2,837,858	0	33,220,027	t.km
Outsourced transport								
Freight transport - Light vehicles (<3.5t)	Scope 3	2,147,351	17,661,333	19,819,983	10,503,248	9,299,453	59,431,369	t.km
Freight transport - Heavy trucks (>15t)	Scope 3	76,702,708	242,831,908	0	0	24,473,021	344,067,637	t.km
Freight transport - Shipping	Scope 3	0	0	0	0	31,389,665	31,389,665	t.km
Freight transport - Air	Scope 3	0	0	0	0	111,911,297	111,911,297	t.km

Table A.3: Growth rates for 3 scenarios for sensitivity analysis

Activity	Scenario	Scope	Mail	Parcel	Germany	Italy	Spring
Buildings	Expected	Scope 1 & 2	-1.6%	5.2%	1.0%	1.0%	1.0%
Own transport	Expected	Scope 1 & 2	-2.6%	8.0%	2.0%	3.1%	3.5%
Outsourced transport	Expected	Scope 3	-2.6%	8.0%	2.0%	3.1%	3.5%
Buildings	Low growth	Scope 1 & 2	-1.6%	5.2%	1.0%	1.0%	1.0%
Own transport	Low growth	Scope 1 & 2	-3.2%	7.8%	1.0%	2.5%	2.9%
Outsourced transport	Low growth	Scope 3	-3.2%	7.8%	1.0%	2.5%	2.9%
Buildings	High growth	Scope 1 & 2	-1.6%	5.2%	1.0%	1.0%	1.0%
Own transport	High growth	Scope 1 & 2	-2.0%	8.3%	3.0%	3.8%	4.1%
Outsourced transport	High growth	Scope 3	-2.0%	8.3%	3.0%	3.8%	4.1%

Table A.4: Gross emissions absolute targets for PostNL in total for different growth scenario's

SDA	Scope	2017 (tCO$_2$)	2030 (tCO$_2$)	2050 (tCO$_2$)	% 2050 vs 2017
Expected scenario					
Buildings	Scope 1&2	52,729	35,747	41,031	-22%
Own freight transport	Scope 1&2	37,392	40,353	71,660	92%
Own passenger transport	Scope 1&2	5,332	3,860	1,485	-72%
Subtotal Scope 1&2	Scope 1&2	95,453	79,960	114,176	20%
Outsourced freight transport	Scope 3	217,910	192,905	192,095	-12%
Total	Scope 1,2,3	313,364	272,865	306,271	-2%
Low growth scenario					
Buildings	Scope 1&2	1&2	33,831	37,305	-29%
Own freight transport	Scope 1&2	1&2	39,736	66,278	77%
Own passenger transport	Scope 1&2	1&2	3,860	1,485	-72%
Subtotal Scope 1&2	Scope 1&2	1&2	77,427	105,068	10%
Outsourced freight transport	Scope 3	3	191,439	181,303	-17%
Total	Scope 1,2,3	1,2,3	268,866	286,371	-9%
High growth scenario					
Buildings	Scope 1&2	1&2	37,788	45,237	-14%
Own freight transport	Scope 1&2	1&2	40,992	77,457	107%
Own passenger transport	Scope 1&2	1&2	3,860	1,485	-72%
Subtotal Scope 1&2	Scope 1&2	1&2	82,641	124,179	30%
Outsourced freight transport	Scope 3	3	194,457	204,186	-6%
Total	Scope 1,2,3	1,2,3	277,098	328,366	5%

Table A.5: Gross emissions absolute targets for PostNL Parcels for different growth scenario's

SDA	Scope	2017 (tCO$_2$)	2030 (tCO$_2$)	2050 (tCO$_2$)	% 2050 vs 2017
Expected scenario					
Buildings	Scope 1&2	10,626	15,670	35,448	234%
Own freight transport	Scope 1&2	24,251	30,444	70,000	189%
Own passenger transport	Scope 1&2	976	704	265	-73%
Subtotal Scope 1&2	Scope 1&2	35,853	46,818	105,713	195%
Outsourced freight transport	Scope 3	54,191	57,634	110,181	103%
Total	Scope 1,2,3	90,044	104,452	215,894	140%
Low growth scenario					
Buildings	Scope 1&2	10,626	15,214	32,885	209%
Own freight transport	Scope 1&2	24,251	30,010	64,940	168%
Own passenger transport	Scope 1&2	976	704	265	-73%
Subtotal Scope 1&2	Scope 1&2	35,853	45,928	98,091	174%
Outsourced freight transport	Scope 3	54,191	56,952	102,217	89%
Total	Scope 1,2,3	90,044	102,879	200,308	122%
High growth scenario					
Buildings	Scope 1&2	10,626	16,135	38,182	259%
Own freight transport	Scope 1&2	24,251	30,886	75,399	211%
Own passenger transport	Scope 1&2	976	704	265	-73%
Subtotal Scope 1&2	Scope 1&2	35,853	47,725	113,846	218%
Outsourced freight transport	Scope 3	54,191	58,331	118,679	119%
Total	Scope 1,2,3	90,044	106,056	232,525	158%

Table A.6: Intensity targets for PostNL in total for different growth scenario's

SDA	Scope	2017	2030	2050	% 2050 vs 2017
Expected scenario					
Buildings	Scope 1&2 (gCO_2/m^2)	58,683	28,988	10,957	-81%
3Ws	Scope 1&2 (gCO_2/t.km)	5,440	3,773	16	-100%
Light commercial		613	354	104	-83%
Heavy trucks		103	58	28	-73%
Passenger transport	Scope 1&2 (gCO_2/p.km)	161	116	45	-72%
Light commercial	Scope 3 (gCO_2/t.km)	1,239	518	104	-92%
Heavy trucks		110	61	28	-75%
Shipping		19	11	3	-84%
Air		946	519	195	-79%
Low growth scenario					
Buildings	Scope 1&2 (gCO_2/m^2)	58,683	28,988	10,957	-81%
3Ws	Scope 1&2 (gCO_2/t.km)	5,440	4,109	16	-100%
Light commercial		613	368	104	-83%
Heavy trucks		103	59	28	-73%
Passenger transport	(gCO_2/p.km)	161	116	45	-72%
Light commercial	Scope 3(gCO_2/t.km)	1,239	547	104	-92%
Heavy trucks		110	63	28	-75%
Shipping		19	12	3	-84%
Air		946	562	239	-75%
High growth scenario					
Buildings	Scope 1&2 (gCO_2/m^2)	58,683	28,988	10,957	-81%
3Ws	Scope 1&2 (gCO_2/t.km)	5,440	3,566	16	-100%
Light commercial		613	341	104	-83%
Heavy trucks		103	57	28	-73%
Passenger transport	Scope 1&2 (gCO_2/p.km)	161	116	45	-72%
Light commercial	Scope 3 (gCO_2/t.km)	1,239	490	104	-92%
Heavy trucks		110	60	28	-75%
Shipping		19	11	3	-84%
Air		946	480	160	-83%

Table A.7: Intensity targets for PostNL Parcels for different growth scenario's

SDA	Scope	2017	2030	2050	% 2050 vs 2017
Expected scenario					
Buildings	Scope 1&2 (gCO_2/m^2)	42.212	22.765	10.957	-74%
Light commercial	Scope 1&2 (gCO_2/t.km)	1.159	354	104	-91%
Heavy trucks		103	53	28	-73%
Passenger transport	Scope 1&2 (gCO_2/p.km)	164	119	45	-73%
Light commercial	Scope 3 (gCO_2/t.km)	1.653	471	104	-94%
Heavy trucks		103	52	28	-73%
Low growth scenario					
Buildings	Scope 1&2 (gCO_2/m^2)	42.212	22.765	10.957	-74%
Light commercial	Scope 1&2 (gCO_2/m^2)	1.159	362	104	-91%
Heavy trucks		103	53	28	-73%
Passenger transport	(gCO_2/p.km)	164	119	45	-73%
Light commercial	Scope 3(gCO_2/t.km)	1.653	482	104	-94%
Heavy trucks		103	53	28	-73%
High growth scenario					
Buildings	Scope 1&2 (gCO_2/m^2)	42.212	22.765	10.957	-74%
Light commercial	Scope 1&2 (gCO_2/t.km)	1.159	347	104	-91%
Heavy trucks		103	52	28	-73%
Passenger transport	Scope 1&2 (gCO_2/p.km)	164	119	45	-73%
Light commercial	Scope 3 (gCO_2/t.km)	1.653	461	104	-94%
Heavy trucks		103	52	28	-73%

B

CO_2 Emissions

This chapter outlines the international as well as the Dutch emissions with regard to CO_2. Both figures show the main contributors, together more than 50% relative to the total in absolute terms. Figure B.1 shows the main contributors concerning CO_2 emissions globally. The subgraph of figure B.1 is focused on the European Union since the fact that PostNL' delivery area is mainly focused on the Netherlands. There can be concluded that the Netherlands is responsible for a very low contribution in absolute emission terms relative to other countries in the world (0%). Concerning its emissions relative to other European Members, the Netherlands are responsible for 5%.

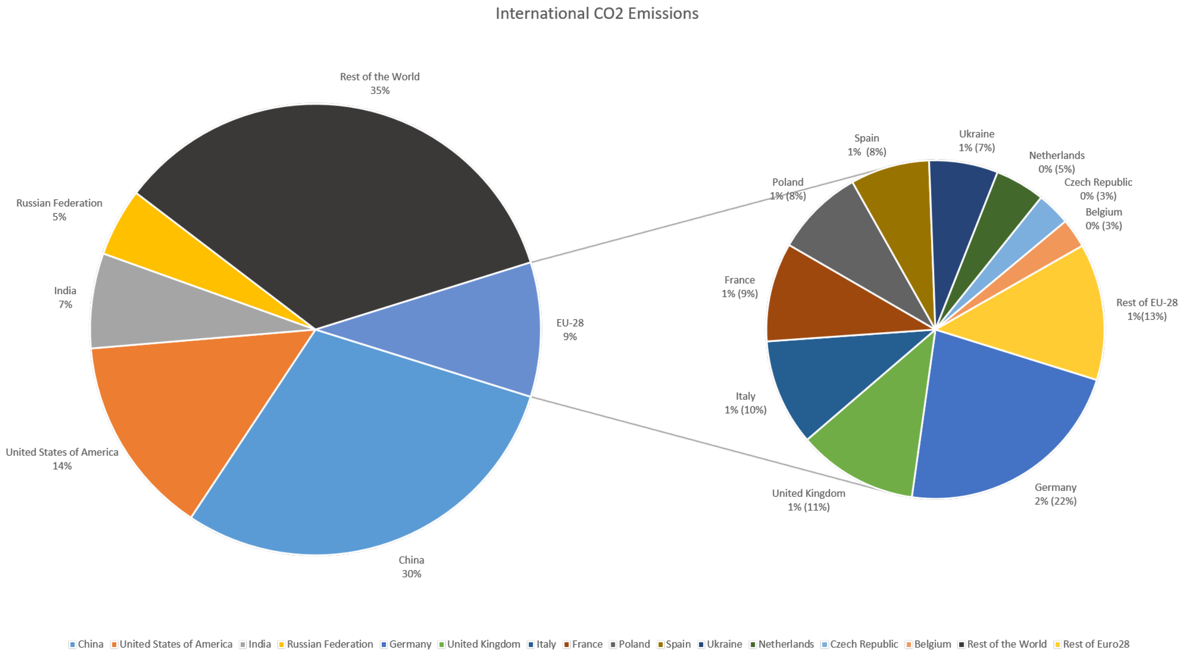

Figure B.1: An overview of countries and unions which contributes to over 50 % (in absolute terms) of the total CO_2 emissions globally in 2015 (European Commission, 2015). The sub-chart shows the CO_2 emissions divided over members of EU-28 in which the value between the brackets shows the contribution relative to the EU-28 group in total.

Concerning emission of CO_2 by fuel combustion of (road)transport [1] relative to other sectors, are outlined by the International Energy Agency (2017). Other emission sectors are industry, heat and energy, residential and services.

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[1] Transportation of goods and persons by different modes

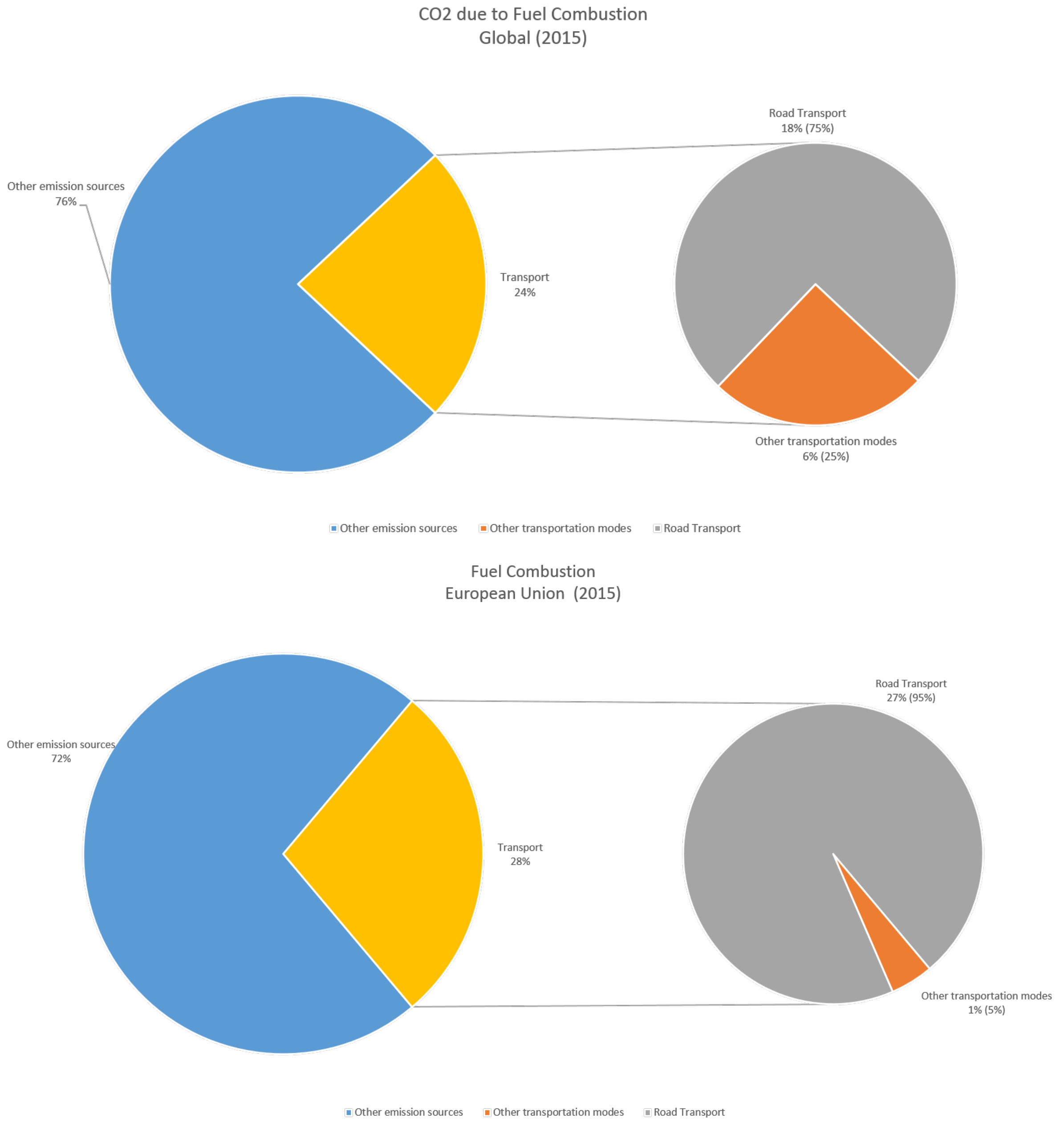

Figure B.2: CO_2 emission (globally and in the European Union) due to fuel combustion of transportation [1] relative to other sources in 2015 (International Energy Agency, 2017). The value between the brackets show the contribution relative to other sources in that sector

C

Well-to-Wheels Analyse

The difference in well to tank (WTT) and tank to wheels (TTW) emissions can be explained by figure C.1. Combining WTT and TTW gives well to tank (WTW) emissions.

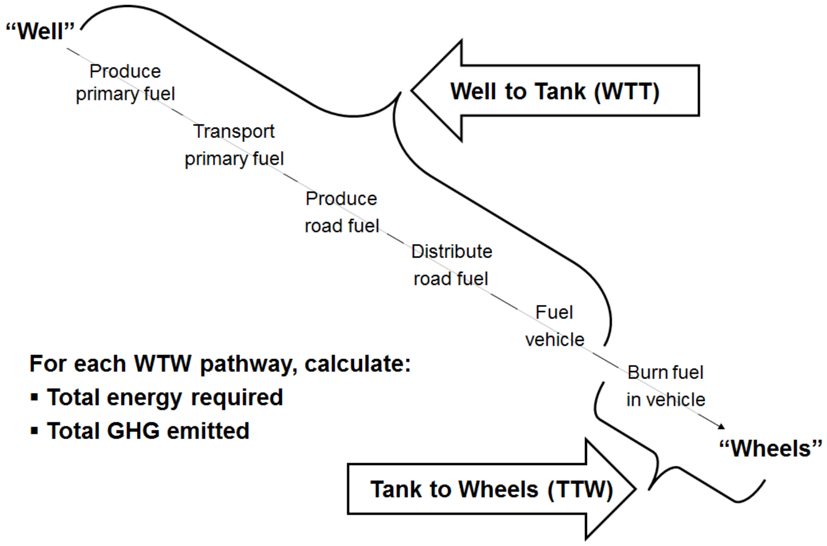

Figure C.1: Representation of Well-to-Wheels (WTW) Analyse (European Commission, 2016)

D

Fleet characteristics

MAN trucks

Table D.1: Average fleet characteristics for MAN trucks retrieved from onboard computers concerning the first 14 weeks of 2018.

Week	Total distance (km)	Driving time (Hour)	Consumption (ltr/100 km)	Cruise Control	Idle time	Roll out
1	158,663	2,795	27.2	51%	16%	3%
2	190,449	3,357	25.8	50%	16%	4%
3	183,036	3,328	27.4	47%	17%	4%
4	186,524	3,307	26.3	50%	16%	4%
5	183,919	3,289	26.8	49%	16%	4%
6	176,833	3,142	26.7	50%	16%	4%
7	170,552	3,020	26.6	51%	16%	4%
8	173,409	3,084	26.8	50%	16%	4%
9	179,965	3,244	28.8	49%	17%	4%
10	173,992	3,080	26.1	50%	15%	4%
11	173,054	3,096	26.7	49%	16%	4%
12	173,054	3,096	26.7	49%	16%	4%
13	183,458	3,265	26.1	49%	16%	4%
14	153,051	2,750	26.5	49%	16%	4%

Renault trucks

Table D.2: Average fleet characteristics for Renault trucks based on board computers concerning the first 14 weeks of 2018

Week	Total distance (km)	Driving time (Hour)	Consumption (ltr/100 km)	Cruise Control	Idle time	Roll out
1	190.580	3,449	28.0	47%	14%	6%
2	219,010	3,953	26.4	45%	14%	7%
3	218,254	4,006	27.5	42%	14%	7%
4	187,878	3,363	26.4	45%	14%	7%
5	181,908	3,254	26.8	45%	14%	7%
6	180,170	3,173	26.4	46%	14%	6%
7	175,967	3,145	26.8	45%	14%	6%
8	169,827	3,090	27.1	45%	14%	7%
9	179,325	3,261	29.1	45%	14%	6%
10	173,872	3,134	26.6	46%	13%	7%
11	171,380	3,100	27.2	45%	13%	7%
12	175,847	3,180	26.9	45%	13%	7%
13	177,613	3,210	26.2	45%	13%	7%
14	154,585	2,796	26.6	45%	13%	7%

E

Network characteristics

E.1. Distance matrix

Table E.1: Distance matrix between depots

Depot	AMF (+)	BORN	BD	HT (+)	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG (+)	OPM	RD	SSH	SON	UT	WVN (+)	ZWL	DOR (X)
(+) AMF	0	170	92	75	92	67	169	72	105	182	159	33	98	88	83	104	40	69	70	83
BORN	170	0	122	98	189	128	177	199	223	317	295	139	236	163	210	74	153	183	206	148
BD	92	122	0	50	68	109	77	120	199	270	232	66	163	40	93	68	80	62	163	25
(+) HT	75	98	50	0	100	59	124	103	154	249	211	48	142	75	116	32	58	88	137	59
HBD	92	189	68	100	0	129	118	61	196	249	195	72	109	33	32	132	69	29	159	44
ELT	67	128	109	59	129	0	177	129	102	197	174	70	167	100	141	70	84	113	85	96
GS	169	177	77	124	118	177	0	174	268	338	301	134	222	94	145	134	156	119	231	83
HW	72	199	120	103	61	129	174	0	172	213	143	65	58	89	35	133	51	72	136	99
HGL	105	223	199	154	196	102	268	172	0	149	166	138	202	193	187	165	145	174	59	191
KHM	182	317	270	249	249	197	338	213	149	0	80	209	176	262	225	260	207	244	118	286
LW	159	295	232	211	195	174	301	143	166	80	0	167	99	222	169	236	167	203	94	217
(+) NIWG	33	139	66	48	72	70	134	65	138	209	167	0	104	57	77	73	20	48	59	53
OPM	98	236	163	142	109	167	222	58	202	176	99	104	0	137	84	171	90	120	111	147
RD	88	163	40	75	33	100	94	89	193	262	222	57	137	0	59	103	66	29	154	17
SSH	83	210	93	116	32	141	145	35	187	225	169	77	84	59	0	144	64	44	147	71
SON	104	74	68	32	132	70	134	133	165	260	236	73	171	103	144	0	87	117	147	86
UT	40	153	80	58	69	84	156	51	145	207	167	20	90	66	64	87	0	46	108	67
WVN	69	183	62	88	29	113	119	72	174	244	203	48	120	29	44	117	46	0	136	40
ZL	70	206	163	137	159	85	231	136	59	118	94	59	111	154	147	147	108	136	0	151
(x) DOR	83	148	25	59	44	96	83	99	191	286	217	53	147	17	71	86	67	40	151	0

E.2. Trip measurement on working days

Table E.2: All measured trips between depots on working days

Depot	AMF (+)	BORN	BD	HT (+)	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG (+)	OPM	RD	SSH	SON	UT	WVN (+)	ZWL	DOR (X)	**TOTAL OUT**
(+) AMF	0	1	0	6	1	1	0	2	13	15	12	5	0	0	1	1	1	7	16	7	89
BORN	4	0	0	4	0	0	0	0	0	1	1	5	0	0	0	1	1	5	0	4	26
BD	5	1	0	6	0	0	0	0	1	0	0	6	0	0	0	0	1	6	1	7	34
(+) HT	6	14	1	0	1	16	0	0	1	1	0	6	0	0	0	18	1	6	1	5	77
HBD	5	1	0	4	0	0	0	0	0	0	0	4	0	0	0	0	1	4	0	4	23
ELT	4	1	0	3	0	0	0	0	1	0	0	4	0	0	0	0	1	4	1	3	22
GS	4	1	0	4	0	0	0	0	0	0	0	4	0	0	0	0	1	4	0	6	24
HW	4	1	0	4	1	0	0	0	0	0	1	3	1	0	1	0	1	4	0	4	25
HGL	4	1	0	5	0	1	0	0	0	0	0	5	1	0	0	0	0	5	2	4	28
KHM	4	0	0	4	0	0	0	0	0	0	1	4	0	0	0	0	0	3	0	3	19
LW	3	0	0	3	0	0	0	1	0	2	0	2	0	0	0	0	0	3	0	3	17
(+) NIWG	8	1	2	9	0	2	1	17	2	1	1	0	19	1	1	2	16	9	2	7	101
OPM	3	0	0	4	1	0	0	0	0	0	1	3	0	0	0	0	1	3	0	3	19
RD	3	1	0	3	0	0	0	0	1	0	0	4	0	0	0	0	0	3	0	4	19
SSH	4	0	0	4	0	0	0	0	0	0	0	4	0	0	0	0	0	3	0	3	18
SON	7	2	0	6	0	0	0	0	1	0	0	7	0	0	0	0	1	7	1	5	37
UT	5	1	1	3	1	1	0	1	5	0	0	3	1	1	0	1	0	3	1	3	31
(+) WVN	7	1	0	7	18	1	0	1	1	0	0	6	1	19	17	0	0	0	1	5	85
ZL	4	1	0	4	0	0	0	0	1	1	1	4	0	0	0	0	0	4	0	4	24
(x) DOR	0	0	16	1	0	0	13	0	0	0	0	0	0	0	0	0	0	1	0	0	31
TOTAL IN	84	28	20	84	23	22	14	22	27	21	18	79	23	21	20	23	26	84	26	84	

E.3. Trip measurement on Sundays

Table E.3: All measured trips on average between depots on Sundays

Depot	AMF (+)	BORN	BD	HT (+)	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG (+)	OPM	RD	SSH	SON	UT	WVN (+)	ZWL	DOR (X)	**TOTAL OUT**
(+) AMF	0	1	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	2	8
BORN	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	4
BD	2	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	3	8
(+) HT	2	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0	3	10
HBD	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
ELT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GS	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	5
HW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HGL	1	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	1	7
KHM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(+) NIWG	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	8
OPM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SON	2	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	7
UT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(+) WVN	2	0	0	1	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	1	8
ZL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(x) DOR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL IN	12	1	0	14	0	0	0	0	0	0	0	11	0	0	0	0	0	13	0	15	

F

Demand characteristics

Production/attraction between locations

Table F.1: Origin - destination matrix in terms of volume (m^3) from depot (column 1) to depot (row 1) on an average day

Depot	AMF (+)	BORN	BD	HT (+)	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG (+)	OPM	RD	SSH	SON	UT	WVN (+)	ZWL	DOR (X)
AMF (+)	103	70	43	85	44	52	34	46	59	42	32	77	49	43	42	45	45	55	52	104
BORN	53	151	50	65	49	58	33	46	52	42	30	63	52	48	43	53	43	54	47	80
BD	54	65	99	77	51	53	38	52	53	42	34	68	55	53	44	50	47	59	49	216
HT(+)	60	66	58	117	56	57	39	52	55	49	35	71	56	55	47	58	50	60	55	97
HBD	41	51	28	70	89	36	23	29	41	27	19	57	30	31	32	36	28	52	31	49
ELT	49	52	34	66	33	95	26	33	51	39	24	55	43	38	30	38	30	52	43	51
GS	37	41	33	52	36	34	53	35	34	28	22	45	35	33	34	33	34	39	31	153
HW	40	41	29	64	38	32	21	106	34	27	25	58	42	30	36	32	42	40	33	57
HGL	57	64	46	70	51	55	34	48	98	45	33	62	54	48	48	52	47	56	51	56
KHM	32	39	23	45	26	30	18	28	37	68	22	43	29	25	22	26	27	31	32	45
LW	33	34	23	38	25	27	18	24	29	28	56	37	31	24	26	25	23	30	29	94
NIWG (+)	67	71	56	85	61	63	38	61	57	49	36	126	58	57	55	60	55	69	55	107
OPM	36	47	27	57	31	31	20	33	36	26	20	52	92	28	28	31	30	36	30	43
RD	35	47	27	59	30	28	22	28	38	24	18	54	29	77	27	29	26	41	29	56
SSH	31	55	25	65	27	26	21	29	36	21	15	60	29	25	66	28	29	35	26	34
SON	89	97	69	113	70	81	48	70	80	63	44	98	71	70	63	132	66	86	69	94
UT	51	46	37	53	39	45	22	43	38	34	25	58	43	37	36	39	67	46	41	51
WVN (+)	64	59	42	72	56	52	31	48	56	48	32	69	56	52	44	44	44	121	58	59
ZL	47	54	32	62	30	41	23	30	55	41	30	56	37	29	29	35	29	40	90	54
DOR (x)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

G

IBM CPLEX Optimisation Studio

This chapter shows the used optimisation model for the implementation of the suggested model in chapter 6. To run the suggested model, CPLEX model as solver is used by modifying a standard trucking problem. This CPLEX model, which is licensed material and property of IBM, make use of a different formulation language then presented at chapter 6. However, by analysing and modifying the given trucking problem model by IBM, the CPLEX optimisation model can be used for the case as discussed in 6. The reason why this report modifies this given trucking problem CPLEX model is because of its agreements with the model of chapter 6 and its ability to handle the time aspect. Besides, acknowledge about this solver is gathered during lectures of Maknoon (2017).

G.1. Methodology

Solving the model as discussed in this chapter, is based on the Branch and Cut method for a mixed integer program. This method is a generalisation of the Branch and Bound method and consists of three parts (Khorramizade et al., 2014): 1) Enumerative part, 2) Branch and Cut algorithm and 3) Branch and Cut Method. In the first part, the initialisation, bounding, fixing and settings of the variables, bounding, selection and fathoming are performed. The second part is focused on the branch and cut which is concerned with the computation of a lower bound. This part consists of initialisation a new node, solving the corresponding LP (Linear programming), separation and elimination. The final part, part three, the upper bound is computed by branch and cut. Trying to find a feasible solution for MIP (Mixed Integer Programming). CPLEX uses this procedure by using a search tree consisting of nodes. Every node represents an LP or QP (Quadratic programming) subproblem which has to be processed. This processing, or solving, checks the integrity and possibility of further research. A node can be called active if they have not been processed or not active when processing is already done. As follow, a branch will be created of new nodes from parent nodes. This happens when the bounds of a single variable are modified and the remaining in effect for a new node and below that node. Further, a cut will be added to the model as a constraint. This will limit the size of the solution domain without elimination legal integer solution. Thereafter, the procedure continues by performing branches and cuts at nodes of the tree. Each node, after relaxation is solved, possesses an optimal objective value. At any given point in the algorithm, there will be a node with a better optimal value than all the others. The resulting MIP gap shows a measure of progress towards finding the most optimal value. A MIP gap of 0 means that there are no active nodes existing and so the latest active node is the most optimal (IBM, 2018). Where normally CPLEX stops with MIP gap lower than 0.0001(=0.01%), the model used in this report automatically stops after 3600 seconds to prevent the used computer was running out of memory. With regard to the five hub design a MIP gap of 1.20 % is reached. Concerning the open network design, there was a MIP gap of 2,19%.

G.2. Mathematical model implementation

Table G.1 shows in a brief way the following things: In the first column sets, parameters, variables, objective and constraints are shown used in the model of IBM's Trucking Problem. In relation to the model presented in chapter 6, the last column shows the related sets parameter, variable, objective and constraints. To include some guidance for section G.3 and G.4, the second en third column of table G.1 shows the notation of that certain set, parameter, variable, objective or constraints and its definition. There can be concluded that most of the sets, parameters, variables, constraints and objective are in line with the one given in chapter 6.

Table G.1: Conversion table from model mathematical model to cplex

CPLEX - Sets	Notation	Definition	Math model
Location <locationname>	{A,. . . ,T}	All depot locations	N
Trucktypes <trucktype>	{BigTruck}	Different truck types	V
Spokes <locationname>	{A,. . . ,T}	All depot locations	N
Hubs <locationname>	{A,D,L,R,T} or {A,. . . ,T}	Hub locations	H
Cplex - Parameters	Notation	Definition	Math model
SpokeInfo <earliest departure time spoke, latest arrival time spoke >	[<MinDepTime, maxArrTime >]	Earliest departure and latest arrival time at a certain Spoke	E_i, A_i
TruckTypeInfo [t] <capacity in RC,emission per km, speed>	[<capacity,costpermile,milesperhour>]	Truck type characteristics	u_{ij}, c_{ij}, s
Routes [r] <spoke,hub,distance>	{<s,h,dist>}	Distance of an arc between spoke and hub	d_{ij}
Shipment [s] <origin, destination,volume>	{<o,d,v>}	Demand between origin spoke and destination spoke	w^p
Loadtime	[<loadtime per truck>]	truck (un)loading time	t_l
Maxvolume	[<maxvolume>]	Max amount of trucks on a single route	
MaxTruck	[<maxtrucks>]	Max amount of volume handeled by a hub	
Cplex - Variable	Notation	Definition	Math model
TruckOnRoute.r.t.	<s,h,dist>	if Trucktype t is allocated to route r	y_{ijv}
Triples [tr] {origin, hub, destination}	<s,h,dest>	path from spokes to spokes via one hub	l
OutVolumeThroughHubOnTruck [Triples][TruckType]	<0,. . . maxvolume>	Outbound volume per trip between 0 and maxvolume	$h^l a^l_{ji}$
IntVolumeThroughHubOnTruck [Triples][TruckType]	<0,. . . maxvolume>	Inbound volume per trip between 0 and maxvolume	$h^l a^l_{ij}$
Cplex - Objective	Notation	Range	Math model
Minimize Total costs	sum(r in Routes, t in TruckTypes) 2*r.distance*TruckTypeInfos[t].costPerMile*TruckOnRoute[r][t]	-	6.1
Cplex - Constraint	Notation	Range	Math model
Make sure that the max arrival time is greater than the min departure time	Max arrival time >Min departure time	-	-
Formulation earliest unloading time	EarliestUnloadingTime=(loadtime hub + earliest departure time spoke + 60*distance/speed)	-	6.2
Formulation latest loading time	LatestloadingTime= (Latest arrival time spoke - loading time hub-60*distance/speed)	-	6.3
Formulation of arc options	Possibletruckonroute = 1 if latestloadingtime >earliestunloadingtime	-	6.4
Truck capacity	Trucksonroute[r][t] possibletruckonroute[r][t]*Maxtrucks	For all r in Routes, t in Trucktypes	6.8
inbound flow hub less than capacity of a truck	sum(<s,h,dest>in Triples) InVolumeThroughHubOnTruck[<s,h,dest>]< = TrucksOnRoute[<s,h,dist>]*TruckTypeInfo.capacity	For all <s,h,dist>in Routes, t in Trucktypes	6.7 & 6.8
outbound flow hub less than capacity of truck	sum(<o,h,s>in Triples) OutVolumeThroughHubOnTruck[<o,h,s>]< = TrucksOnRoute[<s,h,dist>]*TruckTypeInfo.capacity	For all <s,h,dist>in Routes, t in Trucktypes	6.7 & 6.8
flow in = flow out at every hub	sum(t in Trucktypes) InvolumeThroughHubOnTruck[tr][t] <= sum(t in Trucktypes) OutvolumeThroughHubOnTruck[tr][t]	For all tr in Triples	-
Sum flows between origin-destination = sum of shipments between o-d	sum(t in Trucktypes, <o,h,d>in Triples) InvolumeThroughHubOnTruck[<o,h,d>][t]==v	For all <o,d,v>in Shipments	6.7
All shipments from spokes must arrive before a truck leaves at the hub	sum(<o,h,s>in Triples, t1 in Trucktypes, <o,h,dist1>in Routes: EarliestUnloadingTime[o,h,dist1>][t1]< = LatestLoading[LatestLoadingTime[s,h,dist>][t]) InvolumeThorughHubOntruck[<o,h,s>][t1] >= sum (<o,h,s>in Triples, t2 in Trucktypes, <o,h,dist2>in Routes : LatestLoadingTime[<o,h,dist2>][t2] <= LatestLoadingTime[<s,h,dist>][t])OutVolumeThroughHubOnTruck[<o,h,s>][t2]	For all <s,h,dist>in Routes, t in Trucktypes	6.4 & 6.8

G.3. 5 hub network design

G.3.1. Data

```
// --------------------------------------------------------------------------
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// --------------------------------------------------------------------------
// POSTNL HUB NETWORK DESIGN
Location = {A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T};
TruckTypes = {BigTruck};

Spokes = {A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T};
Hubs = {A, D, L, R, T};

Spoke = [<30, 480>,<30, 480>,<30, 480>,<30, 480>,<30, 480>,
<30, 480>,<30, 480>,<30, 480>,<30, 480>,<30, 480>,<30, 480>,
<30, 480>,<30, 480>,<30, 480>,<30, 480>,<30, 480>,<30, 480>,
<30, 480>,<30, 480>, <30, 480>]; //Earliest departure time, latest arrive time

TruckTypeInfos = [<48,713,71>]; //capacity in RC, emission cost in gram per km, km per hour

LoadTime = [[25],[25],[25],[25],[25]]; //load time per hub

Routes = {<A,A,0>,<A,D,75>,<A,L,33>,<A,R,69>,<A,T,83>,
<B,A,170>,<B,D,98>,<B,L,139>,<B,R,183>,<B,T,148>,
<C,A,92>,<C,D,50>,<C,L,66>,<C,R,62>,<C,T,25>,
<D,A,75>,<D,L,48>,<D,D,0>,<D,R,88>,<D,T,59>,
<E,A,92>,<E,D,100>,<E,L,72>,<E,R,29>,<E,T,44>,
<F,A,67>,<F,D,59>,<F,L,70>,<F,R,113>,<F,T,96>,
<G,A,169>,<G,D,124>,<G,L,134>,<G,R,119>,<G,T,83>,
<H,A,72>,<H,D,103>,<H,L,65><H,R,72>,<H,T,99>,
<I,A,105>,<I,D,154>,<I,L,138>,<I,R,174>,<I,T,191>,
<J,A,182>,<J,D,249>,<J,L,209>,<J,R,244>,<J,T,286>,
<K,A,159>,<K,D,211>,<K,L,167>,<K,R,203>,<K,T,217>,
<L,A,33>,<L,D,48>,<L,L,0>,<L,R,48>,<L,T,53>,
<M,A,98>,<M,D,142>,<M,L,104>,<M,R,120>,<M,T,147>,
<N,A,88>,<N,D,75>,<N,L,57>,<N,R,29>,<N,T,17>,
<O,A,83>,<O,D,116>,<O,L,77>,<O,R,44>,<O,T,71>,
<P,A,104>,<P,D,32>,<P,L,73>,<P,R,117>,<P,T,86>,
<Q,A,40>,<Q,D,58>,<Q,L,20>,<Q,R,46>,<Q,T,67>,
<R,A,69>,<R,D,88>,<R,L,48>,<R,R,0>,<R,T,40>,
<S,A,70>,<S,D,137>,<S,L,59>,<S,R,136>,<S,T,151>,
<T,A,83>,<T,D,59>,<T,L,53>,<T,R,40>,<T,T,0>}; //spoke, hub, distance


Shipments = {<A,B,78>,<A,C,43>,<A,D,100>,<A,E,49>,<A,F,55>,<A,G,34>,<A,H,52>,<A,I,67>,
<A,J,44>,<A,K,32>,<A,L,90>,<A,M,51>,<A,N,45>,<A,O,46>,<A,P,51>,<A,Q,51>,<A,R,62>,
<A,S,54>,<B,A,70>,<B,C,64>,<B,D,84>,<B,E,67>,<B,F,74>,<B,G,39>,<B,H,64>,<B,I,69>,
<B,J,59>,<B,K,42>,<B,L,82>,<B,M,70>,<B,N,63>,<B,O,59>,<B,P,70>,<B,Q,59>,<B,R,73>,
<B,S,63>,<C,A,56>,<C,B,69>,<C,D,91>,<C,E,50>,<C,F,54>,<C,G,42>,<C,H,51>,<C,I,58>,
<C,J,42>,<C,K,32>,<C,L,76>,<C,M,53>,<C,N,58>,<C,O,44>,<C,P,56>,<C,Q,48>,<C,R,62>,
<C,S,49>,<D,A,81>,<D,B,86>,<D,C,70>,<D,E,72>,<D,F,76>,<D,G,45>,<D,H,71>,<D,I,72>,
<D,J,63>,<D,K,45>,<D,L,95>,<D,M,73>,<D,N,69>,<D,O,64>,<D,P,75>,<D,Q,67>,<D,R,82>,
<D,S,69>,<E,A,59>,<E,B,68>,<E,C,39>,<E,D,89>,<E,F,51>,<E,G,33>,<E,H,44>,<E,I,58>,
```

```
<E,J,38>,<E,K,27>,<E,L,79>,<E,M,45>,<E,N,48>,<E,O,54>,<E,P,50>,<E,Q,42>,<E,R,84>,
<E,S,45>,<F,A,58>,<F,B,66>,<F,C,44>,<F,D,81>,<F,E,41>,<F,G,33>,<F,H,39>,<F,I,62>,
<F,J,46>,<F,K,31>,<F,L,70>,<F,M,49>,<F,N,44>,<F,O,39>,<F,P,50>,<F,Q,36>,<F,R,57>,
<F,S,51>,<G,A,41>,<G,B,47>,<G,C,36>,<G,D,58>,<G,E,41>,<G,F,38>,<G,H,39>,<G,I,38>,
<G,J,31>,<G,K,24>,<G,L,51>,<G,M,38>,<G,N,36>,<G,O,38>,<G,P,37>,<G,Q,37>,<G,R,44>,
<G,S,34>,<H,A,49>,<H,B,49>,<H,C,34>,<H,D,68>,<H,E,46>,<H,F,38>,<H,G,24>,<H,I,39>,
<H,J,32>,<H,K,26>,<H,L,67>,<H,M,47>,<H,N,35>,<H,O,43>,<H,P,38>,<H,Q,50>,<H,R,52>,
<H,S,36>,<I,A,66>,<I,B,74>,<I,C,54>,<I,D,78>,<I,E,60>,<I,F,65>,<I,G,38>,<I,H,56>,
<I,J,55>,<I,K,39>,<I,L,74>,<I,M,63>,<I,N,56>,<I,O,54>,<I,P,58>,<I,Q,53>,<I,R,67>,
<I,S,60>,<J,A,42>,<J,B,50>,<J,C,30>,<J,D,59>,<J,E,35>,<J,F,40>,<J,G,23>,<J,H,38>,
<J,I,49>,<J,K,28>,<J,L,56>,<J,M,38>,<J,N,33>,<J,O,30>,<J,P,35>,<J,Q,35>,<J,R,43>,
<J,S,39>,<K,A,39>,<K,B,43>,<K,C,28>,<K,D,45>,<K,E,32>,<K,F,34>,<K,G,20>,<K,H,30>,
<K,I,38>,<K,J,35>,<K,L,45>,<K,M,37>,<K,N,31>,<K,O,30>,<K,P,31>,<K,Q,28>,<K,R,39>,
<K,S,35>,<L,A,80>,<L,B,82>,<L,C,63>,<L,D,96>,<L,E,71>,<L,F,71>,<L,G,42>,<L,H,70>,
<L,I,67>,<L,J,53>,<L,K,39>,<L,M,64>,<L,N,65>,<L,O,64>,<L,P,69>,<L,Q,65>,<L,R,84>,
<L,S,59>,<M,A,65>,<M,B,79>,<M,C,52>,<M,D,90>,<M,E,63>,<M,F,60>,<M,G,35>,<M,H,60>,
<M,I,64>,<M,J,50>,<M,K,37>,<M,L,86>,<M,N,57>,<M,O,52>,<M,P,59>,<M,Q,55>,<M,R,70>,
<M,S,57>,<N,A,39>,<N,B,54>,<N,C,30>,<N,D,68>,<N,E,34>,<N,F,32>,<N,G,25>,<N,H,32>,
<N,I,44>,<N,J,26>,<N,K,20>,<N,L,63>,<N,M,31>,<N,O,30>,<N,P,36>,<N,Q,29>,<N,R,51>,
<N,S,30>,<O,A,55>,<O,B,82>,<O,C,44>,<O,D,97>,<O,E,52>,<O,F,48>,<O,G,34>,<O,H,52>,
<O,I,60>,<O,J,39>,<O,K,28>,<O,L,93>,<O,M,52>,<O,N,47>,<O,P,50>,<O,Q,49>,<O,R,64>,
<O,S,46>,<P,A,81>,<P,B,105>,<P,C,67>,<P,D,121>,<P,E,68>,<P,F,77>,<P,G,44>,<P,H,67>,
<P,I,77>,<P,J,58>,<P,K,40>,<P,L,99>,<P,M,67>,<P,N,66>,<P,O,60>,<P,Q,63>,<P,R,83>,
<P,S,64>,<Q,A,83>,<Q,B,73>,<Q,C,58>,<Q,D,88>,<Q,E,63>,<Q,F,75>,<Q,G,36>,<Q,H,70>,
<Q,I,62>,<Q,J,54>,<Q,K,40>,<Q,L,90>,<Q,M,72>,<Q,N,59>,<Q,O,56>,<Q,P,62>,<Q,R,73>,
<Q,S,64>,<R,A,69>,<R,B,66>,<R,C,43>,<R,D,84>,<R,E,59>,<R,F,53>,<R,G,34>,<R,H,51>,
<R,I,60>,<R,J,47>,<R,K,31>,<R,L,82>,<R,M,55>,<R,N,57>,<R,O,48>,<R,P,47>,<R,Q,47>,
<R,S,55>,<S,A,61>,<S,B,66>,<S,C,39>,<S,D,79>,<S,E,38>,<S,F,51>,<S,G,28>,<S,H,37>,
<S,I,75>,<S,J,55>,<S,K,40>,<S,L,74>,<S,M,44>,<S,N,36>,<S,O,37>,<S,P,44>,<S,Q,37>,
<S,R,54>,<A,T,102>,<B,T,90>,<C,T,359>,<D,T,90>,<E,T,80>,<F,T,59>,<G,T,113>,<H,T,56>,
<I,T,49>,<J,T,45>,<K,T,76>,<L,T,77>,<M,T,54>,<N,T,43>,<O,T,45>,<P,T,81>,<Q,T,138>,
<R,T,75>,<S,T,65>}; //origin, destination, total volume related to Q1-2018
```

G.3.2. Model

```
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/************************************************************************************

  OPL Model for Trucking Problem

*************************************************************************************/
POSTNL HUB NETWORK DESIGN

execute timeTermination {
    cplex.tilim = 3600; // maximum Runtime = 1h =3600
  }

{string} Location = ...;
{string} TruckTypes = ...;
```

```
{string} Spokes = ...;
{string} Hubs = ...;

tuple spokeInfo {
  int    minDepTime; // Earliest departure time at spoke
  int    maxArrTime; // Latest arrive time at spoke
};

spokeInfo Spoke[Spokes] = ...;

// Make sure the data is consistent: latest arrival time >= earliest departure time
assert forall(s in Spokes) Spoke[s].maxArrTime > Spoke[s].minDepTime;

tuple truckTypeInfo {
  int   capacity;
  int   costPerMile;
  int   milesPerHour; //speed
}

truckTypeInfo TruckTypeInfos[TruckTypes] = ...;
int LoadTime[Hubs][TruckTypes] = ...; // in minutes; loadTime = unloadTime

tuple routeInfo {
  key string  spoke;
  key string  hub;
  int      distance; // in kilometer
}
{routeInfo} Routes = ...;

// The following assertion is to make sure that the spoke
// in each route is indeed in the set of Spokes.
assert forall(r in Routes : r.spoke not in Spokes) 1 == 0;

// The following assertion is to make sure that the hub
// in each route is indeed in the set of Hubs.
assert forall(r in Routes : r.hub not in Hubs) 1 == 0;

tuple triple {
  string origin;
  string hub;
  string destination;
}

{triple} Triples = // feasible paths from spokes to spokes via one hub
{<r1.spoke,r1.hub,r2.spoke> | r1,r2 in Routes : r1 != r2 && r1.hub == r2.hub};

tuple shipment {
  key string  origin;
  key string  destination;
  int       totalVolume;
}
{shipment} Shipments = ...;

// The following assertion is to make sure that the origin
// of each shipment is indeed in the set of Spokes.
assert forall(s in Shipments : s.origin not in Spokes) 1 == 0;

// The following assertion is to make sure that the destination
// of each shipment is indeed in the set of Spokes.
assert forall(s in Shipments : s.destination not in Spokes) 1 == 0;
```

```
int PossibleTruckOnRoute[Routes][TruckTypes];

// the earliest unloading time at a hub for each type of truck
int EarliestUnloadingTime[Routes][TruckTypes];
// the latest loading time at a hub for each type of truck
int LatestLoadingTime[Routes][TruckTypes];

// Compute possible truck types that can be assigned on a route
execute INITIALIZE {
  for(var r in Routes)
    for(var t in TruckTypes) {
      EarliestUnloadingTime[r][t] = Math.ceil(LoadTime[r.hub][t] + Spoke[r.spoke].minDepTime +
          60*r.distance/TruckTypeInfos[t].milesPerHour);
      LatestLoadingTime[r][t] = Math.floor(Spoke[r.spoke].maxArrTime - LoadTime[r.hub][t] -
          60*r.distance/TruckTypeInfos[t].milesPerHour);
      // A type of truck can be assigned on a route only if it can make it to the hub and back
      //  before the max arrival time at the spoke.
      if ( EarliestUnloadingTime[r][t] < LatestLoadingTime[r][t]) {
        PossibleTruckOnRoute[r][t] = 1;
      }
      else {
        PossibleTruckOnRoute[r][t] = 0;
      }
    }
}

int MaxTrucks = 151; // Maximum # of trucks for each type on a route

// Maximum Volume of goods that can be handled
// on each path for each type of truck
int MaxVolume = 5000;

dvar int+ TruckOnRoute[Routes][TruckTypes] in 0..MaxTrucks;

// This represents the volumes shipped out from each hub
// by each type of truck on each triple
// The volumes are distinguished by truck types because trucks of different types
// arrive at a hub at different times and the timing is used in defining
// the constraints for volume availability for the trucks leaving the hub.
dvar int+ OutVolumeThroughHubOnTruck[Triples][TruckTypes] in 0..MaxVolume;

// This represents the volume shipped into each hub by each type of truck on each triple
// It is used in defining timing constraints.
dvar int+ InVolumeThroughHubOnTruck[Triples][TruckTypes] in 0..MaxVolume;

dexpr float TotalCost =
  sum(r in Routes, t in TruckTypes)
      2*r.distance*TruckTypeInfos[t].costPerMile*TruckOnRoute[r][t];

minimize TotalCost;

subject to {
  // The # of trucks of each type should be less than "maxTrucks", and if a type of truck
  // is impossible for a route, its # should be zero
  forall(r in Routes, t in TruckTypes)
      ctMaxTruck:
      TruckOnRoute[r][t] <= PossibleTruckOnRoute[r][t]*MaxTrucks;


  // On each route s-h, the total inbound volume carried by trucks of each type
  // should be less than the total capacity of the trucks of this type.
```

```
  forall(<s,h,dist> in Routes, t in TruckTypes)
    ctInCapacity:
      sum(<s,h,dest> in Triples) InVolumeThroughHubOnTruck[<s,h,dest>][t]
         <= TruckOnRoute[<s,h,dist>][t]*TruckTypeInfos[t].capacity;

  // On each route s-h, the total outbound volume carried by each truck type should be less
      than
  // the total capacity of this type of truck.

  forall(<s,h,dist> in Routes, t in TruckTypes)
    ctOutCapacity:
      sum(<o,h,s> in Triples) OutVolumeThroughHubOnTruck[<o,h,s>][t]
           <= TruckOnRoute[<s,h,dist>][t]*TruckTypeInfos[t].capacity;

  // On any triple, the total flows in the hub = the total flows out the hub
  forall (tr in Triples)
    ctFlow:
      sum(t in TruckTypes) InVolumeThroughHubOnTruck[tr][t]
        == sum(t in TruckTypes) OutVolumeThroughHubOnTruck[tr][t];

  // The sum of flows between any origin-destination pair via all hubs is equal to the
      shipment between the o-d pair.

  forall (<o,d,v> in Shipments )
    ctOrigDest:
      sum(t in TruckTypes, <o,h,d> in Triples) InVolumeThroughHubOnTruck[<o,h,d>][t] == v;


  // There must be enough volume for a truck before it leaves a hub.
  // In another words, the shipments for a truck must arrive
  // at the hub from all spokes before the truck leaves.
  // The constraint can be expressed as the following:
  // For each route s-h and leaving truck of type t:
  // Cumulated inbound volume arrived before the loading time of the truck >=
  // Cumulated outbound volume up to the loading time of the truck (including the shipments
      being loaded).
  forall (<s,h,dist> in Routes, t in TruckTypes)
    ctTiming:
      sum (<o,h,s> in Triples, t1 in TruckTypes, <o,h,dist1> in Routes :
          // The expression below defines the indices of the trucks unloaded before truck t
              starts loading.
          EarliestUnloadingTime[<o,h,dist1>][t1] <= LatestLoadingTime[<s,h,dist>][t])
          InVolumeThroughHubOnTruck[<o,h,s>][t1] >=
      sum (<o,h,s> in Triples, t2 in TruckTypes, <o,h,dist2> in Routes :
          // The expression below defines the indices of the trucks left before truck t starts
              loading.
          LatestLoadingTime[<o,h,dist2>][t2] <= LatestLoadingTime[<s,h,dist>][t])
          OutVolumeThroughHubOnTruck[<o,h,s>][t2];
}



/************************************************************
      POST-PROCESSING
*************************************************************/
// Post processing: result data structures are exported as post-processed tuple or tuple sets
// Solve objective value
tuple result {
  float totalCost;
}
result Result = <TotalCost>;
```

```
// Number of trucks assigned to each route, for each truck type
tuple nbTrucksOnRouteRes {
  key string  spoke;
  key string  hub;
  key string  truckType;
  int       nbTruck;
}
{nbTrucksOnRouteRes} NbTrucksOnRouteRes = {<r.spoke, r.hub, t, TruckOnRoute[r][t]> | r in
     Routes, t in TruckTypes};

// Volume shipped into each hub by each type of truck and each pair (origin, destination)
tuple inVolumeThroughHubOnTruckRes {
  key string  origin;
  key string  hub;
  key string  destination;
  key string  truckType;
  int       quantity;
}
{inVolumeThroughHubOnTruckRes} InVolumeThroughHubOnTruckRes =
   {<tr.origin, tr.hub, tr.destination, t, InVolumeThroughHubOnTruck[tr][t]> | tr in Triples,
        t in TruckTypes};

// Volume shipped from each hub by each type of truck and each pair (origin, destination)
tuple outVolumeThroughHubOnTruckRes {
  key string  origin;
  key string  hub;
  key string  destination;
  key string  truckType;
  int       quantity;
}
{outVolumeThroughHubOnTruckRes} OutVolumeThroughHubOnTruckRes =
   {<tr.origin, tr.hub, tr.destination, t, OutVolumeThroughHubOnTruck[tr][t]> | tr in Triples,
        t in TruckTypes};

execute {
  Result;
  NbTrucksOnRouteRes;
  InVolumeThroughHubOnTruckRes;
  OutVolumeThroughHubOnTruckRes;
}
```

G.4. Open network design

G.4.1. Data

```
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// --------------------------------------------------------------------------
// POSTNL OPEN NETWORK DESIGN

Location = {A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T};
```

```
TruckTypes = {BigTruck};

Spokes = {A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T};
Hubs = {A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T};

Spoke = [<30, 480>,<30, 480>,<30, 480>,<30, 480>,<30, 480>,
<30, 480>,<30, 480>,<30, 480>,<30, 480>,<30, 480>,<30, 480>,
<30, 480>,<30, 480>,<30, 480>,<30, 480>,<30, 480>,<30, 480>,
<30, 480>,<30, 480>, <30, 480>]; //Earliest departure time, latest arrive time

TruckTypeInfos = [<48,713,71>]; //capacity in RC, emission cost gr per km, km per hour

LoadTime = [[20],[20],[20],[20],[20],[20],[20],[20],[20],[20],[20],[20],
[20],[20],[20],[20],[20],[20],[20],[20]]; //

Routes = {<A,A,0>,<B,A,170>,<C,A,92>,<D,A,75>,<E,A,92>,<F,A,67>,<G,A,169>,<H,A,72>,
<I,A,105>,<J,A,182>,<K,A,159>,<L,A,33>,<M,A,98>,<N,A,88>,<O,A,83>,<P,A,104>,<Q,A,40>,
<R,A,69>,<S,A,70>,<T,A,83>,<A,B,170>,<B,B,0>,<C,B,122>,<D,B,98>,<E,B,189>,<F,B,128>,
<G,B,177>,<H,B,199>,<I,B,223>,<J,B,317>,<K,B,295>,<L,B,139>,<M,B,236>,<N,B,163>,
<O,B,210>,<P,B,74>,<Q,B,153>,<R,B,183>,<S,B,206>,<T,B,148>,<A,C,92>,<B,C,122>,
<C,C,0>,<D,C,50>,<E,C,68>,<F,C,109>,<G,C,77>,<H,C,120>,<I,C,199>,<J,C,270>,<K,C,232>,
<L,C,66>,<M,C,163>,<N,C,40>,<O,C,93>,<P,C,68>,<Q,C,80>,<R,C,62>,<S,C,163>,<T,C,25>,
<A,D,75>,<B,D,98>,<C,D,50>,<D,D,0>,<E,D,100>,<F,D,59>,<G,D,124>,<H,D,103>,<I,D,154>,
<J,D,249>,<K,D,211>,<L,D,48>,<M,D,142>,<N,D,75>,<O,D,116>,<P,D,32>,<Q,D,58>,<R,D,88>,
<S,D,137>,<T,D,59>,<A,E,92>,<B,E,189>,<C,E,68>,<D,E,100>,<E,E,0>,<F,E,129>,<G,E,118>,
<H,E,61>,<I,E,196>,<J,E,249>,<K,E,195>,<L,E,72>,<M,E,109>,<N,E,33>,<O,E,32>,<P,E,132>,
<Q,E,69>,<R,E,29>,<S,E,159>,<T,E,44>,<A,F,67>,<B,F,128>,<C,F,109>,<D,F,59>,<E,F,129>,
<F,F,0>,<G,F,177>,<H,F,129>,<I,F,102>,<J,F,197>,<K,F,174>,<L,F,70>,<M,F,167>,<N,F,100>,
<O,F,141>,<P,F,70>,<Q,F,84>,<R,F,113>,<S,F,85>,<T,F,96>,<A,G,169>,<B,G,177>,<C,G,77>,
<D,G,124>,<E,G,118>,<F,G,177>,<G,G,0>,<H,G,174>,<I,G,268>,<J,G,338>,<K,G,301>,<L,G,134>,
<M,G,222>,<N,G,94>,<O,G,145>,<P,G,134>,<Q,G,156>,<R,G,119>,<S,G,231>,<T,G,83>,<A,H,72>,
<B,H,199>,<C,H,120>,<D,H,103>,<E,H,61>,<F,H,129>,<G,H,174>,<H,H,0>,<I,H,172>,<J,H,213>,
<K,H,143>,<L,H,65>,<M,H,58>,<N,H,89>,<O,H,35>,<P,H,133>,<Q,H,51>,<R,H,72>,<S,H,136>,<T,H,99>,
<A,I,105>,<B,I,223>,<C,I,199>,<D,I,154>,<E,I,196>,<F,I,102>,<G,I,268>,<H,I,172>,<I,I,0>,
<J,I,149>,<K,I,166>,<L,I,138>,<M,I,202>,<N,I,193>,<O,I,187>,<P,I,165>,<Q,I,145>,<R,I,174>,
<S,I,59>,<T,I,191>,<A,J,182>,<B,J,317>,<C,J,270>,<D,J,249>,<E,J,249>,<F,J,197>,<G,J,338>,
<H,J,213>,<I,J,149>,<J,J,0>,<K,J,80>,<L,J,209>,<M,J,176>,<N,J,262>,<O,J,225>,<P,J,260>,
<Q,J,207>,<R,J,244>,<S,J,118>,<T,J,286>,<A,K,159>,<B,K,295>,<C,K,232>,<D,K,211>,<E,K,195>,
<F,K,174>,<G,K,301>,<H,K,143>,<I,K,166>,<J,K,80>,<K,K,0>,<L,K,167>,<M,K,99>,<N,K,222>,
<O,K,169>,<P,K,236>,<Q,K,167>,<R,K,203>,<S,K,94>,<T,K,217>,<A,L,33>,<B,L,139>,<C,L,66>,
<D,L,48>,<E,L,72>,<F,L,70>,<G,L,134>,<H,L,65>,<I,L,138>,<J,L,209>,<K,L,167>,<L,L,0>,
<M,L,104>,<N,L,57>,<O,L,77>,<P,L,73>,<Q,L,20>,<R,L,48>,<S,L,59>,<T,L,53>,<A,M,98>,
<B,M,236>,<C,M,163>,<D,M,142>,<E,M,109>,<F,M,167>,<G,M,222>,<H,M,58>,<I,M,202>,<J,M,176>,
<K,M,99>,<L,M,104>,<M,M,0>,<N,M,137>,<O,M,84>,<P,M,171>,<Q,M,90>,<R,M,120>,<S,M,111>,
<T,M,147>,<A,N,88>,<B,N,163>,<C,N,40>,<D,N,75>,<E,N,33>,<F,N,100>,<G,N,94>,<H,N,89>,
<I,N,193>,<J,N,262>,<K,N,222>,<L,N,57>,<M,N,137>,<N,N,0>,<O,N,59>,<P,N,103>,<Q,N,66>,
<R,N,29>,<S,N,154>,<T,N,17>,<A,O,83>,<B,O,210>,<C,O,93>,<D,O,116>,<E,O,32>,<F,O,141>,
<G,O,145>,<H,O,35>,<I,O,187>,<J,O,225>,<K,O,169>,<L,O,77>,<M,O,84>,<N,O,59>,<O,O,0>,
<P,O,144>,<Q,O,64>,<R,O,44>,<S,O,147>,<T,O,71>,<A,P,104>,<B,P,74>,<C,P,68>,<D,P,32>
,<E,P,132>,<F,P,70>,<G,P,134>,<H,P,133>,<I,P,165>,<J,P,260>,<K,P,236>,<L,P,73>,<M,P,171>,
<N,P,103>,<O,P,144>,<P,P,0>,<Q,P,87>,<R,P,117>,<S,P,147>,<T,P,86>,<A,Q,40>,<B,Q,153>,
<C,Q,80>,<D,Q,58>,<E,Q,69>,<F,Q,84>,<G,Q,156>,<H,Q,51>,<I,Q,145>,<J,Q,207>,<K,Q,167>,
<L,Q,20>,<M,Q,90>,<N,Q,66>,<O,Q,64>,<P,Q,87>,<Q,Q,0>,<R,Q,46>,<S,Q,108>,<T,Q,67>,
<A,R,69>,<B,R,183>,<C,R,62>,<D,R,88>,<E,R,29>,<F,R,113>,<G,R,119>,<H,R,72>,<I,R,174>,
<J,R,244>,<K,R,203>,<L,R,48>,<M,R,120>,<N,R,29>,<O,R,44>,<P,R,117>,<Q,R,46>,<R,R,0>,
<S,R,136>,<T,R,40>,<A,S,70>,<B,S,206>,<C,S,163>,<D,S,137>,<E,S,159>,<F,S,85>,<G,S,231>,
<H,S,136>,<I,S,59>,<J,S,118>,<K,S,94>,<L,S,59>,<M,S,111>,<N,S,154>,<O,S,147>,<P,S,147>,
<Q,S,108>,<R,S,136>,<S,S,0>,<T,S,151>,<A,T,83>,<B,T,148>,<C,T,25>,<D,T,59>,<E,T,44>,<F,T,96>,
<G,T,83>,<H,T,99>,<I,T,191>,<J,T,286>,<K,T,217>,<L,T,53>,<M,T,147>,<N,T,17>,<O,T,71>,<P,T,86>,
<Q,T,67>,<R,T,40>,<S,T,151>,<T,T,0>}; //spoke, hub, distance
```

```
Shipments = {<A,B,78>,<A,C,43>,<A,D,100>,<A,E,49>,<A,F,55>,<A,G,34>,<A,H,52>,<A,I,67>,
<A,J,44>,<A,K,32>,<A,L,90>,<A,M,51>,<A,N,45>,<A,O,46>,<A,P,51>,<A,Q,51>,<A,R,62>,<A,S,54>,
<B,A,70>,<B,C,64>,<B,D,84>,<B,E,67>,<B,F,74>,<B,G,39>,<B,H,64>,<B,I,69>,<B,J,59>,<B,K,42>,
<B,L,82>,<B,M,70>,<B,N,63>,<B,O,59>,<B,P,70>,<B,Q,59>,<B,R,73>,<B,S,63>,<C,A,56>,<C,B,69>,
<C,D,91>,<C,E,50>,<C,F,54>,<C,G,42>,<C,H,51>,<C,I,58>,<C,J,42>,<C,K,32>,<C,L,76>,<C,M,53>,
<C,N,58>,<C,O,44>,<C,P,56>,<C,Q,48>,<C,R,62>,<C,S,49>,<D,A,81>,<D,B,86>,<D,C,70>,<D,E,72>,
<D,F,76>,<D,G,45>,<D,H,71>,<D,I,72>,<D,J,63>,<D,K,45>,<D,L,95>,<D,M,73>,<D,N,69>,<D,O,64>,
<D,P,75>,<D,Q,67>,<D,R,82>,<D,S,69>,<E,A,59>,<E,B,68>,<E,C,39>,<E,D,89>,<E,F,51>,<E,G,33>,
<E,H,44>,<E,I,58>,<E,J,38>,<E,K,27>,<E,L,79>,<E,M,45>,<E,N,48>,<E,O,54>,<E,P,50>,<E,Q,42>,
<E,R,84>,<E,S,45>,<F,A,58>,<F,B,66>,<F,C,44>,<F,D,81>,<F,E,41>,<F,G,33>,<F,H,39>,<F,I,62>,
<F,J,46>,<F,K,31>,<F,L,70>,<F,M,49>,<F,N,44>,<F,O,39>,<F,P,50>,<F,Q,36>,<F,R,57>,<F,S,51>,
<G,A,41>,<G,B,47>,<G,C,36>,<G,D,58>,<G,E,41>,<G,F,38>,<G,H,39>,<G,I,38>,<G,J,31>,<G,K,24>,
<G,L,51>,<G,M,38>,<G,N,36>,<G,O,38>,<G,P,37>,<G,Q,37>,<G,R,44>,<G,S,34>,<H,A,49>,<H,B,49>,
<H,C,34>,<H,D,68>,<H,E,46>,<H,F,38>,<H,G,24>,<H,I,39>,<H,J,32>,<H,K,26>,<H,L,67>,<H,M,47>,
<H,N,35>,<H,O,43>,<H,P,38>,<H,Q,50>,<H,R,52>,<H,S,36>,<I,A,66>,<I,B,74>,<I,C,54>,<I,D,78>,
<I,E,60>,<I,F,65>,<I,G,38>,<I,H,56>,<I,J,55>,<I,K,39>,<I,L,74>,<I,M,63>,<I,N,56>,<I,O,54>,
<I,P,58>,<I,Q,53>,<I,R,67>,<I,S,60>,<J,A,42>,<J,B,50>,<J,C,30>,<J,D,59>,<J,E,35>,<J,F,40>,
<J,G,23>,<J,H,38>,<J,I,49>,<J,K,28>,<J,L,56>,<J,M,38>,<J,N,33>,<J,O,30>,<J,P,35>,<J,Q,35>,
<J,R,43>,<J,S,39>,<K,A,39>,<K,B,43>,<K,C,28>,<K,D,45>,<K,E,32>,<K,F,34>,<K,G,20>,<K,H,30>,
<K,I,38>,<K,J,35>,<K,L,45>,<K,M,37>,<K,N,31>,<K,O,30>,<K,P,31>,<K,Q,28>,<K,R,39>,<K,S,35>,
<L,A,80>,<L,B,82>,<L,C,63>,<L,D,96>,<L,E,71>,<L,F,71>,<L,G,42>,<L,H,70>,<L,I,67>,<L,J,53>,
<L,K,39>,<L,M,64>,<L,N,65>,<L,O,64>,<L,P,69>,<L,Q,65>,<L,R,84>,<L,S,59>,<M,A,65>,<M,B,79>,
<M,C,52>,<M,D,90>,<M,E,63>,<M,F,60>,<M,G,35>,<M,H,60>,<M,I,64>,<M,J,50>,<M,K,37>,<M,L,86>,
<M,N,57>,<M,O,52>,<M,P,59>,<M,Q,55>,<M,R,70>,<M,S,57>,<N,A,39>,<N,B,54>,<N,C,30>,<N,D,68>,
<N,E,34>,<N,F,32>,<N,G,25>,<N,H,32>,<N,I,44>,<N,J,26>,<N,K,20>,<N,L,63>,<N,M,31>,<N,O,30>,
<N,P,36>,<N,Q,29>,<N,R,51>,<N,S,30>,<O,A,55>,<O,B,82>,<O,C,44>,<O,D,97>,<O,E,52>,<O,F,48>,
<O,G,34>,<O,H,52>,<O,I,60>,<O,J,39>,<O,K,28>,<O,L,93>,<O,M,52>,<O,N,47>,<O,P,50>,<O,Q,49>,
<O,R,64>,<O,S,46>,<P,A,81>,<P,B,105>,<P,C,67>,<P,D,121>,<P,E,68>,<P,F,77>,<P,G,44>,<P,H,67>,
<P,I,77>,<P,J,58>,<P,K,40>,<P,L,99>,<P,M,67>,<P,N,66>,<P,O,60>,<P,Q,63>,<P,R,83>,<P,S,64>,
<Q,A,83>,<Q,B,73>,<Q,C,58>,<Q,D,88>,<Q,E,63>,<Q,F,75>,<Q,G,36>,<Q,H,70>,<Q,I,62>,<Q,J,54>,
<Q,K,40>,<Q,L,90>,<Q,M,72>,<Q,N,59>,<Q,O,56>,<Q,P,62>,<Q,R,73>,<Q,S,64>,<R,A,69>,<R,B,66>,
<R,C,43>,<R,D,84>,<R,E,59>,<R,F,53>,<R,G,34>,<R,H,51>,<R,I,60>,<R,J,47>,<R,K,31>,<R,L,82>,
<R,M,55>,<R,N,57>,<R,O,48>,<R,P,47>,<R,Q,47>,<R,S,55>,<S,A,61>,<S,B,66>,<S,C,39>,<S,D,79>,
<S,E,38>,<S,F,51>,<S,G,28>,<S,H,37>,<S,I,75>,<S,J,55>,<S,K,40>,<S,L,74>,<S,M,44>,<S,N,36>,
<S,O,37>,<S,P,44>,<S,Q,37>,<S,R,54>,<A,T,102>,<B,T,90>,<C,T,359>,<D,T,90>,<E,T,80>,<F,T,59>,
<G,T,113>,<H,T,56>,<I,T,49>,<J,T,45>,<K,T,76>,<L,T,77>,<M,T,54>,<N,T,43>,<O,T,45>,<P,T,81>,
<Q,T,138>,<R,T,75>,<S,T,65>}; //origin, destination, total volume related to Q1 2018
```

G.4.2. Model

```
// --------------------------------------------------------------------------
// Licensed Materials - Property of IBM
//
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/************************************************************************************

  OPL Model for Trucking Problem

**************************************************************************************/
// POSTNL OPEN NETWORK DESIGN

execute timeTermination {
```

```
    cplex.tilim = 3600; // maximum Runtime = 1h =3600
  }

{string} Location = ...;
{string} TruckTypes = ...;

{string} Spokes = ...;
{string} Hubs = ...;

tuple spokeInfo {
  int    minDepTime; // Earliest departure time at spoke
  int    maxArrTime; // Latest arrive time at spoke
};

spokeInfo Spoke[Spokes] = ...;

// Make sure the data is consistent: latest arrival time >= earliest departure time
assert forall(s in Spokes) Spoke[s].maxArrTime > Spoke[s].minDepTime;

tuple truckTypeInfo {
  int   capacity;
  int   costPerMile;
  int   milesPerHour; //speed
}

truckTypeInfo TruckTypeInfos[TruckTypes] = ...;
int LoadTime[Hubs][TruckTypes] = ...; // in minutes; loadTime = unloadTime

tuple routeInfo {
  key string  spoke;
  key string  hub;
  int      distance; // in kilometer
}
{routeInfo} Routes = ...;

// The following assertion is to make sure that the spoke
// in each route is indeed in the set of Spokes.
assert forall(r in Routes : r.spoke not in Spokes) 1 == 0;

// The following assertion is to make sure that the hub
// in each route is indeed in the set of Hubs.
assert forall(r in Routes : r.hub not in Hubs) 1 == 0;

tuple triple {
  string origin;
  string hub;
  string destination;
}

{triple} Triples = // feasible paths from spokes to spokes via one hub
{<r1.spoke,r1.hub,r2.spoke> | r1,r2 in Routes : r1 != r2 && r1.hub == r2.hub}; //!= means is
    not equal to

tuple shipment {
  key string  origin;
  key string  destination;
  int       totalVolume;
}
{shipment} Shipments = ...;

// The following assertion is to make sure that the origin
```

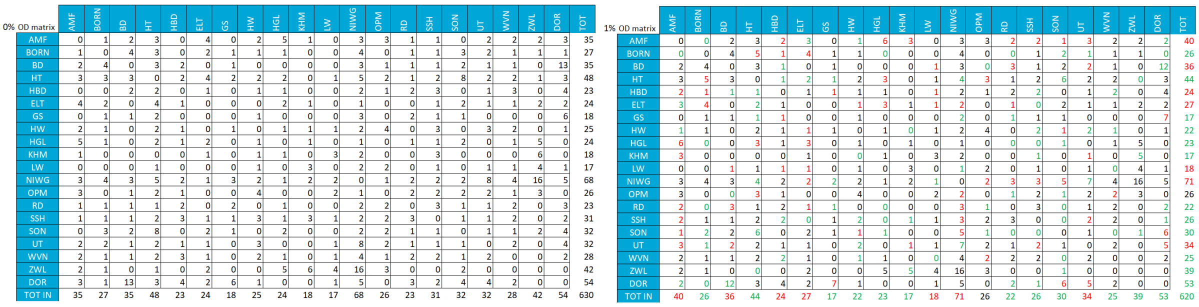
```
// of each shipment is indeed in the set of Spokes.
assert forall(s in Shipments : s.origin not in Spokes) 1 == 0;

// The following assertion is to make sure that the destination
// of each shipment is indeed in the set of Spokes.
assert forall(s in Shipments : s.destination not in Spokes) 1 == 0;

int PossibleTruckOnRoute[Routes][TruckTypes];

// the earliest unloading time at a hub for each type of truck
int EarliestUnloadingTime[Routes][TruckTypes];
// the latest loading time at a hub for each type of truck
int LatestLoadingTime[Routes][TruckTypes];

// Compute possible truck types that can be assigned on a route
execute INITIALIZE {
  for(var r in Routes)
    for(var t in TruckTypes) {
      EarliestUnloadingTime[r][t] = Math.ceil(LoadTime[r.hub][t] + Spoke[r.spoke].minDepTime +
          60*r.distance/TruckTypeInfos[t].milesPerHour); //mathceil = returns to the smallest
          integer greater than or equal to a given number
      LatestLoadingTime[r][t] = Math.floor(Spoke[r.spoke].maxArrTime - LoadTime[r.hub][t] -
          60*r.distance/TruckTypeInfos[t].milesPerHour);
      // A type of truck can be assigned on a route only if it can make it to the hub and back
      //  before the max arrival time at the spoke.
      if ( EarliestUnloadingTime[r][t] < LatestLoadingTime[r][t]) {
        PossibleTruckOnRoute[r][t] = 1;
      }
      else {
        PossibleTruckOnRoute[r][t] = 0;
      }
    }
}

int MaxTrucks = 151; // Maximum # of trucks for each type on a route

// Maximum Volume of goods that can be handled
// on each path for each type of truck
int MaxVolume = 5000;

dvar int+ TruckOnRoute[Routes][TruckTypes] in 0..MaxTrucks;

// This represents the volumes shipped out from each hub
// by each type of truck on each triple
// The volumes are distinguished by truck types because trucks of different types
// arrive at a hub at different times and the timing is used in defining
// the constraints for volume availability for the trucks leaving the hub.
dvar int+ OutVolumeThroughHubOnTruck[Triples][TruckTypes] in 0..MaxVolume;

// This represents the volume shipped into each hub by each type of truck on each triple
// It is used in defining timing constraints.
dvar int+ InVolumeThroughHubOnTruck[Triples][TruckTypes] in 0..MaxVolume;

dexpr float TotalCost =
  sum(r in Routes, t in TruckTypes)
      2*r.distance*TruckTypeInfos[t].costPerMile*TruckOnRoute[r][t];

minimize TotalCost;

subject to {
  // The # of trucks of each type should be less than "maxTrucks", and if a type of truck
```

```
  // is impossible for a route, its # should be zero
  forall(r in Routes, t in TruckTypes)
      ctMaxTruck:
      TruckOnRoute[r][t] <= PossibleTruckOnRoute[r][t]*MaxTrucks;


  // On each route s-h, the total inbound volume carried by trucks of each type
  // should be less than the total capacity of the trucks of this type.
  forall(<s,h,dist> in Routes, t in TruckTypes)
    ctInCapacity:
      sum(<s,h,dest> in Triples) InVolumeThroughHubOnTruck[<s,h,dest>][t]
         <= TruckOnRoute[<s,h,dist>][t]*TruckTypeInfos[t].capacity;

  // On each route s-h, the total outbound volume carried by each truck type should be less
      than
  // the total capacity of this type of truck.

  forall(<s,h,dist> in Routes, t in TruckTypes)
    ctOutCapacity:
      sum(<o,h,s> in Triples) OutVolumeThroughHubOnTruck[<o,h,s>][t]
           <= TruckOnRoute[<s,h,dist>][t]*TruckTypeInfos[t].capacity;

  // On any triple, the total flows in the hub = the total flows out the hub
  forall (tr in Triples)
    ctFlow:
      sum(t in TruckTypes) InVolumeThroughHubOnTruck[tr][t]
        == sum(t in TruckTypes) OutVolumeThroughHubOnTruck[tr][t];

  // The sum of flows between any origin-destination pair via all hubs is equal to the
      shipment between the o-d pair.

  forall (<o,d,v> in Shipments )
    ctOrigDest:
      sum(t in TruckTypes, <o,h,d> in Triples) InVolumeThroughHubOnTruck[<o,h,d>][t] == v;


  // There must be enough volume for a truck before it leaves a hub.
  // In another words, the shipments for a truck must arrive
  // at the hub from all spokes before the truck leaves.
  // The constraint can be expressed as the following:
  // For each route s-h and leaving truck of type t:
  // Cumulated inbound volume arrived before the loading time of the truck >=
  // Cumulated outbound volume up to the loading time of the truck (including the shipments
      being loaded).
  forall (<s,h,dist> in Routes, t in TruckTypes)
    ctTiming:
      sum (<o,h,s> in Triples, t1 in TruckTypes, <o,h,dist1> in Routes :
          // The expression below defines the indices of the trucks unloaded before truck t
              starts loading.
          EarliestUnloadingTime[<o,h,dist1>][t1] <= LatestLoadingTime[<s,h,dist>][t])
          InVolumeThroughHubOnTruck[<o,h,s>][t1] >=
      sum (<o,h,s> in Triples, t2 in TruckTypes, <o,h,dist2> in Routes :
          // The expression below defines the indices of the trucks left before truck t starts
              loading.
          LatestLoadingTime[<o,h,dist2>][t2] <= LatestLoadingTime[<s,h,dist>][t])
          OutVolumeThroughHubOnTruck[<o,h,s>][t2];
}


/***********************************************************
```

```
      POST-PROCESSING
*************************************************************/
// Post processing: result data structures are exported as post-processed tuple or tuple sets
// Solve objective value
tuple result {
  float totalCost;
}
result Result = <TotalCost>;

// Number of trucks assigned to each route, for each truck type
tuple nbTrucksOnRouteRes {
  key string  spoke;
  key string  hub;
  key string  truckType;
  int         nbTruck;
}
{nbTrucksOnRouteRes} NbTrucksOnRouteRes = {<r.spoke, r.hub, t, TruckOnRoute[r][t]> | r in
    Routes, t in TruckTypes};

// Volume shipped into each hub by each type of truck and each pair (origin, destination)
tuple inVolumeThroughHubOnTruckRes {
  key string  origin;
  key string  hub;
  key string  destination;
  key string  truckType;
  int         quantity;
}
{inVolumeThroughHubOnTruckRes} InVolumeThroughHubOnTruckRes =
   {<tr.origin, tr.hub, tr.destination, t, InVolumeThroughHubOnTruck[tr][t]> | tr in Triples,
       t in TruckTypes};

// Volume shipped from each hub by each type of truck and each pair (origin, destination)
tuple outVolumeThroughHubOnTruckRes {
  key string  origin;
  key string  hub;
  key string  destination;
  key string  truckType;
  int         quantity;
}
{outVolumeThroughHubOnTruckRes} OutVolumeThroughHubOnTruckRes =
   {<tr.origin, tr.hub, tr.destination, t, OutVolumeThroughHubOnTruck[tr][t]> | tr in Triples,
       t in TruckTypes};

execute {
  Result;
  NbTrucksOnRouteRes;
  InVolumeThroughHubOnTruckRes;
  OutVolumeThroughHubOnTruckRes;
}
```

H

Effects volume reduction per parcel

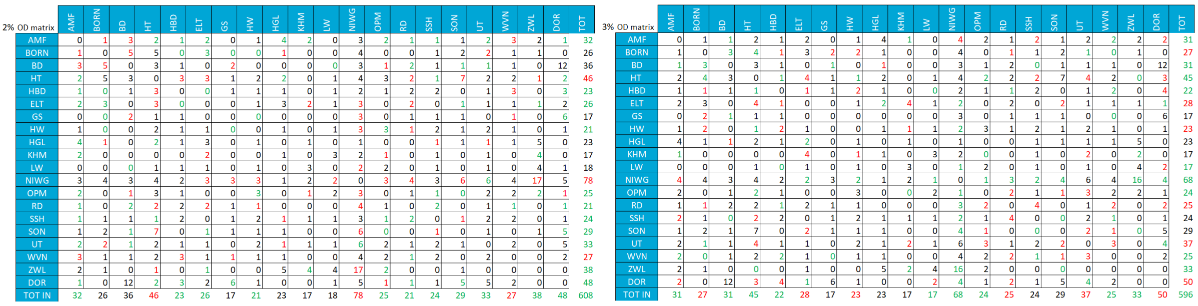


(a) 0% volume reduction results in 38.90 tCO_2

0% OD matrix	AMF	BORN	BD	HT	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG	OPM	RD	SSH	SON	UT	WVN	ZWL	DOR	TOT
AMF	0	1	2	3	0	4	0	2	5	1	0	3	3	1	1	0	2	2	2	3	35
BORN	1	0	4	3	0	2	1	1	1	0	0	4	0	1	1	3	2	1	1	1	27
BD	2	4	0	3	2	0	1	0	0	0	0	3	1	1	1	2	1	1	0	13	35
HT	3	3	3	0	2	4	2	2	2	0	1	5	2	1	2	8	2	2	1	3	48
HBD	0	0	2	2	0	1	0	1	1	0	0	2	1	2	3	0	1	3	0	4	23
ELT	4	2	0	4	1	0	0	0	2	1	0	1	0	0	1	2	1	1	2	2	24
GS	0	1	1	2	0	0	0	1	0	0	0	3	0	2	1	1	0	0	0	6	18
HW	2	1	0	2	1	0	1	0	1	1	1	2	4	0	3	0	3	2	0	1	25
HGL	5	1	0	2	1	2	0	1	0	1	0	1	0	1	1	2	0	1	5	0	24
KHM	1	0	0	0	0	1	0	1	1	0	3	2	0	0	3	0	0	0	6	0	18
LW	0	0	0	1	0	0	0	1	0	3	0	2	2	0	1	0	1	1	4	1	17
NIWG	3	4	3	5	2	1	3	2	1	2	2	0	1	2	2	2	8	4	16	5	68
OPM	3	0	1	2	1	0	0	4	0	0	2	1	0	2	2	2	2	1	3	0	26
RD	1	1	1	1	2	0	2	0	1	0	0	2	2	0	3	1	1	2	0	3	23
SSH	1	1	1	2	3	1	1	3	1	3	1	2	2	3	0	1	1	2	0	2	31
SON	0	3	2	8	0	2	1	0	2	0	0	2	2	1	1	0	1	1	2	4	32
UT	2	2	1	2	1	1	0	3	0	0	1	8	2	1	1	1	0	2	0	4	32
WVN	2	1	1	2	3	1	0	2	1	0	1	4	1	2	2	1	2	0	0	2	28
ZWL	2	1	0	1	0	2	0	0	5	6	4	16	3	0	0	2	0	0	0	0	42
DOR	3	1	13	3	4	2	6	1	0	0	1	5	0	3	2	4	4	2	0	0	54
TOT IN	35	27	35	48	23	24	18	25	24	18	17	68	26	23	31	32	32	28	42	54	630

(b) 1% volume reduction results in 37.87 tCO_2

1% OD matrix	AMF	BORN	BD	HT	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG	OPM	RD	SSH	SON	UT	WVN	ZWL	DOR	TOT
AMF	0	0	2	3	2	3	0	1	6	3	0	3	3	2	2	1	3	2	2	2	40
BORN	0	0	4	5	1	4	1	1	0	0	0	4	0	0	1	2	1	1	1	0	26
BD	2	4	0	3	1	0	1	0	0	0	1	3	0	3	1	2	2	1	0	12	36
HT	3	5	3	0	1	2	1	2	3	0	1	4	3	1	2	6	2	2	0	3	44
HBD	2	1	1	1	0	1	1	1	1	0	1	2	1	2	2	0	1	2	0	4	24
ELT	3	4	0	2	1	0	0	1	3	1	1	2	0	1	0	2	1	1	2	2	27
GS	0	1	1	1	1	0	0	1	0	0	0	2	0	1	1	1	0	0	0	7	17
HW	1	1	0	2	1	1	1	0	1	0	1	2	4	0	2	1	2	1	0	1	22
HGL	6	0	0	3	1	3	0	1	0	1	0	1	0	0	0	1	0	1	5	0	23
KHM	3	0	0	0	0	1	0	0	1	0	3	2	0	0	1	0	1	0	5	0	17
LW	0	0	1	1	1	1	0	1	0	3	0	1	2	0	1	0	1	0	4	1	18
NIWG	3	4	3	4	2	2	2	2	1	2	1	0	2	3	3	5	7	4	16	5	71
OPM	3	0	0	3	1	0	0	4	0	0	2	2	0	1	2	1	2	2	3	0	26
RD	2	0	3	1	2	1	1	0	0	0	0	3	1	0	3	0	1	2	0	2	22
SSH	2	1	1	2	2	0	1	2	0	1	1	3	2	3	0	0	2	2	0	1	26
SON	1	2	2	6	0	2	1	1	1	0	0	5	1	0	0	0	1	0	1	6	30
UT	3	1	2	2	1	1	0	2	0	1	1	7	2	1	2	1	0	2	0	5	34
WVN	2	1	1	2	2	1	0	1	1	0	0	4	2	2	2	0	2	0	0	2	25
ZWL	2	1	0	0	0	2	0	0	5	5	4	16	3	0	0	1	0	0	0	0	39
DOR	2	0	12	3	4	2	7	1	0	0	1	5	0	2	1	6	5	2	0	0	53
TOT IN	40	26	36	44	24	27	17	22	23	17	18	71	26	22	26	30	34	25	39	53	620

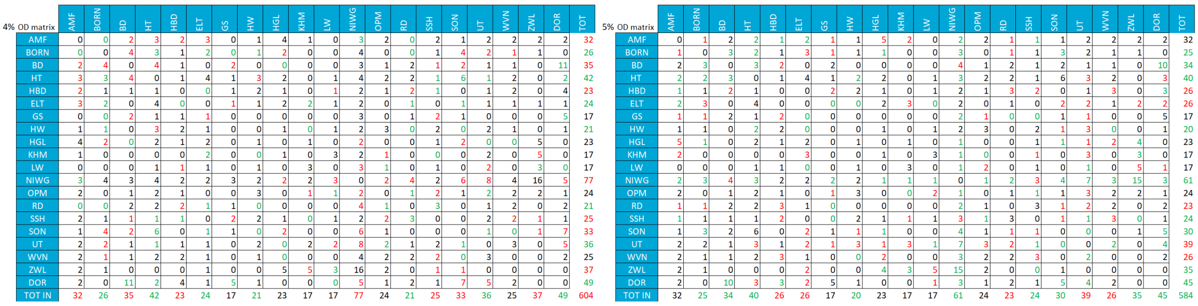


(c) 2% volume reduction results in 37.64 tCO_2

2% OD matrix	AMF	BORN	BD	HT	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG	OPM	RD	SSH	SON	UT	WVN	ZWL	DOR	TOT
AMF	0	1	3	2	1	2	0	1	4	2	0	3	2	1	1	1	2	3	2	1	32
BORN	1	0	5	5	0	3	0	0	1	0	0	4	0	0	1	2	2	1	1	0	26
BD	3	5	0	3	1	0	2	0	0	0	0	3	1	2	1	1	1	1	0	12	36
HT	2	5	3	0	3	3	1	2	2	0	1	4	3	2	1	7	2	2	1	2	46
HBD	1	0	1	3	0	0	1	1	1	0	1	2	1	2	2	0	1	3	0	3	23
ELT	2	3	0	3	0	0	0	1	3	2	1	3	0	2	0	1	1	1	1	2	26
GS	0	0	2	1	1	0	0	0	0	0	0	3	0	1	1	1	0	1	0	6	17
HW	1	0	0	2	1	1	0	0	1	0	1	3	3	1	2	1	2	1	0	1	21
HGL	4	1	0	2	1	3	0	1	0	1	0	1	0	0	1	1	1	1	5	0	23
KHM	2	0	0	0	0	2	0	0	1	0	3	2	1	0	1	0	1	0	4	0	17
LW	0	0	0	1	1	1	0	1	0	3	0	2	2	0	1	0	1	0	4	1	18
NIWG	3	4	3	4	2	3	3	3	1	2	2	0	3	4	3	6	6	4	17	5	78
OPM	2	0	1	3	1	0	0	3	0	1	2	3	0	1	1	0	2	2	2	1	25
RD	1	0	2	2	2	2	1	1	0	0	0	4	1	0	2	0	1	1	0	1	21
SSH	1	1	1	1	2	0	1	2	1	1	1	3	1	2	0	1	2	2	0	1	24
SON	1	2	1	7	0	1	1	1	1	0	0	6	0	0	1	0	1	0	1	5	29
UT	2	2	1	2	1	1	0	2	1	1	1	6	2	1	2	1	0	2	0	5	33
WVN	3	1	1	2	3	1	1	1	1	0	0	4	2	1	2	0	2	0	0	2	27
ZWL	2	1	0	1	0	1	0	0	5	4	4	17	2	0	0	1	0	0	0	0	38
DOR	1	0	12	2	3	2	6	1	0	0	1	5	1	1	1	5	5	2	0	0	48
TOT IN	32	26	36	46	23	26	17	21	23	17	18	78	25	21	24	29	33	27	38	48	608

(d) 3% volume reduction results in 37.41 tCO_2

3% OD matrix	AMF	BORN	BD	HT	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG	OPM	RD	SSH	SON	UT	WVN	ZWL	DOR	TOT
AMF	0	1	1	2	1	2	0	1	4	1	0	4	2	1	2	1	2	2	2	2	31
BORN	1	0	3	4	1	3	2	2	1	0	0	4	0	1	1	2	1	0	1	0	27
BD	1	3	0	3	1	0	1	0	1	0	0	3	1	2	0	1	1	1	0	12	31
HT	2	4	3	0	1	4	1	1	2	0	1	4	2	2	2	7	4	2	0	3	45
HBD	1	1	1	1	0	1	1	2	1	0	0	2	1	1	2	0	1	2	0	4	22
ELT	2	3	0	4	1	0	0	1	2	4	1	2	0	2	0	2	1	1	1	1	28
GS	0	2	1	1	1	0	0	0	0	0	0	3	0	1	1	1	0	0	0	6	17
HW	1	2	0	1	2	1	0	0	1	1	1	2	3	1	2	1	2	1	0	1	23
HGL	4	1	1	2	1	2	0	1	0	1	0	1	0	0	1	1	1	1	5	0	23
KHM	1	0	0	0	0	4	0	1	1	0	3	2	0	0	1	0	2	0	2	0	17
LW	0	0	0	1	0	1	0	1	0	3	0	1	2	0	1	0	1	0	4	2	17
NIWG	4	4	3	4	2	2	3	2	1	2	1	0	1	3	2	4	6	4	16	4	68
OPM	2	0	1	2	1	0	0	3	0	0	2	1	0	2	1	1	3	2	2	1	24
RD	1	1	2	2	1	2	1	1	0	0	0	3	2	0	4	0	1	2	0	2	25
SSH	2	1	0	2	2	0	1	2	1	1	1	2	1	4	0	0	2	1	0	1	24
SON	1	2	1	7	0	2	1	1	1	0	0	4	1	0	0	0	2	1	0	5	29
UT	2	1	1	4	1	1	0	2	1	2	1	6	3	1	2	2	0	3	0	4	37
WVN	2	0	1	2	2	1	0	1	1	0	0	4	2	2	1	1	3	0	0	2	25
ZWL	2	1	0	0	0	1	0	0	5	2	4	16	2	0	0	0	0	0	0	0	33
DOR	2	0	12	3	4	1	6	1	0	0	2	4	1	2	1	5	4	2	0	0	50
TOT IN	31	27	31	45	22	28	17	23	23	17	17	68	24	25	24	29	37	25	33	50	596

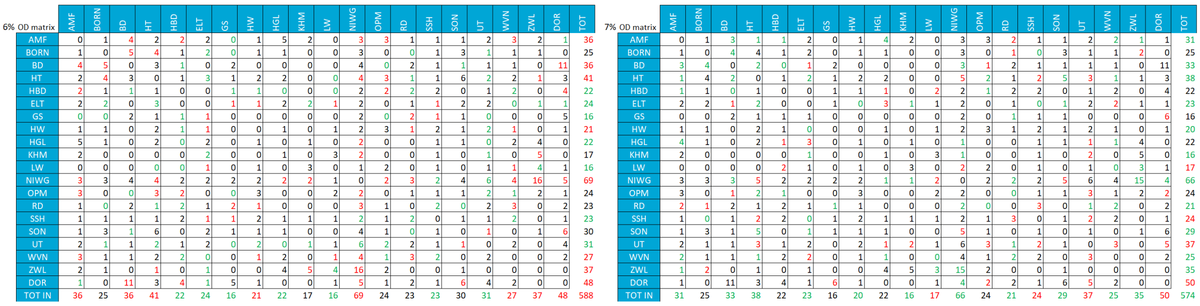


(e) 4% volume reduction results in 37.202 tCO_2

4% OD matrix	AMF	BORN	BD	HT	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG	OPM	RD	SSH	SON	UT	WVN	ZWL	DOR	TOT
AMF	0	0	2	3	2	3	0	1	4	1	0	3	2	0	2	1	2	2	2	2	32
BORN	0	0	4	3	1	2	0	1	2	0	0	4	0	0	1	4	2	1	1	0	26
BD	2	4	0	4	1	0	2	0	0	0	0	3	1	2	1	2	1	1	0	11	35
HT	3	3	4	0	1	4	1	3	2	0	1	4	2	2	1	6	1	2	0	2	42
HBD	2	1	1	1	0	0	1	2	1	0	1	2	1	2	1	0	1	2	0	4	23
ELT	3	2	0	4	0	0	1	1	2	2	1	2	0	1	0	1	1	1	1	1	24
GS	0	0	2	1	1	1	0	0	0	0	0	3	0	1	2	1	0	0	0	5	17
HW	1	1	0	3	2	1	0	0	1	0	1	2	3	0	2	0	2	1	0	1	21
HGL	4	2	0	2	1	2	0	1	0	1	0	2	0	0	1	2	0	0	5	0	23
KHM	1	0	0	0	0	2	0	0	1	0	3	2	1	0	0	0	2	0	5	0	17
LW	0	0	0	1	1	1	0	1	0	3	0	3	1	0	1	0	2	0	3	0	17
NIWG	3	4	3	4	2	2	3	2	2	2	3	0	2	4	2	6	8	4	16	5	77
OPM	2	0	1	2	1	0	0	3	0	1	1	2	0	1	2	1	2	2	2	1	24
RD	0	0	2	2	2	1	1	0	0	0	0	4	1	0	3	0	1	2	0	2	21
SSH	2	1	1	1	1	0	2	2	1	0	1	2	2	3	0	0	2	2	1	1	25
SON	1	4	2	6	0	1	1	0	2	0	0	6	1	0	0	0	1	0	1	7	33
UT	2	2	1	1	1	1	0	2	0	2	2	8	2	1	2	1	0	3	0	5	36
WVN	2	1	1	2	2	1	0	1	0	0	0	4	2	2	2	0	3	0	0	2	25
ZWL	2	1	0	0	0	1	0	0	5	5	3	16	2	0	1	1	0	0	0	0	37
DOR	2	0	11	2	4	1	5	1	0	0	0	5	1	2	1	7	5	2	0	0	49
TOT IN	32	26	35	42	23	24	17	21	23	17	17	77	24	21	25	33	36	25	37	49	604

(f) 5% volume reduction results in 36.71 tCO_2

5% OD matrix	AMF	BORN	BD	HT	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG	OPM	RD	SSH	SON	UT	WVN	ZWL	DOR	TOT
AMF	0	1	2	2	1	2	1	1	5	2	0	2	2	1	1	1	2	2	2	2	32
BORN	1	0	3	2	1	3	1	1	1	0	0	3	0	1	1	3	2	1	1	0	25
BD	2	3	0	3	2	0	2	0	0	0	0	4	1	2	1	2	1	1	0	10	34
HT	2	2	3	0	1	4	1	2	2	0	1	3	2	2	1	6	3	2	0	3	40
HBD	1	1	2	1	0	0	2	2	1	0	1	2	1	3	2	0	1	3	0	3	26
ELT	2	3	0	4	0	0	0	0	2	3	0	2	0	1	0	2	2	1	2	2	26
GS	1	1	2	1	2	0	0	0	0	0	0	2	1	0	0	1	1	0	0	5	17
HW	1	1	0	2	2	0	0	0	1	0	1	2	3	0	2	1	3	0	0	1	20
HGL	5	1	0	2	1	2	0	1	0	1	0	1	0	0	1	1	1	2	4	0	23
KHM	2	0	0	0	0	3	0	0	1	0	3	1	0	0	1	0	3	0	3	0	17
LW	0	0	0	1	1	0	0	1	0	3	0	1	2	0	1	0	1	0	5	1	17
NIWG	2	3	4	3	2	2	2	2	1	1	1	0	1	2	3	4	7	3	15	3	61
OPM	2	0	1	2	1	0	1	3	0	0	2	1	0	1	1	1	3	2	2	1	24
RD	1	1	2	2	3	1	0	0	0	0	0	2	1	0	3	1	2	2	0	2	23
SSH	1	1	1	1	2	0	0	2	1	1	1	3	1	3	0	1	1	3	0	1	24
SON	1	3	2	6	0	2	1	1	1	0	0	4	1	1	1	0	0	0	1	5	30
UT	2	2	1	3	1	2	1	3	1	3	1	7	3	2	1	0	0	2	0	4	39
WVN	2	1	1	2	3	1	0	0	2	0	0	3	2	2	3	0	2	0	0	2	26
ZWL	2	1	0	0	0	2	0	0	4	3	5	15	2	0	0	1	0	0	0	0	35
DOR	2	0	10	3	3	2	5	1	0	0	1	3	1	2	1	5	4	2	0	0	45
TOT IN	32	25	34	40	26	26	17	20	23	17	17	61	24	23	24	30	39	26	35	45	584

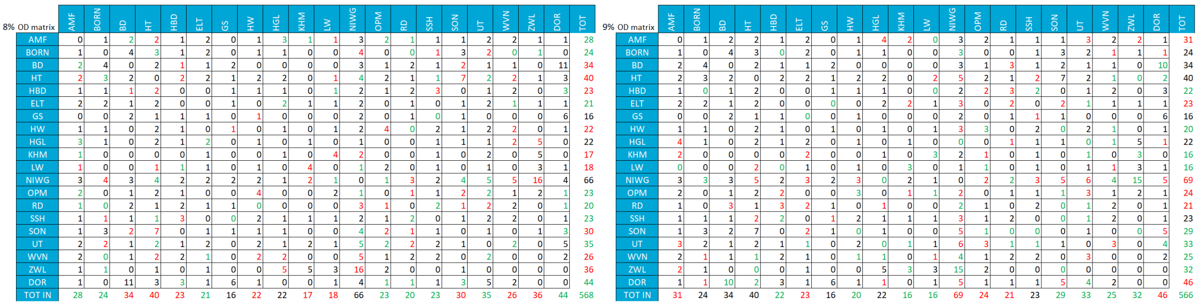


(g) 6% volume reduction results in 36.15 tCO_2

6% OD matrix	AMF	BORN	BD	HT	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG	OPM	RD	SSH	SON	UT	WVN	ZWL	DOR	TOT
AMF	0	1	4	2	2	2	0	1	5	2	0	3	3	1	1	1	2	3	2	1	36
BORN	1	0	5	4	1	2	0	1	1	0	0	3	0	0	1	3	1	1	1	0	25
BD	4	5	0	3	1	0	2	0	0	0	0	4	0	2	1	1	1	1	0	11	36
HT	2	4	3	0	1	3	1	2	2	0	0	4	3	1	1	6	2	2	1	3	41
HBD	2	1	1	1	0	0	1	1	0	0	0	2	2	2	2	0	1	2	0	4	22
ELT	2	2	0	3	0	0	1	1	2	2	1	2	0	1	1	2	2	0	1	1	24
GS	0	0	2	1	1	1	0	0	0	0	0	2	0	2	1	1	0	0	0	5	16
HW	1	1	0	2	1	1	0	0	1	0	1	2	3	1	2	1	2	1	0	1	21
HGL	5	1	0	2	0	2	0	1	0	1	0	2	0	0	1	1	0	2	4	0	22
KHM	2	0	0	0	0	2	0	0	1	0	3	2	0	0	1	0	1	0	5	0	17
LW	0	0	0	0	0	1	0	1	0	3	0	1	2	0	1	0	1	1	4	1	16
NIWG	3	3	4	4	2	2	2	2	2	2	1	0	2	3	2	4	6	4	16	5	69
OPM	3	0	0	3	2	0	0	3	0	0	2	2	0	1	1	1	2	1	2	1	24
RD	1	0	2	1	2	1	2	1	0	0	0	3	1	0	2	0	2	3	0	2	23
SSH	1	1	1	1	2	1	1	2	1	1	1	2	1	2	0	1	1	2	0	1	23
SON	1	3	1	6	0	2	1	1	1	0	0	4	1	0	1	0	1	0	1	6	30
UT	2	1	1	2	1	2	0	2	0	1	1	6	2	2	1	1	0	2	0	4	31
WVN	3	1	1	2	2	0	0	1	2	0	1	4	1	3	2	0	2	0	0	2	27
ZWL	2	1	0	1	0	1	0	0	4	5	4	16	2	0	0	1	0	0	0	0	37
DOR	1	0	11	3	4	1	5	1	0	0	1	5	1	2	1	6	4	2	0	0	48
TOT IN	36	25	36	41	22	24	16	21	22	17	16	69	24	23	23	30	31	27	37	48	588

(h) 7% volume reduction results in 35.74 tCO_2

7% OD matrix	AMF	BORN	BD	HT	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG	OPM	RD	SSH	SON	UT	WVN	ZWL	DOR	TOT
AMF	0	1	3	1	1	2	0	1	4	2	0	3	3	2	1	1	2	2	1	1	31
BORN	1	0	4	4	1	2	0	1	1	0	0	3	0	1	0	3	1	1	2	0	25
BD	3	4	0	2	0	1	2	0	0	0	0	3	1	2	1	1	1	1	0	11	33
HT	1	4	2	0	1	2	1	2	2	0	0	5	2	1	2	5	3	1	1	3	38
HBD	1	1	0	1	0	0	1	1	1	0	2	2	1	2	2	0	1	2	0	4	22
ELT	2	2	1	2	0	0	1	0	3	1	1	2	0	1	0	1	2	2	1	1	23
GS	0	0	2	1	1	1	0	0	0	0	0	2	0	1	1	1	0	0	0	6	16
HW	1	1	0	2	1	0	0	0	1	0	1	2	3	1	2	1	2	1	0	1	20
HGL	4	1	0	2	1	3	0	1	0	1	0	1	0	0	1	1	1	1	4	0	22
KHM	2	0	0	0	0	1	0	0	1	0	3	1	0	0	1	0	2	0	5	0	16
LW	0	0	0	0	2	1	0	1	0	3	0	2	2	0	1	0	1	0	3	1	17
NIWG	3	3	3	5	2	2	2	2	1	1	2	0	2	2	2	5	6	4	15	4	66
OPM	3	0	1	2	1	0	0	3	0	0	2	2	0	0	1	1	3	1	2	2	24
RD	2	1	2	1	2	1	1	1	0	0	0	2	0	0	3	0	1	2	0	2	21
SSH	1	0	1	2	2	0	1	2	1	1	1	2	1	3	0	1	2	2	0	1	24
SON	1	3	1	5	0	1	1	1	1	0	0	5	1	0	1	0	1	0	1	6	29
UT	2	1	1	3	1	2	0	2	1	2	1	6	3	1	2	1	0	3	0	5	37
WVN	2	1	1	1	2	2	0	1	1	0	0	4	1	2	2	0	3	0	0	2	25
ZWL	1	2	0	1	0	1	0	0	4	5	3	15	2	0	0	1	0	0	0	0	35
DOR	1	0	11	3	4	1	6	1	0	0	1	4	2	2	1	6	5	2	0	0	50
TOT IN	31	25	33	38	22	23	16	20	22	16	17	66	24	21	24	29	37	25	35	50	574



(i) 8% volume reduction results in 35.35 tCO_2

8% OD matrix	AMF	BORN	BD	HT	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG	OPM	RD	SSH	SON	UT	WVN	ZWL	DOR	TOT
AMF	0	1	2	2	1	2	0	1	3	1	1	3	2	1	1	1	2	2	1	1	28
BORN	1	0	4	3	1	2	0	1	1	0	0	4	0	0	1	3	2	0	1	0	24
BD	2	4	0	2	1	1	2	0	0	0	0	3	1	2	1	2	1	1	0	11	34
HT	2	3	2	0	2	2	1	2	2	0	1	4	2	1	1	7	2	2	1	3	40
HBD	1	1	1	2	0	0	1	1	1	0	1	2	1	2	3	0	1	2	0	3	23
ELT	2	2	1	2	0	0	1	0	2	1	1	2	0	1	0	1	2	1	1	1	21
GS	0	0	2	1	1	1	0	1	0	0	0	2	0	1	0	1	0	0	0	6	16
HW	1	1	0	2	1	0	1	0	1	0	1	2	4	0	2	1	2	2	0	1	22
HGL	3	1	0	2	1	2	0	1	0	1	0	1	0	0	1	1	1	2	5	0	22
KHM	1	0	0	0	0	1	0	0	1	0	4	2	0	0	1	0	2	0	5	0	17
LW	1	0	0	1	1	1	0	1	0	4	0	1	2	0	1	0	1	0	3	1	18
NIWG	3	4	3	4	2	2	2	2	1	2	1	0	1	3	2	4	5	5	16	4	66
OPM	2	0	1	2	1	0	0	4	0	0	2	1	0	1	1	2	2	1	2	1	23
RD	1	0	2	1	2	1	1	0	0	0	0	3	1	0	2	1	2	2	0	1	20
SSH	1	1	1	1	3	0	0	2	1	1	1	2	1	2	0	1	2	2	0	1	23
SON	1	3	2	7	0	1	1	1	1	0	0	4	2	1	1	0	1	0	1	3	30
UT	2	2	1	2	1	2	0	2	1	2	1	5	2	2	2	1	0	2	0	5	35
WVN	2	0	1	2	2	1	0	2	2	0	0	5	1	2	2	0	2	0	0	2	26
ZWL	1	1	0	1	0	1	0	0	5	5	3	16	2	0	0	1	0	0	0	0	36
DOR	1	0	11	3	3	1	6	1	0	0	1	4	1	1	1	3	5	2	0	0	44
TOT IN	28	24	34	40	23	21	16	22	22	17	18	66	23	20	23	30	35	26	36	44	568

(j) 9% volume reduction results in 35.04 tCO_2

9% OD matrix	AMF	BORN	BD	HT	HBD	ELT	GS	HW	HGL	KHM	LW	NIWG	OPM	RD	SSH	SON	UT	WVN	ZWL	DOR	TOT
AMF	0	1	2	2	1	2	0	1	4	2	0	3	2	1	1	1	3	2	2	1	31
BORN	1	0	4	3	0	2	0	1	1	0	0	3	0	0	1	3	2	1	1	1	24
BD	2	4	0	2	1	1	2	0	0	0	0	3	1	3	1	2	1	1	0	10	34
HT	2	3	2	0	2	2	1	2	2	0	2	5	2	1	2	7	2	1	0	2	40
HBD	1	0	1	2	0	0	1	1	1	0	0	2	2	3	2	0	1	2	0	3	22
ELT	2	2	1	2	0	0	0	0	2	2	1	3	0	2	0	2	1	1	1	1	23
GS	0	0	2	1	1	0	0	1	0	0	0	2	0	1	1	1	0	0	0	6	16
HW	1	1	0	2	1	0	1	0	1	0	1	3	3	0	2	0	2	1	0	1	20
HGL	4	1	0	2	1	2	0	1	0	1	0	0	0	1	1	1	0	1	5	1	22
KHM	2	0	0	0	0	2	0	0	1	0	3	2	1	0	1	0	1	0	3	0	16
LW	0	0	0	2	0	1	0	1	0	3	0	1	1	0	1	0	1	1	3	1	16
NIWG	3	3	3	5	2	3	2	3	0	2	1	0	2	2	3	5	6	4	15	5	69
OPM	2	0	1	2	2	0	0	3	0	1	1	2	0	1	1	1	3	1	2	1	24
RD	1	0	3	1	3	2	1	0	1	0	0	2	1	0	2	0	1	2	0	1	21
SSH	1	1	1	2	2	0	1	2	1	1	1	3	1	2	0	0	1	2	0	1	23
SON	1	3	2	7	0	2	1	0	1	0	0	5	1	0	0	0	1	0	0	5	29
UT	3	2	1	2	1	1	0	2	0	1	1	6	3	1	1	1	0	3	0	4	33
WVN	2	1	1	1	2	1	0	1	1	0	1	4	1	2	2	0	3	0	0	2	25
ZWL	2	1	0	0	0	1	0	0	5	3	3	15	2	0	0	0	0	0	0	0	32
DOR	1	1	10	2	3	1	6	1	1	0	1	5	1	1	1	5	4	2	0	0	46
TOT IN	31	24	34	40	22	23	16	20	22	16	16	69	24	21	23	29	33	25	32	46	566

Figure H.1: Fleet allocation for different average volume per parcel. Green = less trips, red = more trips relative to the figure before

I

Expert Interviews and Meetings

I.1. Expert Interview PostNL - 23/01/2018

Table I.1: Attendees during interview 23/01

Present	Function
Theun Lourens	Senior Advisor Sustainability PostNL
Rutger van Ouwerkerk	TU Delft Student
Marc Wagemans	CR Reporting Specialist PostNL

Highlighted comments during meeting

Data: Fuel efficiency and CO_2 emissions currently based on driven kilometres and consumed fuel. The CO_2 target of 2017 is set on 13% reduction in 2030 relative to 2016.

I.2. Meeting transportation planning - 26/03/2018

Table I.2: Attendees during interview 10/04/2018

Present	Function
Rutger van Ouwerkerk	TU Delft Student
Peter van Soest	Strategic planner transport PostNL

Highlighted comments during meeting

- PostNL tries to allocation their fleet as optimal as possible regarding cost minimisation within the limits of constraints.

- Currently, the average utilisation of trucks is around 86/87%.

- routing depends on volume, time and distance.

- A parcel is transported by 1.66 trucks on average.

- A single trip during intern transport is on average 89 kilometre and takes 75 minutes. the total allocated trips, 40% is performed by trucks of PostNL. 60% of the trips are performed by outsourced parties.

I.3. Tour and interview Depot Ridderkerk - 28/03/2018

Table I.3: Attendees during tour and interview 28/03/2018

Present	Function
Rutger van Ouwerkerk	TU Delft Student
Louis Stellenaar	Process manager PostNL
Henk Verstraten	Process Manager PostNL

General Remarks

- Process is not ’black-and-white’ as sketched in theory. Time and distance play a very important role
- Sorting is based on shifts, every shifts consists of a couple of areas / regions severd by 20 a 25 vans. There are 1 to 9 shifts in Ridderkerk
- In Ridderkerk, only ’bulk’ stream is treated. Parcel delivery that make use of a time window goes through the time-related-network (het tijdgebonden netwerk) which is element of the parcel department since 2018 (before part of mail)
- Evening delivery is part of the bulk stream and is sorted in the last shift (in case of Ridderkerk shift 9)
- PostNL delivery man distribute 110 - 145 parcels a day, with a max of 5 to 6 m^3
- Subcontractor (scope 3) delivers 200 to 350 parcels
- Observation: Vans are to the max loaded with parcels
- Observation: A lot of old looking vans (For sure no Euro 6)
- The prediction of this day was to handle 39000 parcels. This prediction consists of a for-cast of 34000 (done by the headquarter of PostNL parcels) plus a couple of thousand parcels summed by the process manager. Eventually, 42000 parcels have been treated in Ridderkerk (1,2 mil. national). This means that the forecast missed 8000 parcels = around 6 large trucks
- Observation: A lot of large boxes, especially of Bol.com and Zalando. Coolbue had great fitted boxes.

Receiving - Sorting - Distribution

- Parcels are stacked up in roll cages (rolcontainers). The roll cages are received during the night and are already sorted based on shift (1 to 9). The origin of the roll cages are different depots OR roll cages collected in the area of Ridderkerk OR roll cages with parcels which were not delivered the day before. For this last category, people are able to change their delivery moment or place until 22 pm. Hereafter these parcels will be sorted
- The roll cages will be emptied one by one onto the supply belt of the sorter
- The sorter scans the parcels and divide them based on destination linked to docks
- Docks are located alternately; Shift 1 is row left, shift 2 is row right, shift 3 is row left, shift 4 is row right etc etc
- Evening delivery is the last shift, in case of Ridderkerk shift 9
- Registered parcels or parcels that which cannot be transported on the belt because of their volume or form, will be handled by hand. Moreover, these parcels will be scanned before they will be loaded into the van, instead of the rest of the transported volume which won’t be scanned during loading.
- A delivery man has approximately 30 - 35 minutes to load 110 - 145 parcels (scope 3 have +200 parcels) into their van
- When an item made three round over the sorting lane without any acceptation of the docks, due to a jam of the dock lane, the item will be addressed to a special lane and get handeled by hand afterwards.

- Driver is not allowed to departure before he/she receives ’green light’ of the planning bureau. They secures that all the allocated parcels are delivered in the dock lane
- Every delivery man has its own region/area based on their capacity with around 16 stops per hour
- Two or more vans in one area is very rare
- Routing is based on delivery list, no navigation like consumers have

Collection - Sorting - Sending

- Starts in general in the afternoon
- two types of inbound:
  - collected at companies, post offices, service points
  - Left overs of that day
- Parcels are always collected in roll cages
- Received parcels will be unloaded on the sorting belt.
- The sorting machine sorts based on end destination and shift. At the end of every dock, around 6 to 9 roll cages are established for a certain shift at a certain destination. Most of the destinations were by passing a cross dock.
- The roll cages will be distributed over the trailers. As mentioned before, most of the destinations were by passing Depot+, this means that a couple of destinations are clustered in one trailer towards a certain Depot+. **However**, one way transport without crossing a Depot+ is not exceptional!
- Planning is made in the control room, located in Hoofddorp. They also decide when a truck has to leave
- Trucks are not always full, empty trucks occur

I.4. Science Based Target Dag - 04/04/2018

Table I.4: Attendees during ’environmental targeting start’ 04/04/2018

Present	**Function**
Edgar van de Brug	Consultant Ecofys
Duco Dalenoord	Portfolio Manager PostNL
George Dermowidjojo	Manager Commercial Strategy PostNL
Gideon Goudsmit	Energy consultant
Rogier Havelaar	Consultant Strategy & Development PostNL
Theun Lourens	Senior Advisor Sustainability PostNL
Erna Meijer	Director GPRF PostNL
Theo Idema	Senior BI Consultant PostNL
Dave Middelburg	Manager Group Reporting PostNL
Rutger van Ouwerkerk	TU Delft Student
Iris Rem	Junior Project Manager PostNL
Eduard Veen	Senior Advisor Fleet PostNL
Heleen Velthuis-Schavenmaker	Manager International Transport PostNL
Karin Vierwind	Portfolio Manager PostNL
Marc Wagemans	CR Reporting Specialist PostNL
Antwan Wiegerink	Manager Quantitative support PostNL

This meeting was all about PostNL and its impact concerning CO_2. Challanges, current state and targets were discussed related to CO_2 reduction. The definition of ’Sience Based Targets’ were introduced by Ecofys. Besides, Ecofys presented the results and gaps concerning the current state and targets.

Highlighted comments during meeting

- The current CO_2 target, as mentioned in PostNL's annual report, is achieved
- however, this target, which is called 'CO_2-efficiency index, is/was not science based. The target was to reduce the CO_2 impact of scope 1+2 in 2020 with 55% relative to base year 2007, which was set as 100 %
- goal CFO: new targets which are including scope 3, relevant and manageable
- Eduard Veen (Senior Fleet Advisor):
  - Start-stop systems are hard to implement due to technical reasons. The distance between stops is too short to load the battery for restarting the engine
  - Current PostNL owns approximately 900 parcel vans, it is estimated that at least half of all this may be used due to the distance beyond 100 kilometres
  - Price electric vehicle 2.5 times diesel
  - Speedlimits are already used: trucks max of 85 km/h and delivery vans max of 130 km/h. An reductions to 100 km/h may be interesting

Highlights presentation Ecofys

- presented calculations of current emissions and targets are indicative
- International Energy Agency (IEA) is the input for Science Based Targets (SBT)
- Transport, goods and persons, is globally responsible for 23% of the total emissions
- 17/23 coming from maritime transport
- Currently PostNL use Goldstandard credits to compensate there emissions of heating buildings. In the new SBT policy (April 2018), only high-quality credits are allowed
- In the case of PostNL, 70% to 80% of their total emissions is comming from outsourced activities
- SBT:
  - Allocated emissions first globally per sector, then per company
  - Take growth of sector and company into account
  - Science based because of the influence of the Intergovernmental Panel on Climate Change (IPCC) [1] and IEA on scenario's and targets
- A correlation factor of 18% is used to upscale the TTW emissions for diesel engines to WTW
- PostNL owns/use only vans <3.5 or trucks >15t
- Currently the intensity is CO_2 per ton.km, Staff of PostNL prefers CO_2 per parcel

I.5. Meeting transport planning - 10/04/2018

Table I.5: Attendees during interview 10/04/2018

Present	Function
Andre Koelemeijer	Supply Chain Planner PostNL
Rutger van Ouwerkerk	TU Delft Student

Highlighted comments during meeting

- Volume measurement done by the sorter covers 90-95%. Other 10-5% is not able to go through the belt because of this form or weight

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[1] IPCC: An organisation owned by the United Nations to evaluate the risks of climate change

- However, the scanner forms every parcel to a square. Moreover, parcels which are too small will be placed on a plate. The scanner measures the volume of the plate instead of only the parcel
- A full truck has 48 roll cages
- 1 order = 1 trip = 1 trailer
- delete the embalage volume, that is not interesting
- trips via a crossdock means 2 trips in planning
- There are 2 different types of RC, 'gray container' with a capacity of 0.66 m^3 and a 'parcel container' with a capacity of 1.04 m^3. It is hard to say how many m^3 is used on average because of the fact that there are two kind of containers. That is the reason why PostNL express everything in 'RC Pakket'. On average 37 parcels are loaded on one RC. Subsequently, PostNL calculated how many volume in m^3 is transported between hubs and how many m^3 there could be transported with the used RC's (both types). This calculation gives an averaged utilisation of 70 to 75%.
- Volume reduction 1:1 with trip planning. Planning software says that a volume reduction of 10% means a transport reduction of 10 %

I.6. Meeting packaging - 02/05/2018

Table I.6: Attendees during interview 02/05/2018

Present	Function
Rutger van Ouwerkerk	TU Delft Student
Mike Zuurbier	Sales Consultant Packaging PostNL

Highlighted comments during meeting

- Reduction in space of parcels will have a small effect in costs of transport lik it has concerning air transportation
- The market plays a very important role, 'the customer is king'.
- According to Mike; the marge that you get in euro's will be zero.
- During contracting of customers, the total transported volume plays (already) a very important role with regard to pricing.
- By using standard boxes (mostly 5 to 7 different sizes) consists on average 30 to 40% of air
- Making customised packages is an expensive job and is only interesting when a customer send over 800,000 parcels a year. A certain packaging machine is around 800,000 to 1,3 million euro.
- There are different manners to customise packages like box-cover method or cut-in method
- Volume based pricing:
  - Won't happen soon because of the wish of the market. If PostNL introduce volume based pricing, it is expected that a lot of customers will switch to competitors of PostNL
  - Currently, the volume of parcels is already taken into account during pricing with customers. For example, a customer that regularly send large volume parcels pays a higher price per parcel than a customer that send very low volume parcels.
  - For the 'standard' shipments, the current way of pricing (weight based) is based on research of common volumes is certain classes. However, this pay of pr icings attributes no responsibility to the sender of the parcel to make the size of the parcel as optimal as possible
  -
- Plastic bags instead of boxes are not an option because:

  - From the perspective of a consumer, a carton box looks more sustainable
  - Carton protects more than plastic
  - Carton has more appearance than plastic. Moreover, advertisement is easier.
  - Handling of carton is easier. Besides a box is stack-able

- PostNL will start with a pilot to test renewable packages to get the bigger picture more sustainable.
- Volume will be a bottleneck for distribution. Sizes of parcels increase over the year while capacity of last mile vehicles (like small pods) decrease
- a lot of reduction in transportation movements is possible for collection (maybe only 1 trailer instead of 2 or more) or intern transport
- Double sized trailers (like Action or Jumbo supermarket use) could be a nice improvement to decrease the total amount of transportation movements.

I.7. Meeting validation - 31/05/2018

Table I.7: Attendees during interview 31/05/2018

Present	**Function**
Rutger van Ouwerkerk	TU Delft Student
Antwan Wiegerinck	Quantitative Support consultant PostNL

Highlighted comments during meeting

Validation of daily emitted amount of CO_2 based on trip registrations

- Difficult to determine if this value is valid or not. Currently, the total amount of CO_2 is concerning heavy transport intended for parcels is determined quite rough:
  1. PostNL only know the <u>total</u> amount of kilometres and consumed fuel of all owned trucks used for all kinds of purposes. In other words, to determine the total amount of emitted CO_2 with regard to parcel transportation we have to use conversion factor.
  2. , Currently, PostNL make use of the 24/76 rule to divide the fuel consumption between mail (24) and parcel (76). This value is based on the ratio of SLA (Service Level Agreement) between the services mail and parcels.
  3. With regard to the calculation of scope 3 trips, PostNL make use of two types of calculations: 1) given amount of kilometres travelled times average fuel consumption or 2) kilometres from the history of PostNL trucks in the case the third parties are not willing/able to give the amount of kilometres times the average fuel consumption
- Besides the given 'problem' of merged amount of consumed fuel, there is also the dilemma of other trip types. For example, other type of trips that play a role in the amount of fuel like in between trips (when a truck shift from parcel transport to mail transport), entry- and exit trips or idle time.
- Do not forget that seasonality play an important role in sampling. December is totally different with smaller and more parcels than the summer with garden related parcels. However, because of the fact that the analyse is based on 81 measurements, is should be large enough to be valid.
- The other mentioned party that calculated emissions is Ecofys. Those results are also different than presented by PostNL. There are a couple of reasons for this difference:
  1. With regard to scope 3, Ecofys use also other market factors into account
  2. Ecofys calculate the WTW emissions while PostNL's results are based on only TTW. The difference between WTW and TTW should be around 18%

Validation of volume reduction and its effects with regard to CO_2 *reduction*

1. It is hard to imagine that every % decrease in parcel volume leads to % in emitted emission. It should be interesting to see what happens with your network, take for example the difference between 0% reduction and 10% reduction.

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