GRA 19502

Master Thesis

The Potentials of Last Mile Logistics by the Use of Cargo Bikes in the City Center of Oslo: A Case Study of DHL Express

Navn:	Anne Marthe Kjønnø, Diem Tran Huong Pham
Start:	02.03.2017 09.00
Finish:	01.09.2017 12.00

Anne Marthe Kjønnø
Diem Tran Huong Pham

BI Norwegian Business School

Master Thesis

The Potentials of Last Mile Logistics by the Use of Cargo Bikes in the City Center of Oslo:

A Case Study of DHL Express

Examination code:

GRA 19502 – Master Thesis

Hand-in date: 01.09.2017

Campus: BI Oslo

Supervisor: Mehdi Sharifyazdi

Program:

Master of Science in Business

Logistics, Operations, and Supply Chain Management

Acknowledgements

This Master thesis marks the finale of five years higher education at BI Norwegian Business School. The submission of this Master thesis completes our Master of Science in Business with a major in Logistics, Operations and Supply Chain Management. The process of writing this Master thesis has been challenging, however, very educational and exciting. There are several people that should be given special thanks.

First, we will thank Jardar Andersen, Karin Fossheim, and Tale Ørving at Transportøkonomisk Institutt for giving us the opportunity to write this Master thesis, as well as their help and support. Furthermore, providing an office at the head office in Forskningsparken. We will also thank DHL Express for their openness, cooperation, and for providing historical data and insightful information to the complex project. Furthermore, welcoming us to their main terminal at Berger in Skedsmo Municipality, and letting us participate on a delivery and pickup route in Oslo.

Second, we will express a deep gratitude to our excellent supervisor Mehdi Sharifyazdi. This thesis would not be possible without his true optimism and advises, as well as his guidance in the right direction when necessary, and to provide us with perceptive feedback. We would also thank Meisam Ashraf, who built and executed the programming and coding of the simulation models.

Last, we will thank family and friends for their support and enthusiasm throughout the duration of this Master thesis.

Abstract

For logistics companies, the last mile is considered the most expensive yet least efficient and most polluting part of the entire supply chain, accounting for 13 to 75 percent of the total costs. The last mile often hinders city logistics due to regulated traffic speed, narrow streets, and limited parking and unloading space. Distribution of goods is an essential part in the development of sustainable transport networks. Cities need to explore new ways of organizing goods transport in addition to new transport modes to meet the negative externalities created by transport companies. A mode that has gained widespread interest for urban deliveries is the use of electric cargo bikes in last mile logistics. An estimation of 51 percent of all goods distribution using motorized transport modes in European countries could be replaced with cargo bikes.

Oslo Municipality and the City Council are establishing new regulations to increase urban life. With this in mind, a joint collaboration between the state, Oslo Municipality and DHL Express was initiated, and led to the cargo bike project. During Summer 2017, DHL Express implemented cargo bikes to their vehicle fleet in order to meet the increasing demand for sustainable solutions in Oslo.

The thesis is a case study in Operations Research that investigates the potentials of last mile freight transport by implementing cargo bikes to DHL Express' vehicle fleet in the city center of Oslo. It evaluates the performance of cargo bikes as supplement for vans within a limited area, and its influence on productivity, environmental impact, and service level. It assesses the existing gap in research regarding the implementation of cargo bikes in Norway from a business perspective.

Two models were developed for the delivery and pickup process, in terms of the current system and pilot project. Simulations were performed to determine the effect of changing the system. In addition, a qualitative analysis was included to strengthen the validity of the study. Based on the analyses, the main findings suggest a potential of implementing cargo bikes to the vehicle fleet. The results of the study prove that by replacing vans with cargo bikes in a limited area in Oslo, DHL Express is able to increase the productivity and service level, while reducing CO_2 emission. Evidently, cargo bikes have the potential of reducing traffic congestions, and handle goods more efficiently in terms of better accessibility to customers.

Table of Contents

List of Tables

List of Figures

List of Illustrations

List of Acronyms

CS – Current System

CVRP – Capacitated Vehicle Routing Problem

KPI – Key Performance Indicator

LSP – Logistics Service Provider

OM – Operations Management

OR – Operations Research

PP – Pilot Project

SC – Supply Chain

TSP – Travelling Salesman Problem

TØI – Transportøkonomisk Institutt

UCC – Urban Consolidation Center

VRP – Vehicle Routing Problem

VRPMPD – Vehicle Routing Problem with Mixed Pickup and Delivery

VRPPD – Vehicle Routing Problem with Pickup and Delivery

VRPSPD – Vehicle Routing Problem with Simultaneous Pickup and Delivery

VRPTW – Vehicle Routing Problem with Time Windows

VRPTWSPD – Vehicle Routing Problem with Time Windows and Simultaneous Pickup and Delivery

SSB – Statistisk Sentralbyrå

Chapter 1:

INTRODUCTION

1.0 Introduction

There has been a significant change to urban living over the last decades. Over 50 percent of the world's populations live in cities, and the number is expected to increase over the next 50 years (Grimm et al., 2008). It follows that freight transport is essential to the function of urban areas (Dablanc, Giuliano, Holliday, & O'Brien, 2013). However, negative externalities due to goods deliveries are of concern: poor air quality, high levels of noise, greenhouse gas emissions, water scarcity, and waste (European Commission, 2014). With the anticipated population growth, an increase in annual tons of goods deliveries is expected. Furthermore, the emergence of express mail deliveries and e-commerce may serve as another explanation to the growing concern (Choubassi, 2015; Gevaers, Van de Voorde, & Vanelslander, 2011). Distribution of goods is a key factor to sustainable transport networks and a critical part of cities' issues on traffic congestion and environmental pollution (Karakikes, 2016). Several empirical studies claim that urban freight vehicles account for 6 to 18 percent of total urban travel (Chatterjee & Cohen, 2004; Figliozzi, 2010; R. King, 2013; Schliwa, Armitage, Aziz, Evans, & Rhoades, 2015), 19 percent of energy consumption and 21 percent of emissions (Russo & Comi, 2012; Schoemaker, Allen, Huschebeck, & Monigl, 2006).

For logistics companies, the first and last mile of a parcel's journey is of great concern. The "last mile" is considered the more expensive, yet least efficient and most polluting part of the entire supply chain (SC); accounting for 13 to 75 percent of the total logistics costs (Gevaers et al., 2011; D. A. King, Gordon, & Peters, 2014). City logistics and SCs are often hindered by the last mile in high-populated areas, for instance due to regulated traffic speed (e.g. rush hour, low emission zones, etc.), limited parking space and unloading space (Aized & Srai, 2014). As freight vehicles are large in size relative to the narrow urban streets, parking and unloading often result in blocked pavements, bikes and vehicle lanes. Moreover, causing increase in costs for the delivery services (e.g. from parking fines), and unsafe surroundings for pedestrians.

An essential point in finding a solution to some of these problems is logistics. Cities need to explore new ways of organizing goods transport in addition to new transportation modes. A mode that has gained widespread interest for urban deliveries is the use of cargo bikes as substitute or supplement for vans in last

mile delivery (Gruber & Kihm, 2016). According to recent literature, it is estimated that about 51 percent of all motorized transport of goods in European cities could be replaced with cargo bikes. A shift from the traditional freight delivery system to this new mode could be successful without increasing overall costs while improving the urban environmental quality (Cox & Rzewnicki, 2015; Nocerino, Colorni, Lia, & Luè, 2016; Schliwa et al., 2015).

It should be noted that cargo bikes will not replace vehicles engaged in heavy goods transport, but rather serve as a substitute or supplement for vans and trucks that operates in urban areas (Rundberget, Storsul, Wilhelmsen, & Osnes, 2016), which delivers or picks up small goods/packages and documents. The emphasis of this thesis is last mile freight transport in Oslo by the use of cargo bikes implemented by DHL Express. DHL Express is a leading express logistics service provider (LSP), operating in several countries all over the world. This thesis investigates the feasibility and potentials from implementing cargo bikes in Oslo, more specifically whether a replacement of vans with cargo bikes in last mile logistics has an influence on productivity, service level and environmental performance. For the purpose of this thesis, the latter will be referred to as the impact on CO_2 emissions in the city.

Previous case studies on this topic have focused on improving delivery systems and the structure of last mile logistics in several metropolitan areas. However, none of them have examined performance regarding a replacement of vans with cargo bikes in a Norwegian context, nor has the case company executed such a study. In light of this, the thesis addresses the existing gap in research regarding the implementation of cargo bikes in Norway, and the case of Oslo and DHL Express. The contribution of this thesis is to provide new results on the subject in a Norwegian context, such that other LSPs in Oslo and Norway can learn from DHL Express' pilot project. The aim of the thesis is to assess the potentials of implementing cargo bikes, and to identify benefits, challenges and barriers in the stated context. For the purpose of this thesis, the terms "freight transport" and "goods delivery" is used interchangeably.

1.1 The Institute of Transport Economics

The thesis is written in collaboration with The Institute of Transport Economics (Transportøkonomisk Institutt (TØI)), department of Economics and Logistics.

TØI is a national, Norwegian institution for transport research and development. The scope of activity includes issues regarding road transport, urban mobility and environmental sustainability (Transportøkonomisk Instistutt, 2017).

The research area "Logistics and Innovation Group" contributes to development and communication of research-based knowledge forming the basis for better planning of logistics as well as more efficient operations. In the Spring 2017, DHL Express initiated a pilot project in the city center of Oslo. The Department of Economics and Logistics was commissioned by The Norwegian Public Roads Administration's (Statens Vegvesen) Urban Logistics Program to conduct an evaluation of the effects by the use of bicycles on DHL Express' performance. Furthermore, to identify opportunities for economically sustainable use of bicycles for deliveries in Oslo and evaluate how public authorities can facilitate further development of such solutions. To complement the research project, the objective of this thesis is the aspects of logistics and business impacts.

1.2 The Case Company

DHL Express is one of three divisions of the world's leading postal and logistics company Deutsche Post DHL Group. DHL Express specializes in the transport of urgent documents and goods from point-to-point in more than 220 countries and regions, and provides services such as critical deliveries (same day/before-12AM-deliveries), timed or throughout-the-day deliveries (next day/after-12AM-deliveries), and day specific deliveries to small and medium sized businesses (DHL, 2016b).

Deutsche Post DHL Group focuses on environmentally friendly solutions, by optimizing transport routes, utilizing alternative vehicles and energy efficient warehouses, reducing emissions and harmful effects in transport and storage of goods. Their goal is to minimize the impact of their business on the environment, by focusing on optimizing the carbon efficiency of all operations. In their effort to reach this goal, they introduced cargo bikes for urban distribution as part of their fleet of vehicles (Deutsche Post DHL Group., 2016).

DHL Express has experienced successful pilot projects in Europe (e.g. the Netherlands, France, Great Britain, Italy, and Germany) by the use of electric cargo bikes as transport modes for express delivery. Thus, they continuously seek

for opportunities to implement this measure in other countries. The aim is to utilize cargo bikes for the next few years anywhere they can improve their customer service and effectiveness (DHL, 2015). According to DHL Express, there are five main reasons why they want to change from vans to cargo bikes: (1) cost reduction, (2) emissions reduction, (3) congestions in the cities, (4) access regulations, and (5) image DHL Express (DHL, 2016a).

According to this, DHL Express in Norway initiated a similar pilot project; distribution by electric cargo bikes (hereafter referred to as cargo bikes) in Oslo for last mile logistics (see Illustration 1), in cooperation with Oslo Municipality and The Norwegian Public Roads Administration. The cargo bike project in Oslo can be illuminated in five basic principles: (1) every bike replaces a van, (2) bike and van routes overlap, (3) total productivity are at least equal, (4) maximum of 1 km per stop, and (5) design routes are based on weight and volume (DHL, 2016a).

Illustration 1: DHL Express' cargo bike for last mile logistics (photo by Diem Pham, 2017)

1.3 The Case of Oslo

To date, the connections between the city districts of Oslo are weak, which affects the experience of a coherent city center (Pedersen, 2015). A challenge is to connect the different urban areas and streets into a common network for pedestrians. The City Council of Oslo has since 2011 been working on the project "Gatebruksplan for Oslo" with the aim to ensure a well-functioning transport system with lower negative environmental impact, and improved traffic conditions for pedestrians. The project consists of measures to provide better public transportation, and to improve the safety and mobility for biking in the city center. It has been suggested a set of initiatives for expansion of bicycle infrastructure: the City Council has approved the marginalization of car

availability in public streets to increase the number of bike lanes, for instance by reducing street parking (Pedersen, 2015).

In 2015, 37.6 million deliveries by vans were performed in Oslo, of which 20 million were performed in the city center of Oslo. This corresponds to approximately 50,000 deliveries and pickups per day (Rundberget et al., 2016). Vans or trucks with diesel engines perform most of these deliveries and pickups. According to EU's IEE program, a large part of freight transport in urban areas could have been performed with cargo bikes. This includes transportation of goods by logistics companies, and transportation of goods or services by mobile service companies, e.g. fast moving consumer goods (Rundberget et al., 2016).

1.4 Purpose of Thesis

The purpose of this thesis is to investigate whether a change from traditional freight delivery to cargo bikes in last mile logistics will be beneficial or not, in terms of productivity, service level and environmental impact. The thesis focuses on DHL Express' delivery process in an adjustive case in the city center of Oslo. Productivity is referred to as the number of deliveries and pickups per day, on-time deliveries, and total kilometers (km) driven per day. Furthermore, the thesis studies influencing factors to convey an understanding of the challenges related to the implementation of cargo bikes for the purpose of last mile freight distribution in Oslo. The results of the thesis determine whether cargo bikes are a sufficiently good solution to the last mile logistics challenges of DHL Express. Previous theories and methods have been used as a basis.

The thesis use simulation as a method to generate routes for the current system (vans) and the pilot project (vans and cargo bikes), based on historical delivery and pickup data from 2016. The simulations of both systems are performed to give a justified comparison.

1.5 Research Question

To structure and investigate the studied situations, a research question has been developed, followed by a set of proposed hypotheses. The focus of the thesis is (1) productivity associated with deliveries and pickups, i.e. minimize total driving distance, (2) evaluate service level, and (3) environmental impact related to the replacement of vans with cargo bikes. Based on the overall purpose of the thesis, the research question is formulated as follows:

"How can an implementation of cargo bikes to a vehicle fleet of vans in Oslo city center contribute to cost efficiency and environmental friendliness, while meeting service level requirements in last mile logistics?"

Table 1 includes a set of statements and the corresponding hypotheses.

Statement 1. Cargo bikes can efficiently deliver goods in motorized vehicle restricted areas and avoid traffic jams and take shorter routes, which leads to Hypothesis 1:

(1) A replacement of vans with cargo bikes will result in increased productivity

Statement 2. Cargo bikes do not emit CO_2 emissions and are able to reduce traffic congestion, which leads to Hypothesis 2:

(2) A replacement of vans with cargo bikes will result in reduced CO_2 emissions

Statement 3. Cargo bikes have the potential to increase service level, in terms of on-time deliveries, which leads to Hypothesis 3:

(3) A replacement of vans with cargo bikes will result in increased service level

---

Table 1: Set of statements and hypotheses

1.6 Relevance of Thesis

To provide a research that gives value and purpose, it is vital to ensure theoretical as well as practical relevance of the thesis. Furthermore, the thesis contribution to the topic is of importance.

1.6.1 Theoretical and Practical Relevance

From a theoretical perspective, this thesis will provide interesting results. The topic of this thesis has been explored in recent literature; however, none have been conducted from a Norwegian perspective. This includes (1) weather conditions, which differs from season to season in terms of snow and heavy rain during autumn and winter, (2) topography, which are uneven compared to for example Copenhagen and Amsterdam, and (3) bicycle conditions. Previous research uses methods for cargo bikes specific for the cities or areas that are studied, and cannot be generalized to Norway and Oslo. Thus, this thesis contributes with valuable insight and a sufficiently good solution from a Norwegian point of view. The thesis includes a set of literature within the topics of city logistics, last mile

logistics, and optimization models. Appendix 1 lists the key literature reviewed for the thesis.

The practical purpose of the thesis is to develop a model for DHL Express, moreover, to provide a decision-making model for similar LSPs in Oslo, to support further knowledge on the last mile issues. The outcome of the study will be an improved last mile service logistics system that is feasible, valuable, and environmentally friendly. The results from this study give DHL Express in Norway valuable insight on the last mile challenges. The thesis analysis and findings will support DHL Express to focus on the most crucial phase in the SC, moreover, provide important information regarding productivity and environmental performance in city logistics. This can help DHL Express and similar LSPs in Oslo to reduce costs, and hence increase their service level. Lastly, the results of this thesis may contribute to new ideas for improvements of current cargo bike distribution settings.

1.6.2 Thesis Contribution

The contribution of this thesis is to provide new results regarding the implementation of cargo bikes to a traditional vehicle fleet, such that other LSPs in Oslo and Norway can learn from DHL Express' pilot project. This thesis attempts to show the potential for small goods and express deliveries by the use of cargo bikes and a micro depot in Oslo city center. The algorithm used for the thesis is customized and improved to fit the specific research problem for this study. A set of KPIs are identified and studied to evaluate the impact of replacing vans with cargo bikes in a restricted area of Oslo. Thus, this study generates important knowledge about a new transportation mode for last mile logistics, which may be valuable in a local and national context.

1.7 Scope of Thesis

City logistics is a broad topic, thus some limits need to be set to narrow the topic and to answer the research question. This thesis focuses on last mile logistics in the city center of Oslo. DHL Express offers a broad range of services, however, point-to-point express deliveries is the main focus. Moreover, DHL Express specializes in the transportation of urgent documents, goods and packages; thus, the package sizes will be limited conventional for bicycle rides. Large packages and orders that exceed the capacity of vans are mainly distributed by trucks,

which this thesis will not cover. Lastly, the focus is on DHL Express' standpoint as sender and receiver have little power to change logistics activities or network structure.

1.8 Limitations

DHL Express' service portfolio consist of deliveries and pickups all over Oslo, however, due to the presumed difficulties of testing cargo bikes in the whole city, a restricted area of the city center was set for the project. Furthermore, there is only one micro depot, located at Filipstad/Tjuvholmen, Oslo. Other key limitations for this study are accuracy and availability of data for simulations. For example, volume of packages, order times for pickups, and real distances were estimated. Thus, the result of this thesis might be biased.

This study concentrates on simulations based on historical data limited to a time period of 10 months (January to October). The simulations focus on the current system using vans, and the pilot project using both vans and cargo bikes in the pilot area. Location decisions were made: this thesis does not study a situation where every van is replaced by cargo bikes in the whole city, rather it concentrates on a restricted area in Oslo, which limits the pilot area where cargo bikes are operating. In the former case, several micro depots would have to be located, which is beyond the scope of this thesis. Prior to the start of the pilot project, DHL Express illuminated a set of limitations that has been taken into consideration: (1) One bike replaces a van, (2) bike and van routes overlap, (3) total productivity are at least equal, (4) the distance has a maximum of 1 km per stop, and (5) design routes are based on weight and volume.

1.9 Thesis Structure

To get a holistic understanding of the thesis, the structure of the thesis is as follows: following the introduction, Chapter 2 provides a comprehensive literature review. Chapter 3 provides the research methodology used for this study to show how the research has been carried out. Chapter 4 presents the generation of routes in this study, followed by Chapter 5 that provides the simulation models for the current system and pilot project, and the results. In Chapter 6, a qualitative comparison between the two systems is discussed. Lastly, Chapter 7 gives the final conclusion of the thesis.

Chapter 2:

THEORY

2.0 Literature review

There are several case studies all over the world concerning the implementation of cargo bikes as a replacement for vans in urban goods deliveries. The literature has emphasized the importance of changing structure for last mile logistics. To date, there is no study that has examined this mode in the Norwegian context. This thesis seeks to address the existing gap in research on cargo bikes in Norway specifically in the case of Oslo. This chapter provides key literature on the field of this thesis.

2.1 City Logistics

The term city logistics is used to denote the specific logistic concepts and practices associated with congested urban areas, the "last mile" transport, with problems including delays caused by congestion, lack of parking space, close interaction with other road users, etc. (Munuzuri, Larraneta, Onieva, & Cortés, 2005). City logistics is an emerging field of study; it attempts to improve freight efficiency while minimizing both economic costs and social externalities (Dablanc et al., 2013). Taniguchi, Thomson, Yamadi, and van Duin (2001, p. 158) define city logistics as "the process for totally optimizing the logistics and transport activities by private companies in urban areas while considering the traffic environment, the traffic congestion and energy consumption within the framework of a market economy." Moreover, city logistics is based on general knowledge about issues including distribution costs, and social and environmental costs. Accordingly, the goal of city logistics is to reduce both and make the whole system more effective.

Schliwa et al. (2015), supported by Morana (2014) and Macharis and Melo (2011) suggest that city logistics may also be referred to as last mile logistics. Last mile logistics is explained as the last part of the traditional supply chain (SC) in an urban area. For many logistics companies, the first and last miles of a parcel's journey are of great concern (R. King, 2013). The last mile is considered the more expensive, least efficient and most polluting part of the entire SC (Gevaers et al., 2011). It accounts for 13 to 75 percent of the total logistics costs (D. A. King et al., 2014). Factors that affect these high proportions are due to inefficiencies, such as traffic (e.g. traffic jams, heavy congestion), and time spent on handling of goods at multiple locations (Aized & Srai, 2014). The last mile often hinders city

logistics and SCs in high-populated areas. For example, due to regulated traffic speed and intensity (e.g. rush hour, low emission zones, etc.), limited parking and unloading space (Aized & Srai, 2014). As freight vehicles are large in size relative to the narrow urban streets, parking and unloading often result in blocked pavements, bikes and vehicle lanes. Moreover, causing an increase in costs for the delivery services, for example from parking fines, and unsafe surroundings for pedestrians.

2.2 The Concept of Cargo Bikes

The concept of cargo bikes has existed for centuries, and has been around for almost as long as the bicycle itself. One of the first documented uses of cargo bikes for a logistics purpose was the use of pedal cycles for urban postal delivery in the late 1870s (Basterfield, Juden, Wood, & Barner, 2011). However, from the mid-twentieth century there was a market decline in the use of bicycles for urban deliveries of goods, due to factors as: greater availability of cars and vans, comparatively lower operating costs per unit carried of cars and vans, and the growing suburbanization of urban areas (Leonardi, Browne, & Allen, 2012). In contrast to the present, the focus was on speed; environmental issues was less of a problem at that time (Maes & Vanelslander, 2012).

A cargo bike, as known today, is a two or three-wheeled vehicle that is operated entirely by human power or with an electric assist (Kamga & Conway, 2013). Hence, it is a zero emission alternative to light freight vehicles, which are commonly powered by diesel engines (Saenz, Figliozzi, & Faulin, 2016; Schliwa et al., 2015). Electric cargo bikes can carry loads of varying weight and volume. Furthermore, cargo bikes with electric motors increase the load capacity, speed, and range (Lenz & Riehle, 2013; Rundberget et al., 2016). Cargo bikes can carry loads up to 250 kg, which makes them capable to manage a range of tasks and possibilities. However, the load capacity/transport characteristics depend on the type of bicycle used and the area of distribution. It follows that cargo bikes can provide the rising demand for point-to-point express deliveries in the city centers (Lenz & Riehle, 2013).

Previous studies have found that implementing cargo bikes as a new transportation mode, is a viable option for urban freight transport (Schliwa et al., 2015). However, there is lack of research into the use of cargo bikes within city

logistics (Decker, 2012; Gruber, Kihm, & Lenz, 2014; Lenz & Riehle, 2013). In light of this, Lenz and Riehle (2013) studied the experiences from 38 service providers in Europe that had implemented bikes for urban freight deliveries. Their research identified Western and Central Europe as the core areas of cycle freight (see Figure 1). In Scandinavia, they could only identify one single example, in Copenhagen. Most studies are limited to the European context as cargo bikes are more convenient to the narrow streets of old towns than to boulevards (Saenz et al., 2016). Chen (2014) studied the Asian compared to the European city logistic characteristics. For instance, street vendors that occupy street space typically characterize many Asian countries, which make the already congested roads even harder to get through. In Europe, however, old towns are featured with narrow streets causing difficulties for delivery vans to get into the urban area, whereas limited parking space forces loading and unloading activities to take place on streets and thus blocking traffic.

Figure 1: Distribution of example companies in Europe (Lenz & Riehle, 2013)

2.3 Changing Structure to Last Mile Logistics Using Bicycle

The last mile problem is regularly known as the triple-P problem: people (social), profit (economic) and planet (environmental) (Quak & Tavasszy, 2011). The social problem refers to traffic accidents, noise nuisance, visual intrusion, and local pollutants such as NOx and Particular Matter (PM) on public health. The economic problem refers to delivery inefficiency with low utilization of resources. The environmental problem contributes to global warming and greenhouse gas

emissions (Chen, 2014). In light of increased environmental and social externalities triggered by decades of heavy motorization, many cities in Europe are somehow "obliged" to move towards alternative methods with lower negative impact on the local environment (Wilmsmeier, Johansson, & Jallow, 2015).

Presently, the last mile logistics is dominated by motorized freight vehicles that generate significant negative effects on the urban environment and directly affect the city inhabitants' health (Iwan, Thompson, & Macharis, 2015). However, cities have an increased focus on implementing policies and smart logistic solutions aimed at improving urban quality, and reduce the city congestion and motorized transportation in the inner-city areas. Combined with land use and traffic constraints, these new policies have created conditions favorable to growth in the use of cargo bikes for last mile logistics (Gruber & Kihm, 2016; Kamga & Conway, 2013). The concept was first recognized in the UK as a method to mitigate the shortage of drivers for heavy trucks (Conway, Fatisson, Eickemeyer, Cheng, & Peters, 2012).

However, over the last decade, the use of cargo bikes has increased rapidly in European cities (Kamga & Conway, 2013). Europe is in the forefront in the development of cargo bikes as a last mile solution and many public and private initiatives have surged in recent years (Wilmsmeier et al., 2015). Authors such as Conway et al. (2012), Ducret and Delaître (2013), Gruber and Kihm (2016), and R. King (2013) investigated case studies from London, Brussels, and Paris. Furthermore, pilot projects in England (Leonardi et al., 2012), Spain (Navarro, Roca-Riu, Furió, & Estrada, 2016), Italy (Nocerino et al., 2016), and Brazil (Hagen, Lobo, & Mendonça, 2013) are examples of recent literature. Ranging from local freight forwarders to global players, these have realized that introducing cargo bikes as a last mile solution will not only relieve traffic congestion in cities, but also leads to increased efficiency and cost savings for companies since a large share of the delivery costs are found in the last mile of the SC (Wilmsmeier et al., 2015).

2.4 Advantages of Implementing Cargo Bikes

Previous studies have identified several advantages of cargo bikes compared to motorized options used for deliveries and pickups. The first is related to *reduce*

cost association with vehicles. According to a previous study in New York, a replacement with cargo bikes has the potential to lower the cost for carriers, which includes purchase, maintenance and running cost. Running costs are related to fuel, insurance, storage, parking and depreciation (Conway et al., 2012; Hagen et al., 2013). Second, while motorized vehicles (specifically heavy trucks) can cause significant damage to roads and bridges, requiring expensive maintenance procedures, cargo bikes incur *minimal infrastructure costs* (Hagen et al., 2013). Third, *the access for goods deliveries is most likely to increase*. Cargo bikes find on street parking much more easily than vans, and can also be parked on sidewalks, which often results in reduced delivery time (Iwan et al., 2015; Kamga & Conway, 2013; Navarro et al., 2016). Furthermore, during rush hours, bikes usually outperform motorized vehicles that are hindered by traffic (Conway et al., 2012). Fourth, *cargo bikes contribute to environmental benefits*. Cargo bikes emit zero greenhouse gases, which lead to significant emission savings (Iwan et al., 2015; Koning & Conway, 2016). According to a study in London, the reduction of CO_2 emission was estimated to be 62 percent per parcel (Hagen et al., 2013). The last advantage is related to *safety in urban areas* (Kamga & Conway, 2013). Kamga and Conway (2013) have, in the study of New York, claimed that reducing the number of heavy trucks and vans from urban areas will result in lower number of accidents of pedestrians and cyclists.

2.5 Disadvantages and Challenges of Implementing Cargo Bikes

Despite the numerous studies emphasizing advantages of implementing cargo bikes, many big logistics companies doubt the concept because of the perceived inefficiency and uncertainty of load capacities (Nocerino et al., 2016). Organizing deliveries using cargo bikes is, to a certain degree, dissimilar to traditional road transport deliveries due to the constraints related to the structure of the vehicles and their energy source which is usually manpower (Iwan et al., 2015). A challenge that has been recognized is bike messengers' age and physical health, which may impose constraints and limit the number of eligible workers. Increased labor costs due to more demanding tasks, as well as higher health insurance and benefits costs may also be essential. Furthermore, weather conditions and topography are challenges that may affect the feasibility of cargo bikes as a mode of last mile logistics; as such factors are not well adopted for cargo bikes in winter seasons or in hilly areas (Choubassi, 2015).

Transport for London (2009, cited in Gruber, Ehler & Lenz, 2013) conducted the first structured potential analysis of cargo bikes in urban transport. The analysis identified disadvantages in terms of security as one of the most important. Similar to Transport for London, Cyclelogistics (2015) emphasized security of bike and goods as the main risk that discourages businesses from shifting to this mode. However, results from interviews in the study by Lenz and Riehle (2013) implied that there were almost no reported cases of theft of cargo bikes or payloads. Businesses that already implemented cargo bikes as a mode of distribution revealed that safety is more of a concern rather than an actual risk. Moreover, factors such as limited range and payload, and driver fatigue were identified as the most important disadvantages (Lenz & Riehle, 2013; Transport for London, 2009)

In addition, an implementation of cargo bikes result in (the short term) a more complex and expensive logistic chain due to the introduction of warehouses or urban consolidation centers (UCCs) (Nocerino et al., 2016). The study by Verlinde, Macharis, Milan, and Kin (2014) exemplifies the latter. The project of study was TNT Express' adoption of the innovative concept of last mile logistics in Brussels, using a mobile depot. In this case they used a trailer fitted with a loading dock as a mobile inner city base. The project was tested for a three-month period and TNT Express succeeded in integrating the concept in their operational structure. A noteworthy finding was that the punctuality of deliveries were dropped from 95 percent to 88 percent, however, there were no complains by senders or receivers of this new concept. Moreover, the emissions of pollutants were dropped significantly. In the case of TNT Express, the mobile depot option resulted in more expensive costs, in contrary to many other studies conducted. The operation costs during the testing period were, in fact 2 times more expensive than the regular concept, which led to TNT Express' preferences of using vans (Verlinde et al., 2014).

2.6 The Vehicle Routing Problem (VRP)

The Vehicle Routing Problem (VRP) has been characterized as one of the great success stories of operational research by providing and facilitating optimal planning solutions for vehicle fleets in a large number of real-life applications. VRP can be described as the problem of determining least-cost routes from one depot to a set of geographically dispersed "customers", such as cities, stores,

warehouses, and private persons. VRP constitutes one of the most challenging combinatorial optimization problems (Bochtis & Sørensen, 2009).

Dantztig and Ramser formulated the first VRP problem in 1959 (cited in Cordeau, Laporte, Savelsbergh, & Vigo, 2007) and many studies and researches have been carried out since then. Moreover, several algorithms have been developed by different researchers to better solve this problem in different applications. Different variants of the basic problem have been put forward (see Figure 2), in addition to the development of numerous heuristics for VRP (Cordeau et al., 2007).
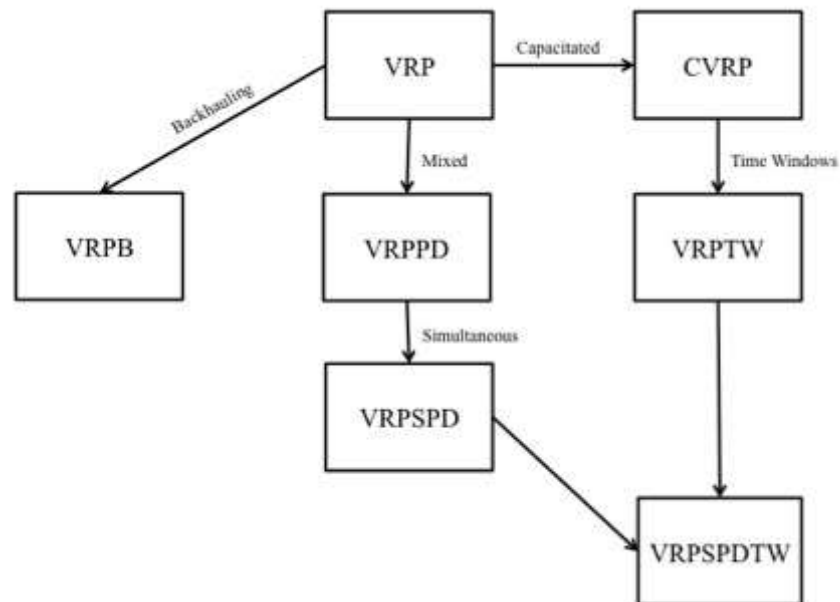
Figure 2: Common VRP subproblems

The VRP lies in the center of distribution management. This problem is encountered every day by thousands of companies and organizations engaged in the distribution of goods to customers, and delivery and pickup problems, for instance in express courier companies (Cordeau et al., 2007; Leung, 2004). Due to the varying conditions from one setting to the next, the objectives and constraints encountered in practice are highly variable. By building enough flexibility in optimization systems one can adapt these to various practical contexts (Cordeau et al., 2007).

Over the past few years, the VRP has been analyzed in many research studies. This problem asks; "what is the optimal set of routes for a fleet of vehicles to pass

17

through in order to deliver a given set of customers?" In many transportation, service and distribution systems, schedule of routes of a fleet of a certain number of vehicles through a set of customers is a key issue, due to the minimization of resources. Common examples are bank deliveries, postal and parcel deliveries, garbage collection, security patrol services and the food delivery industry (Esteruelas, 2016). Previous research has demonstrated how vehicle routing optimization can lead to significant economic savings. The study by Toth and Vigo (2002) suggested the potential of saving 5 to 20 percent on distribution costs, while Hasle and Kloster (2007, cited in Cattaruzza, Absi, Feillet, & González-Feliu, 2015) estimated between 5 to 30 percent.

The classical VRP (simply referred to as VRP) is defined with a single depot and only capacity and route length constraints. The VRP is one of the most popular problems in combinatorial optimization (Cordeau et al., 2007). The VRP aims to find a set of routes at a minimal cost (finding the shortest path, minimizing the number of vehicles, etc.), beginning and ending the route at the depot such that the known demand of all nodes is fulfilled. The solution of VRP need to satisfy the constraint that all the nodes are served only once, and by only one vehicle (Belfiore, Tsugunobu, & Yoshizaki, 2008). The majority of the real world problems are often much more complex than the classical VRP. In practice, the VRP is augmented by constraints, such as the capacity of vehicles or time interval in which each customer has to be served, which leads to the Capacitated Vehicle Routing Problem (CVRP) and Vehicle Routing Problem with Time Windows (VRPTW).

2.6.1 Capacitated VRP (CVRP)

The Capacitated Vehicle Routing Problem (CVRP) is known as the basic form of VRP, in which only the capacity constraints for the vehicles are considered and the objective is to minimize the total cost or length of the routes. Within the field of combinatorial optimization, CVRP is among one of the most studied problems and has served as a benchmark for almost all exact and heuristic solution techniques (Toth & Vigo, 2002).

According to Rizzoli, Montemanni, Lucibello, and Gambardella (2007), an important prerequisite for CVRP is that customer demand is deterministic and known in advance, in addition to a fleet of homogeneous vehicles. The CVRP

consist of determining a set of vehicle routes satisfying the following conditions (Belfiore et al., 2008; El Hassani, Koukam, & Bouhafs, 2008):

- Each route starts and ends at the depot
- Each customer is visited by exactly one vehicle
- The total demand of each route does not exceed the vehicle capacity
- The total "cost" of all routes is minimized

2.6.2 VRP with Time Windows (VRPTW)

The Vehicle Routing Problem with Time Windows (VRPTW) is an extension of the CVRP (Cordeau, Desaulniers, Desrosiers, Solomon, & Soumis, 2000). Moreover, it is a generalization of the VRP where the service at any customer starts within a given time interval and ends at the depot (Kallehauge, Larsen, Madsen, & Solomon, 2006). Cordeau et al. (2000) supported by Kallehauge et al. (2006) distinguish between soft and hard time windows, where the former case can be violated at a penalty cost, whilst the latter does not allow for violation, hence, a vehicle to arrive at a customer no later than the latest time to start the service. In this context, hard time windows are often the most considered approach in the literature. Knight and Hofer (1968) was the first to examine the VRPTW, which is explained as the problem in which "the service at each customer must start within an associated time window and the vehicle has to remain at the customer location during service" (Cordeau et al., 2000, p. 1). Toth and Vigo (2002) point out that capacity constraints are set and each customer i is connected to a time interval $[a_i, b_i]$, i.e. a time window. In addition, the travel time t_{ij}, and service time s_i for each customer is set. This type of problem is encountered in several fields, such as the service sector, including bank deliveries and postal deliveries (Desrosiers, Dumas, Solomon, & Soumis, 1995).

2.6.3 VRP with Pickup and Delivery (VRPPD)

The classical VRP only concerns one type of demand: pickup or delivery. If both pickup and delivery are present, specific routing policies for each particular context must be defined (Montané & Galvao, 2002). The VRPPD is an extension of the VRP. The objective function to this problem is to minimize total driving distance, subject to maximum distance and capacity constraints. The VRPPD is considered NP-hard since it generalizes the classical VRP (Nagy & Salhi, 2005).

Various routing problems with pickup and delivery service are studied in the literature. For example, Savelsbergh and Sol (1995) examine several characteristics of pickup and delivery problems, and present a generalized model that can manage practical complexities of various VRPs. Nagy and Salhi (2005) classify VRPPD literature into three categories:

(i)   Simultaneous Pickup and Delivery (VRPSPD)

(ii)   Mixed Pickup and Delivery (VRPMPD)

(iii)   Pickup can only occur after delivery (Delivery-first, Pickup-second VRPPD)

There are numerous literatures on the VRPPD that cover (iii). However, results from this method are considered to have poor quality (Nagy & Salhi, 2005). Furthermore, few papers deal with (ii). This problem is also referred to as the Vehicle Routing Problem with Backhauling (VRPB). The study of Golden, Baker, Alfaro and Schaffer from 1985 is based on the insertion of pickup (backhaul) customers into the routes formed by delivery (linehaul) customers (Nagy & Salhi, 2005). The next section examines (i).

2.6.4 VRP with Simultaneous Pickup and Delivery (VRPSPD)

The VRP can be classified based on type of demand and how this demand is fulfilled. Vehicle Routing Problem with Simultaneous Pickups and Deliveries (VRPSPD) is an extension to the VRPPD and involves customers who may require two kinds of demands simultaneously (Montané & Galvao, 2002). VRPSPD was first introduced in the study by Min in 1989. The study solved a practical problem of transporting books by a public library, consisting of one depot, two vehicles and 22 customers. To model the VRPSPD, a customer can be seen as two entities: a pickup and a delivery to give a mixed formulation (Nagy & Salhi, 2005). Customers may either be visited once for both pickup and delivery service or twice, one for pickup and one for delivery service (Montané & Galvao, 2006). As stated by Nagy and Salhi (2005) serving pickups and deliveries simultaneously may lead to challenges due to rearrangements of goods during the route.

Montané and Galvao (2002) formulated a mathematical formulation to solve the VRPSPD. The formulation is presumed that each customer has both pickup and delivery demands. The objective function aims to minimize the total driving

distance. The constraints ensure that each vehicle leaves the depot with a volume equal to the sum of the delivery demands of the customer in the route serviced by that vehicle, and that each vehicle returns to the depot with a volume equivalent to the sum of the pickup demands of the clients in the same route.

To solve the VRPSPD problem, Min (1989) suggested a cluster-first-route-second approach; "the customers were first clustered into groups and then in each group the travelling salesman problems (TSPs) were solved. The infeasible arcs were penalized (their lengths set to infinity), and the TSPs solved again" (Nagy & Salhi, 2005). Halse (1992) studied a set of various VRPs, such as the VRPPD. Similar to Min (1989), he solved the problem using the cluster-first-route-second approach.

Many heuristic algorithms for VRPSPD are variations of heuristics for classical VRP. Montané and Galvao (2002) are examples of researchers who extended two heuristics procedures for the classical VRP. These were a Tour Partitioning heuristic and an adaption of the Gillet and Miller's Savings Algorithm from 1974. The Tour Partitioning heuristic groups customers based on a traveling salesman tour, which is partitioned in sequential manner. Once the groups of customers are formed, the routing of each group is performed by solving a Traveling Salesman Problem with Simultaneous Pickup and Delivery (TSPSPD). However, the restriction of pickup and delivery capacity must be satisfied. The tour partitioning is repeated for different starting nodes, with the aim to improve the quality of the solution. Gillet and Miller's Savings Algorithm groups customers based on their polar coordinates. The routes are formed sequentially and customers can be added or removed from the current route if this result in a weakened value of the objective function. In the case of VRPSPD, the groups of customers are formed first, and then solving TSPSPD performs each group routing (Montané & Galvao, 2002).

2.6.5 VRP with Time Windows and Simultaneous Pickup and Delivery (VRPSPDTW)

Several problems in logistics can be modeled as a pickup and delivery problem with time windows (PDPTW) (Savelsbergh & Sol, 1995). In the PDPTW, all transportation demand has a pickup and delivery point (depot) and the fulfillment of service at these points have to be performed within a given time window (Lu &

Dessouky, 2006). Due to the growth in demand for express delivery, Lin (2008) studied a VRPTWPD to determine resource requirements and daily routing of a local courier service of a multinational logistics company. In his study, two time window constraints were present: document pickup at the customer site and delivery to the depot to meet the flight departure time (Lin, 2008). The objective was to find the minimum cost solution to service all customers and satisfy the time window constraints.

In Angelelli and Mansini's (2002) study on the Vehicle Routing Problem with Time Windows and Simultaneous Pickup and Delivery (VRPTWSPD), they examine the problem regarding one depot distribution/collection system that service a set of customers. Moreover, each customer demands two types of service: pickup and delivery. The characteristics of this problem is that both services must be carried out simultaneously by the same vehicle, and each customer must be serviced within a given time window (Angelelli & Mansini, 2002). This problem is a generalization of the VRPTW as each customer demand simultaneous delivery and pickup. Due to the problem being NP-hard, heuristic algorithms is used to solve large sized problems (Savelsbergh & Sol, 1995).

Cordeau et al. (2000) formulate the VRPTW as defined on the graph $G = (V, A)$ where the depot is represented by the two nodes 0 and $n + 1$. Implying that all feasible vehicle routes correspond to paths in G that start from node 0 ("starting depot") and end at node $n + 1$ ("returning depot"). V represents a set of customers or fleet of homogeneous vehicles, and A represents a set of arcs, i.e. direct connections between the depot and the customers and among the customers (Kallehauge et al., 2006). Moreover, each arc (i, j), where $i \neq j$, related *cost* (distance) c_{ij} and *time* (duration) t_{ij}, may include service time at customer i (it is assumed that the travel cost of vehicles are proportional to the driving distance). Each vehicle has a capacity Q and each customer i a delivery demand d_i or pickup demand p_i. A "net delivery" problem, i.e. $p_i < d_i$ $\forall i$, implies that the optimal solution corresponds to the solution of VRP defined on the same graph G where each customer only demand delivery. Similar remarks hold for a "net pickup", i.e. $p_i > d_i$ $\forall i$ (Angelelli & Mansini, 2002). The time window $[a_o, b_0]$ represent the *scheduling horizon*. This means that the vehicles cannot leave the depot before a_0 and return at the latest time b_{n+1}. A solution is a set of at most K routes with start and end point at the depot, whereas all customers are serviced exactly once and

time window and capacity constraints are satisfied (Angelelli & Mansini, 2002). The objective is to minimize total driving distance by all the vehicles. The mathematical formulation is in Appendix 2.

2.7 Solution Methods for VRP: Heuristic Algorithms

The VRP is explained as a NP-hard combinatorial optimization problem where only small instances of the problem can be solved precisely (Belfiore et al., 2008). Subsequently, Kallehauge et al. (2006) state that the VRPTW has become an invaluable tool in modeling a variety of aspects of SC design and operation. They explain, however, that there has been a significant progress in both the design of heuristics and development of optimal methods. Conclusively, a variety of heuristics have been described in the literature.

Cordeau, Gendreau, Laporte, Potvin, and Semet (2002) distinguish between classical heuristics and metaheuristics. The classical heuristics, such as the *Savings Algorithm*, *Sweep Algorithm*, and *Fisher and Jaikumar Algorithm*, has the emphasis to find a feasible solution quickly and apply it to a postoptimization procedure. However, later studies have directed towards an expansion of algorithms based on *metaheuristics*, which is based on the two principles: *local search* and *population search*. The focal point of the former method is to explore the solution by moving at each step from the current solution to another promising solution in its neighborhood. Example of this method is *simulated annealing* (SA) and *TABU search* (TS). The latter method consists of maintaining good (core) solutions that can be revised. The *genetic search* (GS) is a classical example. Moreover, metaheuristics are capable of produce consistent, high quality solutions (Cordeau et al., 2002).

However, Cordeau et al. (2002) argue that most of the available VRP heuristics lack necessary attributes to ensure quality. They present four fundamental attributes for implementing good vehicle routing heuristics, including accuracy, speed, simplicity, and flexibility. *Accuracy* means to measure "the degree of departure of a heuristic solution value from the optimal value" (Cordeau et al., 2002, p. 513). There are some issues related to this approach, including decimal rounding, consistency, and quick (good) solutions. A rule of thumb is to use a heuristic that perform well all the time rather than occasionally. *Speed* is essential

at the planning level of problem solving, and for the degree of accuracy. The authors argue that several VRP heuristics are excluded because they are too complicated, i.e. include too many parameters, and are hard to code. *Simplicity* is therefore important for the heuristic method to make sense to the end-user. The last attribute includes algorithmic *flexibility*. The authors argue that a good heuristic must be flexible enough to accommodate the different side constraints detected in a majority of real-life applications (Cordeau et al., 2002).

2.7.1 Clarke and Wright's Savings Algorithm

The Savings Algorithm of Clarke and Wright (1964) is the most widely applied heuristic of the VRP (Osman, 1993). This is due to its simplicity of implementation and efficient speed of calculation (Pichpibul & Kawtummachai, 2012). The concept is based on computation of savings for combining two customers into the same route (Pichpibul & Kawtummachai, 2013). The goal of the algorithm is to determine the allocation of customers among routes, determine the sequence in which the customers are visited on a route, and which vehicle should cover that route. The overall objective is to minimize the total transportation costs (Mirshekarian, Celikbilek, & Süer, 2015).

2.7.2 Gillet and Miller's Sweep Algorithm

There are numerous papers found in literature addressing the VRPs (Nurcahyo, Alias, Shamsuddin, & Sap, 2002). An extensive amount of different heuristic algorithms have been developed to route vehicles. One of the simplest algorithms is the Sweep Algorithm proposed by Gillett and Miller (1974). In comparison to other approaches which attempt to solve the VRP as one big problem, Sweep Algorithm divides the nodes into a set of routes and then operates on the individual routes until an optimum or near-optimum solution is acquired (Gillett & Miller, 1974). Feasible routes are constructed by rotating a linear ray, centered at the depot and gradually including customers in a vehicle route until the capacity or route length constraint is reached. A new route is then established and the process is repeated until the whole plane has been swept (Cordeau et al., 2002). The Sweep Algorithm is a heuristic based on a set of constraints where the number of nodes generated in a route relies upon the capacity given to every node (Nurcahyo et al., 2002). The Sweep Algorithm is based on two phases, clustering and route generation, which is often referred to as the cluster-first-route-second approach. In the first phase, customers are clustered by their polar coordinates

with the depot in the origin of the coordinate system (Belfiore et al., 2008). In the second phase, the routes are constructed sequentially and customers are added or removed from the current route, based on Nearest Neighbour heuristics, if it reduces the value of the objective function (Montané & Galvao, 2002).

2.7.3 Cheapest Insertion Heuristic

There are different types of heuristics to solve VRP. One heuristic aims to construct "good" route from scratch, namely the Sweep Algorithm, which have been described in section 2.7.2. Another heuristic is Cheapest Insertion, which provides a different set of route generation heuristics. The method begins with a route connecting two of the nodes, and then adds the remaining nodes one by one, in such a way that the route cost, in terms of total distance, is increased by a minimum amount. The insertion of nodes is implemented for each cluster where all the feasible nodes are tested in all position in the route. Subsequently, an unvisited customer is inserted into two visited customers in the route at the shortest distance, and the process continues until no additional nodes can be feasibly inserted. The node for insertion is the one that increases the existing route distance the least (Jing Fan, 2011; Cook, Cunningham, Pulleyblank, Schrivjer, 1997).

Chapter 3:

RESEARCH

METHODOLOGY

3.0 Research Methodology

In this chapter, the focus is on the research methodology that is used in the collection of material and data in this study. Bryman and Bell (2015) states that a research method is a technique for collecting data. This chapter is organized as follows: it starts by an introduction of the DHL Express case study, followed by a discussion on the research strategy, design and method appropriate for the research area. Thereafter, the conceptual model, scientific model, and key performance indicators are presented, followed by a description of the data collection, quality of research, and social and ethical consideration. In conclusion, the objective of data analysis is discussed.

3.1 DHL Express Case Study

DHL Express is specialized in providing international courier and express delivery and pickup services, to both business customers and private costumers. The delivery process is usually twofold: critical deliveries, i.e. before-12-deliveries, and timed, i.e. throughout-the-day deliveries. Critical deliveries constitute a smaller part of DHL Express' portfolio, including special goods such as blood samples and other biomaterials to hospitals, veterinarians and dental clinics, or express documents. These are usually fixed daily deliveries. DHL Express currently uses eight delivery vans from service partners, which corresponds to eight delivery routes in Oslo. These vans depart from the main terminal at Berger in Skedsmo Municipality, between 9AM and 10AM, and return when all loaded goods are delivered and pickups are fulfilled, or other time windows are reached. The loaded goods consist of both critical and timed deliveries, thus, the driver must have a priority order for deliveries.

DHL Express divides the areas of Oslo into carrier routes, dependent on ZIP-codes. The majority of DHL Express' customer base is medium sized businesses in the city center and constitutes a regular customer segment that has fixed packages/documents or shipments in and out of the country. It is on average 100 deliveries and pickups per day per van. Smaller firms receive more sporadic deliveries in terms of smaller packages, e.g. mobile phones. However, the dominating part of delivery is documents, which represents 50 percent of all deliveries. On the outskirt of Oslo, most deliveries are to private individuals and consist of small packages such as gadgets and phone cases. This home delivery

segment has grown in recent years and constitutes for approximately 35 percent of total deliveries.

DHL Express' motivation for implementing cargo bikes is the increasing demand for sustainable solutions. Furthermore, Oslo Municipality and the City Council are establishing new regulations to get a "greener" city center to increase urban life. A pilot project of a car-free city center is introduced Summer 2017 and will be implemented continuously until 2019 (Oslo Kommune, 2017). New regulations and decisions will limit the amount of cars in the city center. The cityscape is altering in terms of infrastructure, parking opportunities, such as less parking space and more biking lanes. As of June 1st 2017, all street parking within Ring 1 is removed (Nordli, 2017). City activities and parking for warehousing, craftsmen, and disabled parking space (HC-parking) will take over all public parking spaces in the pilot areas.

Pilot areas 2017 (Oslo Kommune, 2017), see Illustration 2:
1. Parts of Upper and Lower Slottsgate – Summer 2017
2. Fridtjof Nansens plass, Roald Amundsens gate, and Kjeld Stubs gate – Summer 2017
3. The area outside of UngInfo in Møllergata – Summer 2017
4. Kongens gate - South – Autumn 2017
5. Kongens gate - North – Autumn 2017
6. Tordenskiolds gate and Rosenkrantz gate – Autumn 2017

Illustration 2: Car-free city center 2017 (Oslo Kommune, 2017)

A depot in terms of a 25-foot container (see Illustration 3) is located in the city center at Filipstad/Tjuvholmen, Oslo. The pilot project officially opened June 8th 2017. It is assumed that vans will drive two to three laps per day from the terminal at Berger in Skedsmo to the depot to fill up with goods. For the pilot area, three cargo bikes are implemented and have the same function as the vans they replace. The total number of bike returns to the depot will depend on the weight and volume of the goods, including the pickups. However, it is assumed three returns with five to six stops per trip, and maximum 1 km between each stop. The cargo bikes are built with two loading containers, one in the front and a trailer in the back, with a capacity of three boxes of 60*80*30cm. The loading container in the back can easily be attached and detached to the cargo bike. The boxes of goods have wheels that make it easy to load and unload the bike. The pilot project will only be implemented in a restricted area in the city center of Oslo, more specifically within Ring 1 and a small part of Ring 2 (see Illustration 4). This means that the pilot project covers 3 of 8 routes/areas.

Illustration 3: Micro depot at Filipstad/Tjuvholmen, Oslo (photo by Anne Marthe Kjønnø, 2017)

Illustration 4: Route map for the pilot project in Oslo 2017

3.2 Research Strategy

The research strategy is a general orientation on how to execute the business research (Bryman & Bell, 2015). It is often divided into quantitative and qualitative research. The difference between them are superficial, however, essential to get a better understanding on how to classify the research methods when collecting, analyzing and deducting the data. Both aspects are presented in the following subsection.

Newman and Benz (1998) claim that the most common purposes of qualitative research are theory initiation and theory building, while the most common objectives of quantitative research are testing and modification of theory. Quantitative research focuses on data collection in terms of quantification and measurements, i.e. represented by numbers. By contrast, qualitative research emphasizes words when collecting and analyzing data (Bryman & Bell, 2015; Onwuegbuzie & Leech, 2005). The latter approach is preferred when observing a real situation, relatively to evaluating theory.

This thesis is primarily quantitative. Bertrand and Fransoo (2002, p. 242) claim that quantitative modeling in operations research (OR) plays an important role when solving real-life issues in operations management (OM). The authors describe quantitative model-based research in OM as "based on a set of variables that vary over a specific domain, while quantitative and causal relationships have been defined between these variables." They explain that the model-based OM research can be divided into two distinct classes: axiomatic and empirical

research, which can further be divided into descriptive and normative research (Bertrand & Fransoo, 2002).

The axiomatic quantitative research is mainly driven by the (idealized) model itself, and was introduced by Meredith et al. in 1989 (Bertrand & Fransoo, 2002). This model obtains solutions within the defined model, and ensures that these solutions provide insights to the structure of the problem as defined in the model. The normative research is mainly concerned with developing policies, strategies, and actions, to improve the results that already exist in the literature to find an optimal or good solution for a newly defined problem, or to compare various strategies to address a specific problem. The descriptive research is interested in analyzing a model that leads to an understanding and explanation of the characteristics in the model. The second class of model-based research is mainly driven by empirical findings and measurements. In this case, the main concern is to assure that there is a model fit between observations and actions in reality and the model made of that reality. However, this type of research has not been very productive, in contrast with the former approach.

An axiomatic (normative) quantitative research model was developed to develop good simulations for the research problem. Moreover, heuristic techniques were implemented. This study is based on quantitative data related to the existing delivery and pickup system. This includes historical data on routes, ZIP-codes, activity date, delivery and pickup, weight, activity time, closing time, and coordinates. The developed models for the current system and pilot project are applied to simulate good solutions to the stated research problem. The simulation measures a set of KPIs in order to measure the productivity and environmental impact of DHL Express' deliveries and pickups, and to compare the two systems on equal terms. An algorithm was developed to generate routes for the current system and pilot project, respectively, in order to minimize total driving distance.

In addition, the quantitative data is complemented by the conduct of qualitative research. Both quantitative and qualitative research techniques are necessary to get a complete understanding of the problem statement (Johnson & Onwuegbuzie, 2004; Newman & Benz, 1998). The qualitative research consists of a comparison of the two distribution systems for DHL Express: vans versus cargo bikes. Literature and previous studies is used as a basis, in addition to the qualitative tool

in terms of a SWOT analysis. The researchers attended two separate delivery and pickup routes with vans, which both made it possible to have a semi-structured interview with the chauffeurs, and to observe a real delivery and pickup process. The driver's knowledge and experience gave the researchers valuable information about the performed tasks and its practice. Communication with other important contributors from both participating parties (TØI and DHL Express) was also performed.

The decision of a research strategy alone is inadequate for the business research if it is not linked to the research design and method. This is outlined in the next section.

3.3 Research Design and Method

The research design is a general plan that the researcher uses to answer the research question (Saunders, Lewis, & Thornhill, 2009). This plan provides a framework for the collection and analysis of data, and should reflect prioritized decisions given a range of aspects of the research process (Bryman & Bell, 2015). The objective of thesis and research question should guide the researchers to choose a proper research design.

3.3.1 Research Design

This thesis has a case study design. The term "case study" is generally applied in OM as descriptions of conduct of new methods. A case study is defined as an objective, in-depth examination of current experiences where the researcher has little control over behavioral events (R. K. Yin, 2014). The purpose is to describe a situation, and understand how or why events occur. This design type often engages researchers to gather an extensive volume of data to develop a clear picture of the experience. Data may come from both primary and secondary sources. Moreover, case study research focuses on existing conditions, such as using historical data to understand the information collected about the ongoing situation. The researchers should not have any capability of manipulating the events (McCutcheon & Meredith, 1993).

To compare the results from the two systems, simulation method and qualitative analysis is conducted. For the simulation of the pilot project, only a limited area is chosen. The VRPTWSPD is solved for the simulations to decide which routes to

follow, and it is assumed to use the same method for routing for the current system and pilot project. However, the VRPTWSPD is not central in this thesis. Moreover, the algorithm used for simulations could be improved, and order time is only an estimation of real time, however, the focus is to compare the use of cargo bikes with vans.

3.3.2 Research Method

The method of the thesis is based on the conceptual framework developed by Mitroff, Betz, Pondy, and Sagasti (1974). This framework describes the phases of problem solving in an OR process, to help making better decisions. The four phases of the model contain: (I) Conceptualization, (II) modeling, (III) model solving, and (IV) implementation. The complete problem-solving process is presented in Figure 3.
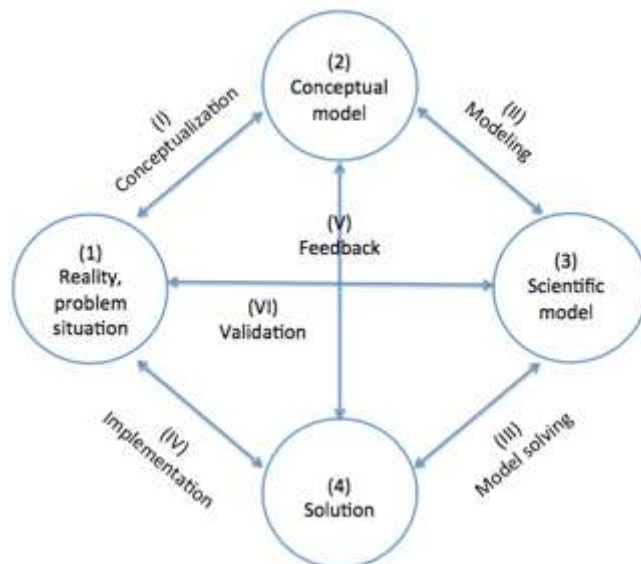
Figure 3: Framework of Research Method (Mitroff et al., 1974)

The *conceptualization* phase involves formulating a conceptual model of the problem situation that is studied. The conceptual model should include a definition of the specific problem to be solved, and the variables that are used to define the problem. The next phase, *modeling*, starts once the conceptual model is defined. This phase focuses on forming a scientific model, and then derives a solution, if one possible. For this thesis research, a mathematical model (see Appendix 2) is formulated, derived from relevant theory and variables from the previous phase. Winston and Goldberg (2004, p. 1) describe a mathematical model as "a mathematical representation of an actual situation that may be used to make better decisions or simply to understand the actual situation better ".

The scientific model is used to solve the problem in the third phase. The study constitutes of two parts that underlies the *model-solving* phase. In this phase, heuristic techniques are applied to find a good solution to compare the current system and pilot project. Furthermore, simulations are performed to achieve results for comparison to determine the degree of efficiency the change in DHL Express' current logistics system gives. In the first part, a quantitative method in terms of simulation of the current system is conducted. The programming language Octave is used to program and code the simulations. The simulation is based on historical data from the previous year given by DHL Express. It illustrates deliveries and pickups using vans in the municipality of Oslo. The analysis of the simulation is used to compare with the second part of the study. In the second part, simulation of the pilot project is executed. The historical data in the first part is applied in the second part, respectively. This simulation is designed for deliveries and pickups with cargo bikes in the areas applicable for the pilot project, and vans for the remaining areas. The pilot project starts June 8th 2017 and terminates June 30th 2019.

The results from simulations of current system and pilot project are compared to evaluate the performance of cargo bikes as supplement for vans. Hence, to have a justified comparison of the pilot project, simulation of the current system is performed. Furthermore, a set of key performance indicators (KPIs) is identified, and a qualitative analysis of the current system and pilot project is included to compare the two systems and strengthen the validity of this study. The latter is based on literature and studies from other countries, and the qualitative tool in terms of a SWOT analysis.

Phase four involves *implementation* of the solution found from model solving phase. Given that the solution provides improved results, this is conducted in the implementation phase. However, this phase has not been carried out in this thesis as the pilot project terminates June 2019.

The framework also involves two additional phases: feedback (V) and validation (VI), on a vertical and horizontal axis respectively. The former implies a simultaneous process that helps finding a good model to the problem situation by feedback. The latter indicates the correspondence between reality and the

scientific model. The path between the two phases highlights the importance of validity, thus, it is significant to maintain a high level correspondence (Mitroff et al., 1974).

3.4 Conceptual Model

The first phase of problem solving involves formulating a conceptual model of the problem situation that is studied (Mitroff et al., 1974). Robinson (2008, p. 283) defines a conceptual model as "... a non-software specific description of the computer simulation model, describing the objectives, inputs, outputs, content, assumptions and simplifications of the model". Which implies that the conceptual model is an abstraction of the simulation model, or a simplification of "reality" (Robinson, 2011).

3.4.1 Objectives

This thesis addresses the following objectives: (1) minimize the total driving distance, hence transportation cost, while satisfying time window and capacity constraints, (2) compare service level of cargo bikes as a supplement for vans, and (3) environmental impact.

3.4.2 Input

To generate routes planning for vans and cargo bikes based on simulations, a set of input parameters are required. This makes the process flexible to endure various circumstances. These parameters include: ZIP-codes, activity date, type (delivery/pickup), weight, activity time, closing time, coordinates, urgency (critical/timed delivery), order time for pickups, due time, product type, and customer type (business/private). Furthermore, number of vans and cargo bikes, capacity, and time windows such as working hours, opening hours, and time of return to depot.

3.4.3 Output

For the simulations, the solution algorithm is performed to give good feasible delivery routes in terms of fulfillment of demands within the time windows and capacity constraints. In this case, time windows are soft constraints, which means that delays can occur, however, avoided to the extent it is possible. Capacity is considered a hard constraint and cannot be violated. The considered outputs generated from the simulation models are: total number of pickups and deliveries, total driving distance, capacity utilization, on-time deliveries/pickups and delays.

Considering the environmental impact, calculations of total CO_2 emissions is based on total driving distance and the amount of CO_2 emitted per km for a similar van to DHL Express.

3.5 Scientific Model for Decision Making

As previously stated, OR is a part of the quantitative research in OM (Bertrand & Fransoo, 2002). Winston and Goldberg (2004, p. 1) define OR as "a scientific approach to decision making that seeks to best design and operate a system, usually under conditions requiring the allocation of scarce resources". OR mainly focus on improving operations in logistic processes, especially in terms of minimizing costs (Dekker, Bloemhof, & Mallidis, 2012). The scientific approach often involves the use of mathematical models. OR provides several techniques to model and analyze the performance of logistics processes. Optimization, heuristics and simulation are common examples of quantitative techniques for OR modeling (Gopal & Cypress, 1993; Maloni & Benton, 1997). In the following sections, optimization and simulation are described further.

3.5.1 Optimization

Hillier and Lieberman (2010) explain that after defining the problem of the decision maker, the next step is to reformulate the problem to a form that is convenient for analysis. In the case of an OR, this implies to formulate a mathematical model that represents the essence of the problem. According to Winston and Goldberg (2004), optimization models aim to detect values of the decision variables that optimize, by either maximize or minimize, an objective function among a set of values in the decision variables that satisfy the given constraints. Optimization models are linked to the process of finding the optimal solution based on the usage of one or several mathematical models, and the elements included are explained by the following (Hillier & Lieberman, 2010; Winston & Goldberg, 2004):

- The objective function is the appropriate measure of performance expressed in a mathematical function of decision variables, e.g. maximize profit or minimize cost.
- Decision variables are a set of quantifiable decisions, whose respective values are under the researcher's control and impact the performance.
- Constraints are limitations on the values of the decision variables.

In this thesis, two models are developed to find good solutions for the delivery and pickup process of DHL Express, in terms of the current system and pilot project.

3.5.2 Simulation

Smart logistics solutions have been developed to reduce the negative impacts of increasing transportation of goods in urban areas. However, the effectiveness of these measures can be questioned if negative impacts during or after solution implementation are not considered. Simulation is recognized as the second most used technique in the field of OM (Karakikes, 2016; Pannirselvam, Ferguson, Ash, & Siferd, 1999), and seen as a decision support tool in logistics at strategic and operational level (Tako & Robinson, 2012). According to Robert E. Shannon (1975, cited in Ingalls, 2002, p. 7), simulation is defined as "the process of designing a model of real system and conducting experiments with this model for the purpose of understanding the behavior of the system or of evaluating various strategies for the operation of the system". Simulation allows for comparison of effects from different solution approaches prior to the practical implementations (Karakikes, 2016).

Simulation usually complement optimization models as they can check various scenarios to identify the best solution (Karakikes, 2016). Simulation consists of a variety of methods due to the ability to consider all relevant characteristics and challenges of the real system, and has been proved to be a valuable tool to model problems related to planning, delivering and evaluating the contribution of urban freight transport to urban mobility and environment (Karakikes, 2016; U TURN., 2015).

Ingalls (2002) differs between "MRP simulation" and discrete-event simulation. MRP simulation is a model, i.e. a copy, of the real system on which scenarios can be run to evaluate various strategies, such as how to respond to a drastic change in the forecast. Discrete-event simulation gives the ability to mimic the dynamics of a real system, which many models such as optimization models cannot take into account (Ingalls, 2002). Discrete-event simulation utilizes the computational and mathematical techniques to quantitatively represent the real world, simulate its dynamic on an event-by-event basis, and creates comprehensive performance report (Babulak & Wang, 2010).

In this thesis, the simulation is part of the model solving phase, where heuristic techniques is used to find a good solution to compare the current system and pilot project. Simulation is used to determine the effect of changing DHL Express' current delivery system.

3.6 Key Performance Indicators

To determine whether an implementation of cargo bikes is beneficial or not, a set of KPIs is identified to evaluate the overall impact of cargo bikes on productivity and the environment (González, Herrero, & León, 2015; Li et al., 2016; Perboli, Rosano, & Gobbato, 2016), see Table 2. These KPIs assist in defining the best measure to success and progression in the simulation models for both the current system and the pilot project.

Productivity	Environment

-Total number of deliveries and pickups
  • Per day
  • Per 10 months
- Total driving distance (km)
  • Per day
  • Per 10 months
- Average capacity utilization
- Service level:
  • Number of on-time deliveries and pickups
	CO_2-emissions:
	  • Per 10 months

Table 2: Key Performance Indicators

3.7 Data Collection

The data collection consists of a combination of primary and secondary data to increase the likelihood of answering the research question, and for evaluating the extent to which findings may be trusted and inferences made (Saunders et al., 2009). Data from the current system and the pilot project form the foundation of the data collection, and is the basis for assessing productivity and the environmental impact for DHL Express. It is essential to identify all relevant parameters and ensure access to relevant data (Bryman & Bell, 2015).

The pilot project for this thesis was delayed during the process (starting June 8th 2017) of writing the thesis. Thus, primary data and historical data have been used as a basis to perform simulations. The methods utilized to gather data would be described and justified in the next sections.

3.7.1 Secondary Data

Secondary data is defined as data that already have been collected for some other purposes, and include raw data, compiled data (i.e. data that have received some form of selection or summarizing) and published summaries. Within business and management research, these types of data are used most frequently as part of a case study (Saunders et al., 2009). On the one hand, secondary data leads to cost and time savings for the researcher. On the other hand, it may have some disadvantages such as outdated or incorrect data.

DHL Express provided the majority of secondary data. The main dataset consists of historical data from 2016, including all pickups and deliveries and the corresponding weights. However, the dataset also contained some errors and missing data that required assumptions to be made in order to fulfill the simulations, see Attachment 1 sheet "Information" for a complete list of assumptions. Furthermore, data regarding ZIP-codes relevant for the pilot-area and information about vehicle capacities were obtained. These data were used as a basis for simulating deliveries and pickups for the current system and pilot project.

3.7.2 Primary Data

Primary data collection is vital to enhance the possibility of success of the thesis. Due to the uncertainty in the quality of the secondary data (Saunders et al., 2009), and the incapability to provide a holistic overview of the situation on its own, additional interviews with relevant actors from DHL Express were performed. These data were related to the operating perspective, for instance sudden changes of routes, additional deliveries, capacity utilization, etc.

3.7.2.1 Distances and Speed

For the purpose of simulations, the following primary data were obtained using Google Maps:

- Measuring real driving distance between nodes: These data were obtained to get an approximately equal distance to reality.
- Estimation of average driving speed (kmph).

3.7.2.2 Interview and Observation

To get an insight of the daily operation and assess the performance of deliveries and pickups by vans, the researchers participated and observed a delivery tour for

two separate routes, namely Skøyen – Solli and Majorstua – Frogner – Grünerløkka. Another purpose of the tour was to assess whether the composition of packages/documents during the route was suitable for cargo bike distribution. An important evaluation was to consider the performance of cargo bikes as supplement for vans. During the tour, semi-structured interviews (Appendix 3) with the two DHL Express chauffeurs were performed.

3.7.3 Input Data

The input data is used as input for the simulation models, and is elaborated in detail in Chapter 4: "Generation of Routes". In the following sections a brief discussion of the input data is presented.

3.7.3.1 Stop, Route and Delivery Data

The routes for delivery and pickup for DHL Express vary from day to day depending on the volumes of packages and documents. However, the relevant route-areas of distribution for vans and cargo bikes are given. Regarding vans, the whole area of Oslo is taken into consideration, whereas cargo bikes were limited to the areas within Ring 1 and a small part of Ring 2.

3.7.3.2 Capacity

DHL Express currently utilizes eight delivery vans. These are standard vehicles that are used for deliveries and pickups in Oslo, and have a capacity of $14m^3$. In the first phase of the pilot project, three cargo bikes and five vans are used. The cargo bikes consist of two loading containers; one placed in the front and a trailer in the back (see Illustration 5). Each of these load containers has a capacity of three boxes of 60*80*30cm.

Illustration 5: Load container of cargo bike (Photo by Anne Marthe Kjønnø, 2017)

3.7.3.3 Schedules and Time Windows

There exist a time window for when deliveries and pickups are going to be performed. DHL Express' services are available Monday to Friday between 8AM and 7PM, and the latest pickup at 5.30PM. Pickups fulfilled after this time is sent the following day. The chauffeurs are expected to follow the restriction of 8 working hours, which includes a 30 minutes break. Furthermore, a time window that is important to comply is the critical deliveries.

3.8 Quality of Research

Reliability and validity are two important aspects to ensure quality of the research. Reliability is concerned with consistency of measures of a concept: whether the results of a study are repeatable. Validity concerns the issue whether an indicator measuring a concept truly measures that specific concept (Bryman & Bell, 2015). Reliability and validity must be considered through the whole process, as well as the associated ethical issues.

3.8.1 Reliability

In general, reliability considers the consistency of the operations of a study, such as whether the procedures or steps can be repeated by another researcher with the same results and conclusions (R. K. Yin, 2014). The aim is to minimize errors and biases in the study. To ensure reliability of a case study, R.K. Yin (2009) suggests two tactics: (1) to use a case study protocol, and (2) to develop a formal and presentable case study database. A case study protocol relates to the data collection technique, procedures and general rules to be followed (R.K. Yin, 2009). In accordance with this, the researchers made summaries of each meeting with relevant actors in the project, such as DHL Express, TØI, The Municipality of Oslo, The Public Road Administration and supervisor. Moreover, questions and answers for the interview with the chauffeurs is attached (Appendix 3). Lastly, overviews of all meetings held (Appendix 4) during the process of writing this thesis are included. By doing this, transparency and an orderly data-gathering process is ensured, which increases the reliability of the thesis.

To develop a case study database relates to the organization and documentation of the data that is collected (R.K. Yin, 2009). A database was made to get a reliable collection of data detached from the thesis, in addition to support the documentation. The database contains all data that can be disclosed, for instance, answers from the interview, delivery and pickup data from DHL Express, and ZIP-codes with the respective areal and kilometers. With regard to the Excel-file used for simulations, a cover page has been added to present all amendments, adjustments, assumptions and entries made in the file.

3.8.2 Validity

Validity is defined as the integrity of the conclusions resulted from the research (Bryman & Bell, 2015). In a quantitative research, *measurement validity* is the criterion that is most applicable. To ensure measurement validity in a case study, R.K. Yin (2009) suggests tactics such as triangulation and key informants to review drafts. To address the latter, the researchers were cooperative with TØI, DHL Express and the supervisor throughout the whole process to improve the validity. Triangulation relates to the use of various sources of data in order to verify the information through interviews, observation and reports (Merriam & Tisdell, 2015; R.K. Yin, 2009). This has been used as a basis to the qualitative part of the thesis to enhance the overall validity.

The data collection consisted of both primary and secondary data. DHL Express provided the majority of secondary data (e.g. routes, ZIP-codes and coordinates, number of deliveries and pickups, and weight) used for the purpose of simulations. Thus, these were regarded as secured validity. However, some assumptions were set due to missing data and errors and may affect the validity of the study. A common typo in the dataset consisted of coordinates located in Oslo, while ZIP-codes were from another city or country, or the contrary. Detections of errors and typos were identified as early as possible during the process of the thesis; however, such factors influence the accuracy and performance of simulation. Another factor that should be reflected in terms of validity is the availability of data for simulation. For instance, the missing data of dimensions and volume of goods led to the need of estimations and generation of random sizes. Furthermore, estimations of real distance based on Google Maps were required, which highly affects the level of accuracy and may not reflect the real life. Estimations, such as traffic congestions were not considered, and environmental performance are highly varied in terms of time and location and may cause difficulties to give a precise answer; hence the validity may be reduced.

In terms of primary data, the two interviewed chauffeurs were given identical questions and observed to verify the information obtained and to enhance the overall validity. On that note, the case study allows the researchers to extract different types of data from diverse sources and opinions, which do not only contribute to achieve a holistic understanding of the phenomenon, but also results in enhanced validity of the research. Furthermore, because the researchers could communicate with the chauffeurs in the local language, the likelihood of negative effects of the cultural barriers were reduced. Despite this, as stated by Welch and Piekkari (2006), cultural barriers sometimes act as barriers in communication. This was taken into account when preparing for the field trip and was kept in mind when interviews were conducted. Nonetheless, the fact that the chauffeurs could express themselves in their local language enhanced the validity to the study since one could come across information that otherwise would be omitted. However, the Hawthorne effect during the observation may pose as a threat to validity.

3.8.2.1 External validity

External validity, or generalizability, of case study research is concerned with whether the findings of this study are equally applicable to other research settings (Saunders et al., 2009). The external validity is questioned when conducting a case study because one specific case cannot represent another. It is likely that the findings and results specifically for DHL Express may be generalized and transferred to a distribution context for other LSPs in Oslo and Norway, such as Posten and Postnord, specifically when the similar strategies or measures are considered. The data and methods for this study are for the purpose of DHL Express' measure in Oslo, and may be difficult to standardize to logistics problems in other countries without making new assumptions. Influencing factors such as road infrastructure, bicycle conditions, weather, and customer demand are based on the Norwegian setting and should be taken into consideration.

3.9 Social and Ethical Considerations

Regardless of data collection technique, several ethical principles need to be taken into account in the study (Saunders et al., 2009). A general ethical principle is the importance of keeping privacy of participants, such as confidentiality and anonymity. For this thesis, it includes protecting the anonymity of the interviewees such as anonymize the answers. Furthermore, sensitive information regarding historical data from DHL Express is handled confidentially, and anonymized. This means that no names, addresses or other personal information can be identified as these are excluded from the data set. Another principle is associated with the maintenance of objectivity, which is related to the reliability and validity of this study. Accordingly, the data received from DHL Express should be handled objectively, such that no fabrication of data is conducted. The maintenance of objectivity is essential during the analysis to make sure that the data is not misrepresented (Saunders et al., 2009). Lastly, the use of observation techniques is considered. For the field trip, the chauffeur's boundaries were taken into account as they could find the observation of their behavior intrusive, for example during private phone calls.

3.10 Data analysis

The inputs obtained from secondary and primary sources are mostly pure numbers and could therefore be directly used for simulations. The main objective of data analysis is to solve the VRPTWSPD in order to compare the two different systems

and assess the productivity and efficiency for vans and cargo bikes. Thus, the outputs of the simulations are analyzed in terms of comparing total driving distance, service level, and environmental impact with regards to CO_2 emissions.

Chapter 4:

GENERATION

OF ROUTES

4.0 Generating the Routes

This chapter presents a description of the model building for the current system and pilot project. The models have been created with great supervision from Mehdi Sharifyazdi, and in collaboration with the programmer Meisam Ashraf. The objectives of the models are to minimize total driving distance while satisfying time window and capacity constraints, and increase service level. Gillet and Miller's Algorithm, Nearest Neighbor heuristic, and Cheapest Insertion heuristic have been used as a basis for the simulations. A motivation for this thesis is to modify the algorithm by using a competitive approach, which can successfully reach a sufficiently good solution. The algorithm divides each customer into either pickup or delivery, and accounts for the constraints. However, this thesis does not solve the VRPSPDTW to optimality. It measures the effect of implementing cargo bikes to the system. The algorithm executed in this thesis is easy to implement and has a fast execution time. Part I concerns the generation of current system, and Part II concerns the generation of pilot project.

4.1 Estimation of Distances

In order to present a more reliable study, it is essential to find distances that are approximately equal to real life driving distances. 100 pairs of random nodes were selected from the historical database. Subsequently, for each pair of node, the real distances of the streets were found by inserting latitude and longitude coordinates into Google Maps. The following formula is used as a function of real distance:

$r = ad^b$, where a and b are variables

r: real distance

D: estimated distance based on d, where d is direct distance

$d = f(lat1, long1; lat2, long2)$, see section "4.1.1 Estimations of Direct Distance" for elaboration of calculations

$Error = r - D$

The data was obtained to find Squared Error and Sum Squared Error (SSE) between direct distance and real distance, with the aim to minimize SSE. Excel

Solver Function was used to minimize SSE by changing variable cells for a and b. The following results were found:

$$r = 1.81d^{0.88}$$

Minimum SSE = 313 meters

Average error = 730 meters

4.1.1 Estimations of Direct Distance

Due to the fact that coordinates on Google Maps are based on latitude and longitude coordinates, and not UTM coordinates, an additional formula is required to estimate direct distances (Wikipedia, 2017):

Let ϕ_1, λ_1 and ϕ_2, λ_2 be geographical latitude and longitude coordinates in radians of two nodes 1 and 2, and $\Delta\phi$, $\Delta\lambda$ to be the respective absolute differences. Subsequently, the central angle between them, $\Delta\sigma$, is given by the spherical law of cosines:

$$\Delta\phi = \arccos(\sin\phi_1 \times \sin\phi_2 + \cos\phi_1 \times \cos\phi_2 \times \cos(\Delta\lambda))$$

The distance d, i.e. the arc length, for a sphere of radius r and $\Delta\sigma$ given in radians

$d = r\Delta\sigma$, where r is the radius of the earth.

For this thesis, the average radius is set to be 6371.

The next sections present Gillet and Miller's Sweep Algorithm and the revised algorithm for this study.

4.2 Gillet and Miller's Algorithm

This thesis studies the productivity and environmental impact of DHL Express' delivery and pickup process based on Gillet and Miller's Sweep Algorithm to generate routes for the current system and pilot project, respectively. The Sweep Algorithm is one of the simplest algorithms to implement for VRPs. It is used to find the shortest path between each node i and j in the network N. The nodes are arranged in a graph and are assigned with X and Y coordinates (Kumar &

Jayachitra, 2016). The goal is to find the shortest path from the depot (node 0) and between each pickup and delivery customer ($n = 1, \ldots, N$). To assess the result of the algorithm, current deliveries and pickups are presented. An application is built based on the algorithm and tested using data of current routes. The route generation is performed repeatedly using different constraints in order to achieve the best solution. A route is chosen based on shortest distance, capacity and time window constraints. Each constraint affects the route choice to gain different combination of routes (Nurcahyo et al., 2002).

Based on the study of Kumar and Jayachitra (2016), the algorithm is described as follows:

Phase 1: Clustering

Start with the unassigned vertex (customer or node, n) with the smallest angle, i.e. the closest customer. Assign vertices to vehicle k ($k = 1, \ldots, K$) as long as the capacity Q of vehicle k is not violated. If there are still un-routed vertices, initialize a new vehicle.

Step 1

A radial line with central depot (*n=0*) as center point starts from 0° and sweeps through nodes ($n = 1, \ldots, N$), surrounding the depot in either clockwise or counterclockwise direction (see Figure 4 and 5).

Step 2

When the first customer (*n=1*) for either pickup or delivery is encountered, it is assigned to the first vehicle *k=1* and verified with the capacity constraint *Q*. If it is available capacity, the customer is assigned as visited. If there are more than one customer at the same node, i.e. customers located at the same stop/building, the customer will be assigned to the cluster, assuming that constraints are not violated.

Step 3

The line continues to sweep to get a second customer (*n=2*) for either pickup or delivery. A pickup customer is dependent on available capacity (negative

utilization), while a delivery customer is independent of the capacity constraint (positive utilization), i.e. capacity is released for every delivery customer.

Step 4

When the second customer of either pickup or delivery is assigned, the capacity constraint is applied first. If the good does not exceed the capacity, Q, it is assigned to the first vehicle ($k=1$) and the customer is set as visited.

Step 5

The sweeping proceeds until all pickups are collected and every delivery is fulfilled given that capacity or time window constraint is not breached. The included customers are set to the first cluster. When a customer cannot be included in the first cluster due to violation of a constraint, this customer becomes the first customer of the second cluster.

Step 6

The previous steps are repeated with the second vehicle ($k=2$) for the remaining customers.

Step 7

The procedure continues and is completed when all customers are assigned to vehicles $K (k = 1, \dots, K)$.
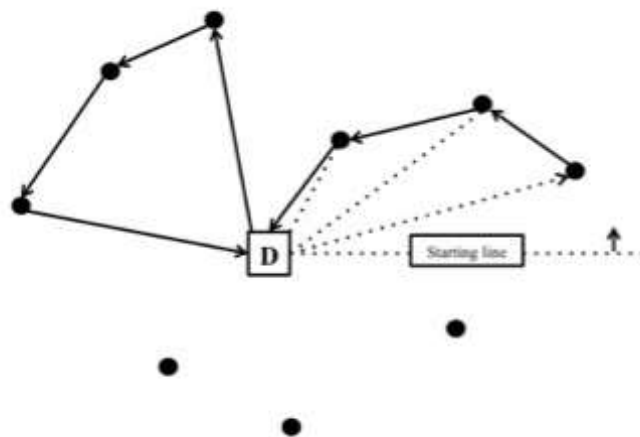
Figure 4: Illustration of Sweep Algorithm (Kumar & Jayachitra, 2016)
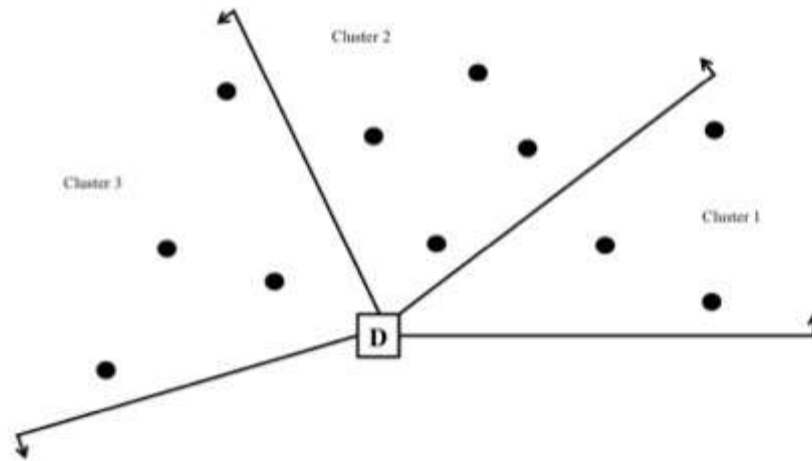
Figure 5: Clustering process (Nurcahyo et al., 2002)

Phase 2: Routing

The purpose of route generation is to connect all nodes in every cluster beginning from and ending at the same depot. To generate each vehicle route, it is required to solve the Traveling Salesman Problem (TSP) for each cluster. The objective of TSP is to identify the shortest path connecting all nodes in the cluster. A tour for TSP is a circuit on a graph including each node exactly once. The nodes are connected based on the distance between each other, assumed that capacity and time window constraints are not violated. The first node to be connected in each cluster is the one with the shortest distance to the depot. The next node to be connected is chosen based on the closest distance to the first node. The same process is executed for the other clusters. This procedure is commonly referred to as Nearest Neighbor heuristic, and is easy to execute and code. It has a fast execution time, and is approximately equal to the "reality" of each chauffeur. However, it does not find the optimal solution. When applying this method to VRPs, care must be taken to make sure that only feasible vehicle routes are developed (Laporte, 1992).

As previously mentioned, this thesis will not find an optimal solution, but rather measure the effect of implementing cargo bikes into the system. Therefore, it is feasible to use an algorithm that is easy and quick to execute. The next section presents the revised algorithm for the purpose of this study.

4.2.1 Revised Algorithm

The revised algorithm is a combination of the Sweep Algorithm, Nearest Neighbor heuristic, and Cheapest Insertion heuristic (see Appendix 5). A set of nodes is given at the beginning of each day, which includes deliveries and pickups. However, chauffeurs will also receive unexpected pickup orders during the day. Packages that are larger than the capacity of cargo bikes are assumed broken down such that it can be distributed. The algorithm is described as follows:

Phase 1: Clustering

The clustering procedure will follow Gillett and Miller's Sweep Algorithm, thus, the sequence of visit is temporarily assumed to be the same. The emphasis of this phase is that it is only based on capacity, and no consideration of time windows yet. Sweep Algorithm is used to estimate available capacity, not time.

Phase 2: Routing

The routing phase for vans and cargo bikes is based on four categories: critical deliveries, business customer, private customer, and pickups. The first step is to generate routes only for critical deliveries by solving the TSP, using Nearest Neighbor Heuristic. Subsequently, business deliveries (nodes) are inserted one by one to the route based on Cheapest Insertion heuristic. The insertions affect the delivery times and determines whether it is feasible or not, i.e. whether it violates time windows and capacity constraints or not. The time windows contain opening hours of the serviced firms (8AM to 5PM), working hours of 8 hours per day (including 30 minutes break), critical deliveries, last pickup at 5.30PM for packages that should be shipped the same day, and the scheduled time of return at the terminal for unloading of pickup goods to be shipped (8PM).

In cases where insertions are feasible, the node is assessed in terms of shortest total additional distance. The route that gives the shortest additional distance to the total distance is then used, due to the fact that greedy algorithms opt to minimize total distance. The nodes that are infeasible and cannot be placed into the routes must be postponed to the next day and considered as critical deliveries. The same procedures are executed for private customers and last priority for pickups.

To illustrate the process, an example is given: D represents the customer waiting to be inserted, while Cr represent two critical deliveries in the existing routing paths. d_1 and d_2 represents the additional length of paths when inserting D, while d_3 is the path eliminated after insertion (see Figure 6).
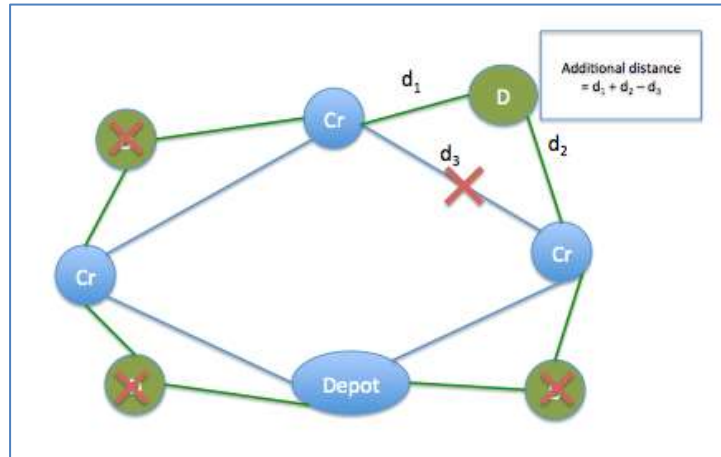
Figure 6: Insertion of delivery to existing route for critical deliveries

The outputs from the revised algorithm are used as inputs to both simulation models to assess and determine whether vans alone or an implementation of cargo bikes are beneficial for solving the VRPSPDTW.

4.3 Part I – Current System

This part presents the assumptions and inputs when formulating the simulation model in the current system, i.e. the base case. In the current system routes are generated daily. The routes vary from day to day due to various customer demands. Goods arrive every day, Monday to Friday, by plane from either Germany (Monday) or Denmark (Tuesday-Friday) to Gardermoen and are distributed by trucks to the terminal at Berger in Skedsmo. At the terminal, the goods are sorted and loaded to vans dependent on the designated routes. The vans do not return to the terminal before the delivery and pickup process is fulfilled or time windows are reached.

4.3.1 Assumptions

Assumptions are set to develop the routes for vans, see Table 3 below.

Assumptions:
Order time for deliveries is not considered
Traffic congestion does not affect travel time
Homogeneous vans are used, i.e. equal capacity
The total quantity of goods to be delivered is known at the start of the trip
Volume is considered a limitation, not weight
Due time of pickups is no earlier than two hours after ordering
Deadline for ordering a pickup is 3.30PM
All pickups can be collected the same day as the pickup is ordered as long as time window is not violated
All deliveries are available 8AM at the terminal (Skedsmo)
The distribution of goods starts from 8AM
Businesses are served 8AM to 5PM, while private customers are served simultaneously 8AM to 11PM
Rest time for chauffeurs is set from 12.30PM to 1.00PM

Table 3: Set of assumptions to develop the routes for vans

4.3.2 Inputs for the Current System

This part presents the inputs to formulate the simulation model for the base case. Historical data from DHL Express and primary data are used as inputs for the model. In addition, the assumptions set above are taken into account.

4.3.2.1 Number of Pickups and Deliveries

The historical data given by DHL Express is used to connect a node to each ZIP-code. Accordingly, each node has a respective coordinate. Based on the routes defined by DHL Express, each link in the network is assigned a route carrier ID, such as OV01, OV11, etc., and categorized by its specific ZIP-code. Each tour starts and ends at the terminal. In the simulation model, a counter variable is used to register each delivery (1=on time, 0=otherwise). The level of service can be calculated as a proportional percentage based on the total number of pickups or deliveries for each node (*i, j*):

$$Service\ level\ = \frac{On-time\ deliveries\ or\ pickups}{Total\ deliveries\ or\ pickups}$$

4.3.2.2 Capacity of Van

The vehicle capacity is considered when assigning customers to a route. Accordingly, the developed routes cannot exceed the vehicle capacity. DHL Express operates with 8 vans in Oslo. The standard delivery vans have a capacity of $14m^3$. Table 4 presents the OPS and Commercial Reporting Standards for DHL Express.

Type	Weight	Dimension
Envelopes	Lower than 0,25kg	28cm*35cm*1cm
Flyer	Up to 3.5kg	Max 48cm*38cm*5cm
Conveyable	Between 0.5kg and 30 kg	Between 48cm*38cm*5cm and 120cm*80cm*80cm
Small Non-Conveyable	Lower than 30kg	Larger than 120cm
Large Non-Conveyable	Between 30kg and 70kg	No dimensions
Pallet (Trucks only)	More than 70 kg	No dimensions

Table 4: The OPS and Commercial Reporting Standards for DHL Express

The capacity may contribute to issues for the route generation due to utilization limit of the vehicles. Some routes may not utilize the vehicle capacity at maximum and vice versa. In a real life scenario, if there are violations of capacity or time window constraints, the chauffeurs help each other with the delivery or pickup they cannot fulfill. A practical example: consider a route based on Gillet and Miller's Sweep Algorithm, and 100 customers in that route. The vehicle is loaded 95 percent with deliveries at the terminal. This means that the vehicle has 5 percent spare capacity for pickups. If the first customer is a delivery, capacity is released. If the first customer is a pickup, available capacity must be considered. If the volume of a pickup exceeds capacity of the vehicle, the customer must either wait until further capacity is released, or another chauffeur must serve this customer.

The capacity of vans can be calculated based on number of deliveries and pickups per trip and size of goods. An estimated package volume can be used to match the pickup and delivery demand to each route. The capacity can be calculated as:

$$Capacity\ of\ van: \frac{Total\ number\ of\ deliveries\ or\ pickups}{Package\ size\ per\ delivery\ or\ pickup} \le 14m^3$$

4.3.2.3 Estimation of Volume

Since volume capacity is a limitation, an estimation of volume based on dimensional weight must be calculated. The historical database lacked information on volume of packages/package size, and therefore weight is used to generate volume (random package size). This may not give exact numbers, however, as both system use the same method it is feasible for comparison. The dimensional weight is calculated based on the weight of a package, estimated from its length, width and height. DHL Express uses a metric shipping factor of 5000 cm^3/kg. DHL Express' dimensional weight can be calculated as follows:

$$Dimensional\ Weight = \frac{Length \times Width \times Height}{5000}$$

4.3.2.4 Time Windows

The time window contains opening hours of the serviced firms (8AM to 5PM), critical deliveries (before 12AM), last pickup is 5.30PM for packages that should be shipped the same day, and the scheduled time of return for pickup goods to the terminal to meet flight departure time (8PM).

4.3.2.5 Order Time

Order times for delivery is not considered as it is assumed all deliveries each day are ready for distribution at the terminal from 8AM. Order time for pickups is estimated. Due time of pickups is assumed to be two hours after ordering. Last ordering for pickup that should be shipped the same day is 3.30PM.

4.3.2.6 Location and Distance

The terminal is located at Berger, Skedsmo. The revised algorithm explains the location of and distances between each customer. Distance between each customer and the terminal is used to minimize total driving distance. The distance is given in kilometers.

4.3.2.7 Average Driving Speed

The driving speed for vans varies dependent on areas and routes. To proceed with the simulation, an average driving speed for vans is calculated to be 6.68 kmph. The following procedure were used to find the average driving speed (see Attachment 1, sheet "Calculation of average speed" for detailed calculations):

1. Four randomly days from the historical dataset were selected.

2. All nodes for each day were plotted in Google Maps to find the total km driven each day.

3. The average driving speed for each day was found by dividing total km with total number of work hours.

4. The average driving speed was found by taking an average of the driving speed of four randomly selected days.

4.4 Part II – Pilot Project

This part presents the assumptions and inputs for the formulation of the simulation model in the pilot project. Principally, one cargo bike will replace one van, i.e. cargo bikes have the same delivery and pickup functions as vans. There are three bike messengers that will distribute mainly in the city center (Ring 1 and a small part of Ring 2), while 5 vans will cover the areas outside of Ring 1 and have the same procedure as in Part I. A micro depot is located at Filipstad/Tjuvholmen, Oslo. The process of this model is that bike messengers will meet up at the depot and travel several laps during a day to load and unload goods. The latter are goods to be forwarded to the terminal for dispatch.

The routes of the pilot project is generated daily, and will be based on the revised algorithm. The routes are not fixed as they vary from day to day due to the different demands for deliveries and pickups. The revised algorithm is the basis for the distances between all the nodes and thereby the foundations in what order the customers are served. However, critical deliveries and deliveries to businesses must have the highest priority due to time windows. Furthermore, the size and weight of packages have an impact on the utilization and capacity of cargo bikes, which affects the number of laps per day. After the routes are developed, bike messengers will start from the top of the list and serve customers in their respective areas. When the capacity of the cargo bike is maximized or all deliveries fulfilled during the route, the bike messenger return to the depot to unload pickups and fill up with a new load of delivery goods.

4.4.1 Assumptions

Assumptions are set to develop the routes for cargo bikes, see Table 5 below.

Assumptions:
Order time for deliveries is not considered
Traffic congestion does not affect travel time
Deliveries in the pilot area are available at all times
Packages that are larger than the capacity are broken down
Homogeneous cargo bikes are used, i.e. equal capacity
Only volume is limiting, not weight
Cargo bikes are operational at all times during work hours – No maintenance and breakdowns
Cargo bikes are always available at the micro depot when needed
The total quantity of goods to be delivered is known at the start of the trip
The distribution of goods starts from 8AM
Due time of pickups is no earlier than two hours after ordering
Deadline for ordering a pickup is 3.30PM
All pickups can be collected the same day as the pickup is ordered as long as time window is not violated
Businesses are served 8AM to 5PM, and private customers are served simultaneously 8AM to 11PM
The total distance of travel for any bike is unlimited
Rest time for chauffeurs and bike messengers is set from 12.30PM to 1.00PM

Table 5: Set of assumptions to develop the routes for cargo bikes

4.4.2 Inputs for the Pilot Project

This part presents inputs made to formulate the model for the pilot project. The majority of inputs for this part of the simulation are similar or applicable to the part of the current system.

4.4.2.1 Capacity of Cargo Bike

Capacity is important when assigning customers to routes and when calculating how many laps to the depot is necessary. Evidently, the cargo bikes cannot exceed capacity during one route. This may cause difficulties when developing the routes due to the impact of size and weight of packages on the utilization. A cargo bike is built with two loading containers: one in the front and one in the back. Each of these loading containers has a capacity of three boxes of 60*80*30cm. In addition, the cargo bikes used by DHL Express can carry goods with a total load up to 125kg.

4.4.2.2 Package and Document Size

Based on DHL Express' document and package specifications, there are two types of containers for documents, namely envelopes and flyers. The package size has a relatively larger dimension. However, for the purpose of distribution with cargo bikes, the size is limited. Table 6 shows the different size and weight limits.

Type	Size (L*W*H)	Maximum Weight
DHL Express Envelopes	35*28*1cm	0,25 kg
DHL Express Flyers	48*38*5cm	4 kg
Packages	Van: Max. 120*80*80cm Bike: Max. 60*80*30cm	30 kg

Table 6: Size and weight limits

4.4.2.3 Time Windows

The time windows contain opening hours of the serviced firms (8AM to 5PM), critical deliveries (before 12AM), last pickup is 5.30PM for packages that should be shipped the same day, and the scheduled time of return for pickup goods from the micro depot to the terminal to meet flight departure time (8PM).

4.4.2.4 Order Time

Order time for delivery is not considered, as it is assumed that all deliveries each day are ready for distribution at the micro depot from 8AM. Order time for pickups is estimated. Due time of pickups is assumed to be two hours after ordering. Last ordering for pickup that should be shipped the same day is 3.30PM.

4.4.2.5 Geographical Area

The geographical areas for distribution of goods are split between vans and cargo bikes. Geographical area I is distributed by cargo bikes and consists of the city center. The following districts are covered: Oslo Sentrum, Frogner, Gamle Oslo, St.Hanshaugen, Ullern, and Grünerløkka. However, in some of the districts, only specific ZIP-codes are included.

Geographical area II is distributed by vans and consists of areas outside of the city center. The respective districts are: Alna, Bjerke, Grorud, Nordre Aker, Nordstrand, Stovner, Søndre Nordstrand, Vestre Aker and Østensjø.

4.4.2.6 Location and Distance

The depot is located at Filipstad/Tjuvholmen, Oslo. The location of each node is based on coordinates given by DHL Express. Distances between each node are

used to minimize the total driving distances for both vans and cargo bikes. The distances are estimated based on the revised algorithm and given in km.

4.4.2.7 Average Driving Speed for Vans and Cargo Bikes

Similar to the current system, the average driving speed for vans in the pilot project is considered to be 6.68 kmph. The average speed for cargo bikes in the pilot project is 15 kmph, based on previous studies in other countries such as London and Paris, and a report by TØI (Browne, Allen, & Leonardi, 2011; Dablanc, 2011; Midttun, Ødegaard, Flatheim, & Stridh, 2012).

The next chapter provides the simulation for the two parts, and presents the results and a comparison of the current system and the pilot project.

Chapter 5:
SIMULATION

5.0 Simulation Model

This chapter presents the simulation models of the current system and pilot project. The programming language GNU Octave is used for the simulations. This chapter is organized as follows: it starts by presenting the programming language used for coding, programming and simulations, followed by a description of the modeling process. In conclusion, the results are analyzed and discussed.

5.1 Programming Language

The simulation models uses the algorithm based on Gillet and Miller's Algorithm, Nearest Neighbor heuristic and Cheapest Insertion heuristic, i.e. the revised algorithm. The revised algorithm, inputs and KPIs were given to the programmer to build and code the simulation models. The algorithm and simulations for both the current system and pilot project was programmed and coded in GNU Octave version 4.2.1 by the programmer Meisam Ashraf.

Octave is a programming language licensed under the GNU General Public Licence (GPL). It has a high-level language, primarily designed for numerical computations. Moreover, it provides extensive tools for solving common numerical linear algebra problems, and for performing other numerical experiments using a language that is compatible with Matlab (Eaton, 2017).

5.2 Modeling

The simulation models generate daily routes for pickups and deliveries, including delivery and pickup orders (planned/executed), on-time delivery and pickup, total delivery and pickup, package type and size, travel distance, and number of used vehicles per day. The structure of the simulation is presented in Figure 7. The simulation is executed for both the current system and the pilot project, at the same time but separately. The day scenario simulation is presented in Figure 8. In order to run the simulations, a set of constants has been used as basis. The daily routes for distribution with vans and cargo bikes are generated based on the algorithm and DHL Express' historical delivery and pickup data for 2016. Figure 9 illustrates the deliveries and pickups from historical data in 2016 separated by months.
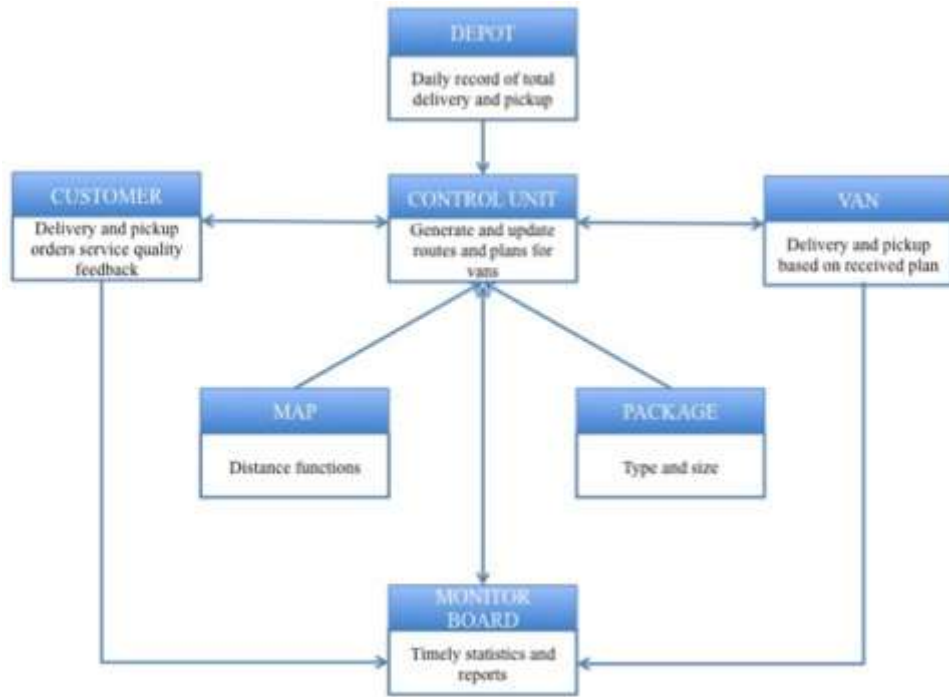
Figure 7: Simulation structure (Meisam Ashraf, 2017)

Figure 8: Day scenario simulation (Meisam Ashraf, 2017)
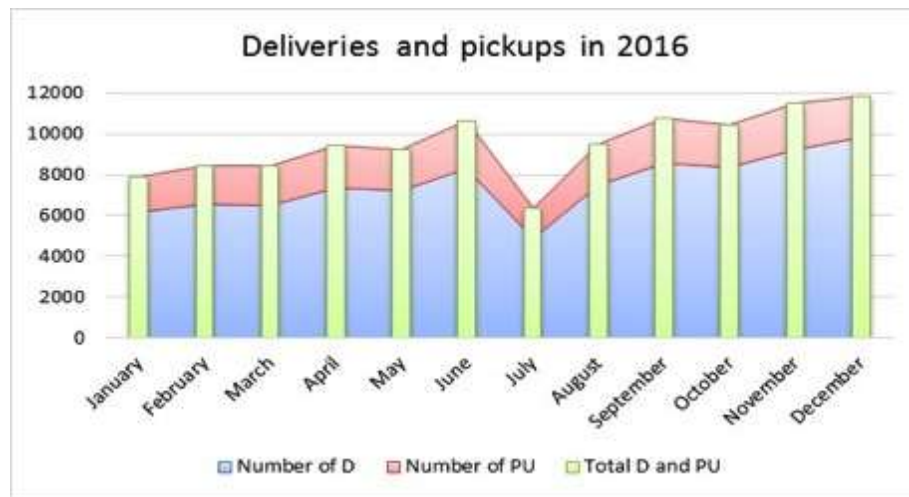
Figure 9: Delivery and pickup based on DHL Express' historical data 2016

5.2.1 Evaluation Measures in Simulation

To compare the two models some indices must be measured in the simulations. These are:

- What is the total number of pickups and deliveries for vans in the current system?
- What is the total number of pickups and deliveries for vans and cargo bikes in the pilot project?
  - What is the difference in total number of pickups and deliveries between the current system and pilot project?
- What is the total driving distance (km) for vans in the current system?
- What is the total driving distance (km) for vans and cargo bikes in the pilot project?
  - What is the difference in total driving distance (km) between the current system and pilot project?
- What is the average capacity utilization for vans in the current system?
- What is the average capacity utilization for vans and cargo bikes in the pilot project?
  - What is the difference in average capacity utilization between the current system and pilot project?
- What is the service level for vans in the current system?
- What is the service level for vans and cargo bikes in the pilot project?
  - What is the difference in service level between the current system and pilot project?
- What is the total CO_2 emission for vans in the current system?

- What is the total CO_2 emission for vans and cargo bikes in the pilot project?
  - What is the difference in total CO_2 emissions between the current system and pilot project?

5.2.2 Inputs to Simulation Test

To achieve the objectives of this study, the constants from Table 7 served as input to the test simulation.

Constant	Parameter
Number of simulation	1
Total number of working days	255
Number of working hours per day (hours)	8
Rest time for drivers and bikers (hours)	0,5
Number of vans in current system	8
Number of vans in pilot project	5
Number of cargo bikes in pilot project	3
Capacity of van (m³)	14
Capacity of cargo bike (m³)	0,864
Driving speed of van (kmph)	6,68
Driving speed of cargo bike (kmph)	15

Table 7: Inputs to simulation model

In the test simulation the programmer started with the above inputs to both models. The test revealed that replacing 3 vans with 3 cargo bikes led to an unstable system with numerous delays and postponements due to the differences in capacity and driving speed. Therefore, the programmer implemented one-by-one cargo bikes, to see how many cargo bikes had to replace the 3 vans to avoid too many postponements and delays.

According to the principle of queuing theory in OR, an arrival rate higher than service rate will lead to an increased length of queue and become infinite in the long term, thus an unstable system. In practice, the principle implies that when implementing 3 cargo bikes to the system, 100% of customer demand will be delayed in the long term. Even implementing 4 and 5 cargo bikes led to an unstable system. For example, at day one of implementing 3 cargo bikes, some delays occurred, for example 50 delays. These delays were transferred to the next day, such that new delays from day two were added the delays from the previous day. The number of delays would increase the longer forward in time measured, and the longer forward in time, the more customers from previous delays would occur, eventually 100% of customers would be queuing for service.

5.2.3 Revised Inputs

The revised inputs to the simulation model contained 210 working days (January to October), 6 cargo bikes, and a driving speed of 40 kmph for vans, which is based on the average driving speed from the report by Norwegian Public Road Administration (Statens vegvesen, 2015), and 25 kmph for cargo bikes (Statens vegvesen, 2016).

5.3 Results

The results from the simulations are presented in Table 8. The results are based on 10 months (January to October) simulations of both systems.

Output	CS	PP (Van/Bike)
Total number of pickups and deliveries per 10 months	90,800	91,524
Total driving distance per 10 months (km)	71,616	82,261
Average capacity utilization deliveries (%)	61	28/111
Average capacity utilization pickups (%)	12	4/25
Number of on-time deliveries	70,485	72,102
Number of on-time pickups	16,002	16,156
Number of delayed deliveries	3,539	2,520
Number of delayed pickups	774	746
CO_2 emission per 10 months (kg)	14,466	7,389

Table 8: Results from simulation

5.3.1 Total Number of Pickups and Deliveries

As shown in Figure 10, the pilot project is able to perform at least the same amount of deliveries and pickups as the current system. The total number of deliveries in the pilot project has increased with a total of 598 deliveries compared to the current system, and corresponds to an increase of 0.08 percent. The total number of pickups increased with 126 pickups, and corresponds to an increase of 0.07 percent. The total number of stops has increased by 724 deliveries and pickups. The results show that the two systems are approximately equal.
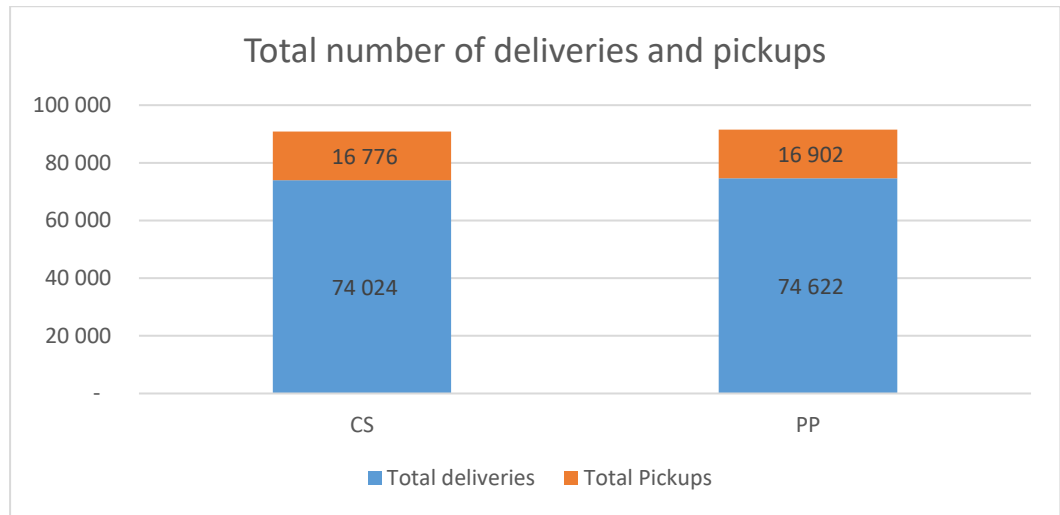
Figure 10: Comparison of total number of pickups and deliveries

Figure 11 illustrates the distribution of deliveries, pickups and delays of both systems. According to the results, the level of critical, business and private deliveries, and on-time pickups are affected at the minimum amount when changing from a system solely operated by vans to a system with vans and cargo bikes. The peak in July can be explained by the Norwegian public holiday.
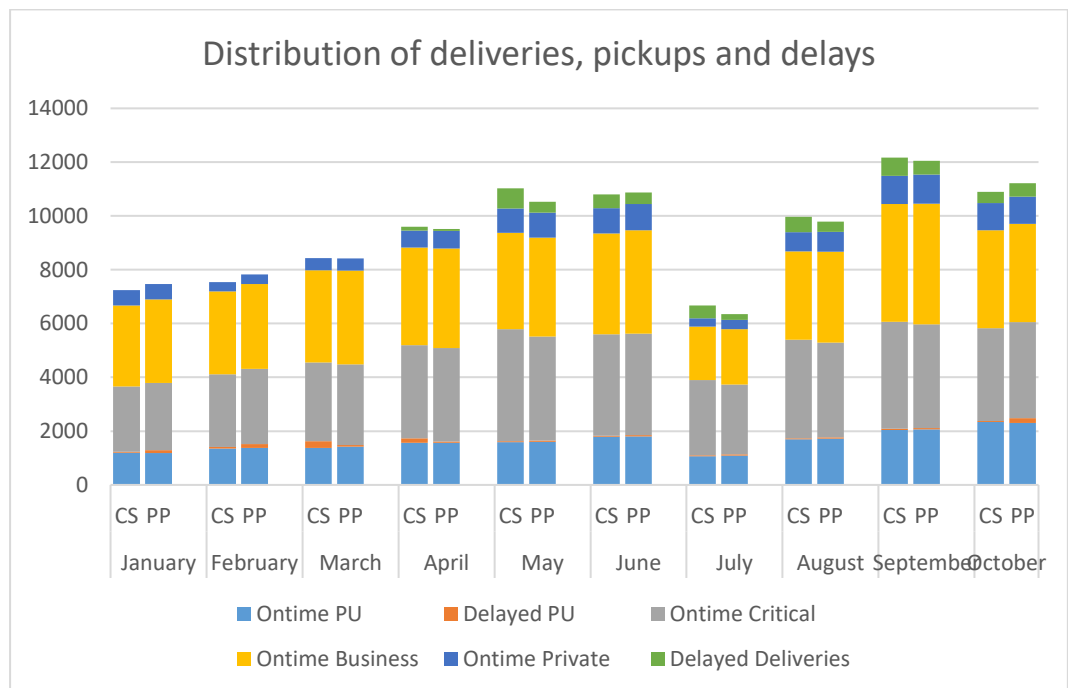
Figure 11: Comparison of distribution of deliveries, pickups and delays

5.3.2 Total Driving Distance

Figure 12 illustrates the comparison of total driving distance for the current system and pilot project. The results show that the total driving distance in the current system is 71,616 km compared to a total driving distance of 82,261 km in the pilot project. The total driving distance for vans is much lower in the pilot project, which is expected due to the replacement of 3 vans with 6 cargo bikes.

The increase in total driving distance is 12.94 percent. The increase in driving distance for cargo bikes can be explained by the multiple returns to the micro depot to load delivery goods into the cargo bikes and unload pickups. The average number of returns to the depot is 7 times per day.
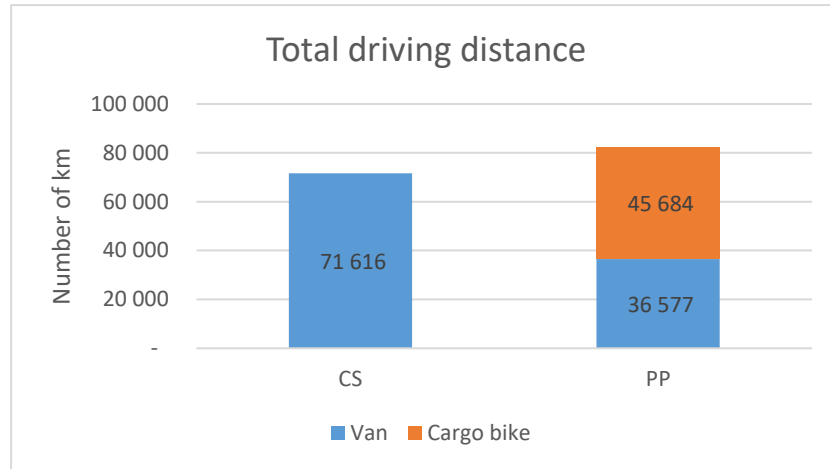
Figure 12: Comparison of total driving distance

5.3.3 Average Capacity Utilization

The average capacity utilization is based on total delivery or pickup weight per capacity divided by number of vehicles. The capacity utilization was calculated as follows:

$$Capacity\ utilization = \frac{Weight\ per\ capacity\ for\ delivery\ or\ pickup}{Number\ of\ vehicles}$$

Figure 13 shows the comparison of average capacity utilization for the current system and pilot project per day, and illustrates how full the vehicles are on average. The results show a difference in the capacity utilization for deliveries. The average capacity utilization for the current system amounts to 61 percent for deliveries, while vans in the pilot project has an average of 28 percent and cargo bikes have an over capacity of 111 percent, which means that demand is higher than the capacity of cargo bikes. DHL Express' main customer base is medium sized businesses located in the pilot area, which explains the over capacity utilization for deliveries with cargo bikes. The opposite occurs in the situation for vans, as they operate in areas outside the city center. The overall low percentage of capacity utilization for pickups in both systems is due to the assumptions for the algorithm for this study. The algorithm is based on fulfilling deliveries before any pickup starts.
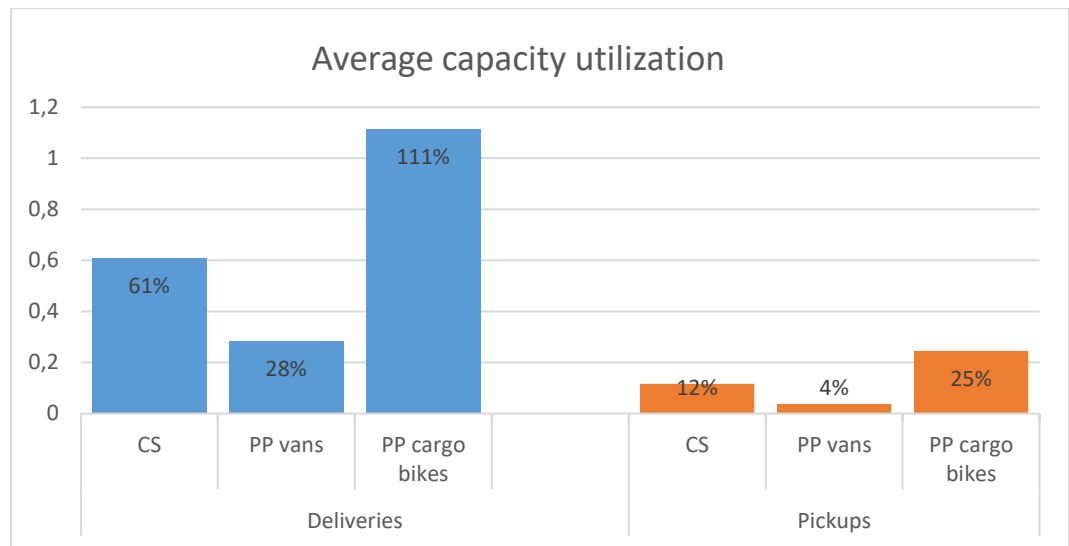
Figure 13: Comparison of average capacity utilization

5.3.4 Service Level

In this thesis, service level is based on on-time deliveries and pickups relative to the total deliveries and pickups. Figure 14 illustrates the comparison of service level for the current system and pilot project. The service levels are separated by deliveries and pickups because this study focuses on the business perspective. The pilot project has a higher delivery and pickup service level due to more on-time services. The difference is not substantial, however, it shows that the pilot project gives a better result than the current system.
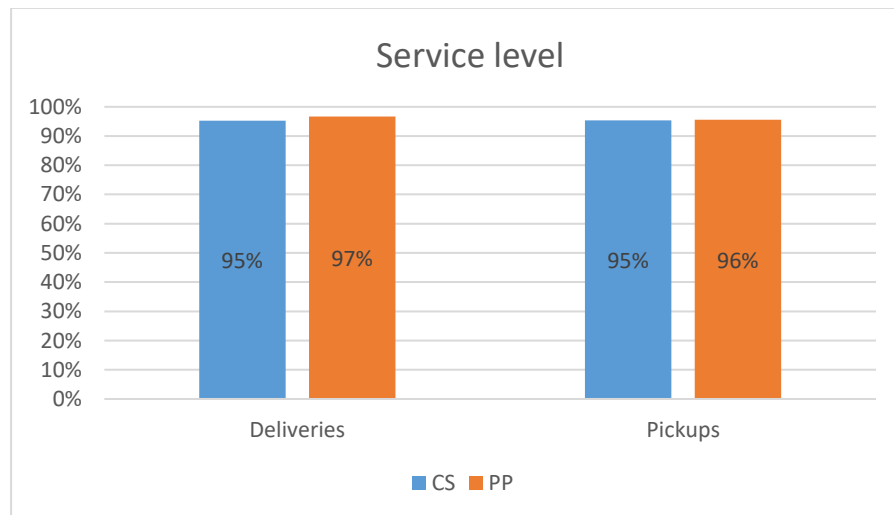
Figure 14: Comparison of service level

5.3.5 CO₂ Emission

Calculation of CO_2 emission is based on total driving distance. To measure the level of environmental impact in terms of CO_2 emission, the researchers only considered the actual CO_2 emitted during the driving of vans, as the cargo bike is considered a transport mode with zero driving emissions. Based on information of

a similar van that DHL Express uses, the estimated CO_2 emission is 0.202kg CO_2 per km (Mobile24, 2017). Figure 15 illustrates the comparison of CO_2 emissions for the current system relative to the pilot project. By implementing cargo bikes, savings of CO_2 emission amounts to approximately 50 percent. The reduction is expected as three vans are replaced in the pilot project.
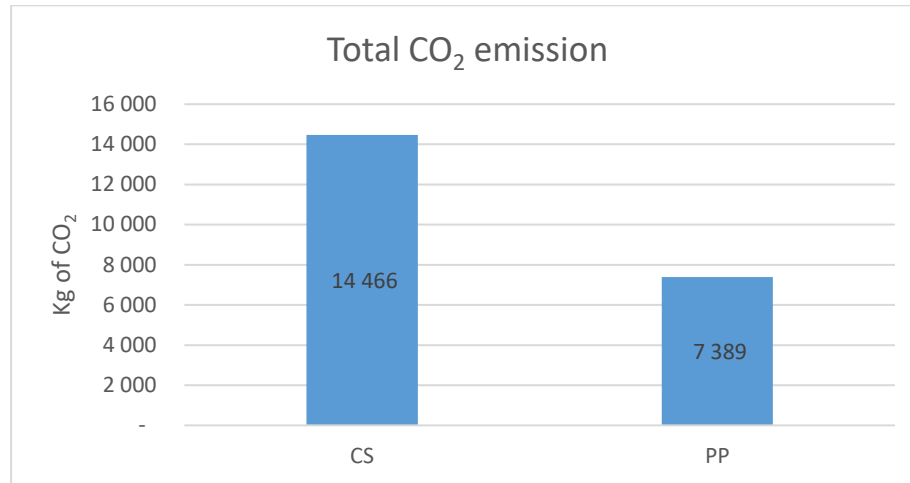
Figure 15: Comparison of CO₂ emissions

5.4 Conclusion

The results show that pilot project is the most feasible solution for express deliveries in Oslo and provides improvements by changing the system. The pilot project is able to serve more customers, which can make the system more productive in terms of number of deliveries and pickups. Moreover, the on-time deliveries and pickups are not affected by implementing cargo bikes, which implies that the productivity is at least equal.

The increase in total driving distance for the pilot project can be explained by the multiple returns to the micro depot to load delivery goods into the cargo bikes and unload pickups. The increase of 10,000 km driven will not be critical for the system, as the distance is distributed among 6 cargo bikes and 210 working days.

The low average capacity utilization for both systems is partly explained by the assumptions made for the algorithm and the location of business customers, i.e. the main customer base of DHL Express, in the pilot area. For the average capacity utilization for delivery, the current number of cargo bikes in the pilot area does not cover the delivery demands. Hence, to get a better capacity utilization, DHL Express should consider implementing additional cargo bikes to their vehicle fleet.

The results from simulation are based on a 10-month period (January to October), as this was managed to be simulated. Based on the results from the simulation, it is proven that by replacing 3 vans in the current vehicle fleet with 6 cargo bikes in a limited area, DHL Express is able to increase the productivity and service level, while reducing CO_2 emission.

Chapter 6:

QUALITATIVE

COMPARISON

6.0 Qualitative Comparison

This chapter outlines a qualitative comparison of the two distribution systems for DHL Express. Bicycles are essential to reach environmental, social and economic goals. Despite the economic aspect from DHL Express' point of view, it is important to consider how and why cargo bikes have environmental and social advantages. This thesis explores previous studies and uses secondary sources as a basis. The qualitative tool in terms of a SWOT analysis is used. Furthermore, the semi-structured interviews with DHL Express' chauffeurs have supported the qualitative part of this thesis. A number of influencing factors are considered to evaluate the decision of implementing cargo bikes to the system.

6.1 Traffic Congestion

Traffic congestion is considered one of the most important influencing factors in the decision of implementing cargo bikes. Vans pollute urban areas and lose enormous amount of time and money in congested areas. The roads of Oslo are heavily congested; in fact, Oslo has been reported to be the leading city in the Nordic in terms of worst congested cities (NRK, 2017). A report by TOMTOM Traffic Index (2017) has estimated that motorized vehicles need 30 percent extra time per day, which corresponds to approximately 38 minutes, due to the high level of traffic congestion. Cargo bikes are proved to have minimal impact on traffic congestion and do not suffer from such problems. Maes and Vanelslander (2010) stated that the more urban areas face traffic congestion, the more bike messengers have an advantage. Delivery times are faster, and a constant reliability is offered as bike messengers always need the same period of time to do a certain route regardless of weather conditions, traffic jams, peak time or off-peak time strikes in public transport.

6.2 Traffic Emission

It is estimated that 16 percent to 50 percent of traffic emissions are caused by freight transport carried by motor vehicles in European cities (Lenz & Riehle, 2013). Saenz et al. (2016) studied the potential of implementing electric cargo bikes to reduce greenhouse gas emissions (CO_2) in the city center of Portland, Oregon. The case study was conducted by using real-world data of a tricycle logistics company, B-Line, which provides last mile distribution services. The results showed that total CO_2 emissions were reduced between 51 percent and 72 percent by replacing vans with cargo bikes. Moreover, B-Line avoided between

10 tons and 26 tons of CO_2 emissions per year (Saenz et al., 2016). Browne et al. (2011) draw the same conclusion in their evaluation of the use of an UCC and cargo bikes in London. The CO_2 emissions were reduced by 54 percent per package delivered.

According to the Norwegian Ministry of Environment, the limits for particle and gas concentration are regularly exceeded in the largest cities, especially in Oslo. Local air pollution is primarily affecting the health of children, elderly and asthmatics. Oslo typically suffers problems with high particle concentrations and has tried to reduce use of studded snow tires during the winter seasons by charging a fee for using them. In January 2017, the city of Oslo implemented for the first time a ban on diesel-powered vehicles on municipal roads due to the critical level of dangerous air pollution. The ban was effective until the air pollution levels were determined to be less dangerous. Thus, the city of Oslo is considering restrictions against diesel engines.

6.3 Number of Deliveries and Pickups

Statistics Norway (SSB) has reported the number of goods deliveries and pickups by vans in Norway during the period 2014-2015 (SSB, 2016). In 2015, a total of 173 million freight deliveries and pickups were fulfilled. This amounts to approximately 500,000 deliveries and pickups per day. In Oslo, a total of 37.6 million freight deliveries and pickups were carried out by vans in a year (Rundberget et al., 2016), whereas 20 million of these were performed in the city center of Oslo. This amounts to approximately 50,000 deliveries and pickups per day, and 1.4 million tons of goods distributed over a total of 364 million vehicle kilometers (Rundberget et al., 2016). In 2016, DHL Express provided a total of 90,511 deliveries and 24,038 pickups, which corresponds to 355 deliveries and 94 pickups per day (based on 255 days/year), on average. According to recent literature, it is estimated that about 51 percent of all motorized transport of goods in European cities, could be replaced with cargo bikes (Schliwa et al., 2015), including Norway.

6.4 Speed

Another relevant factor for this case is speed, which often correlates with the level of congestion. Every major city around the world that has started using bike messengers for goods deliveries has seen that bicycles are just as fast as, or faster

than vans. This is due to a number of reasons, but primarily it is due to traffic congestion and the flexibility regarding one-way streets. Bicycles are less vulnerable to traffic, and can generally be more flexible and travel at faster speeds during rush hours. According to the studies by Cyclelogistics, the average speed for cargo bikes and vans are quite similar in the city center. Cyclelogistics (2015) had a result of 16-19 kmph (continuous) for cargo bikes, while vans had a variation from 8-24 kmph (stop/start). Furthermore, projects from Paris and London estimated typical operating speeds of 12-15 kmph for electrically assisted freight tricycles (Browne et al., 2011; Dablanc, 2011). Although these speeds are relatively low, they are comparable to motorized vehicle speeds in the same locations, e.g. the speeds in Paris are limited to 20 kmph (Dablanc, 2011). A recent project conducted by TØI found that, for electric cargo bikes, the average speed within Ring 1 is approximately 16 kmph, while in the areas between Ring 1 and Ring 2 have an average speed of 17 kmph (Flügel, Fyhri, Hulleberg, Weber, & Ævarsson, 2016). In the corresponding areas of Ring 1, the average speed of motorized vehicles is estimated to be between 20 to 21 kmph (Midttun et al., 2012). Therefore, DHL Express' cargo bikes are expected to have the ability to bypass congestion and increase the level of productivity.

6.5 Capacity

In contrast to traditional vans, cargo bikes are limited due to much lower load capacity of goods. Cargo bikes have a capacity to carry loads between 50 to 250 kg, with exceptions up to 500 kg (Lenz & Riehle, 2013; Leonardi et al., 2012). This opens up for a range of potentials and tasks. DHL Express' cargo bikes have capacity to carry loads up to 125kg. Illustration 6 shows the capacity of a DHL Express van. As explained by van chauffeurs during the field trip, customers (even regular customers) are unpredictable. One day, they may have a single envelope and the next day 15 large boxes – the first can be easily delivered by bicycle, while the latter would require a van or truck. This means that where unpredictability exists, a cargo bike can only act as a supplement to van rather than replace it. This is especially the case when picking up from customers, as such pickups usually give a minimum indication of volume. Thus, the capacity of a cargo bike to collect may not be confirmed until actually in front of the customers.

Illustration 6: Van capacity (photo by Anne Marthe Kjønnø, 2017)

6.6 Accessibility

Another valuable factor is related to accessibility for goods delivery. During the field trip the researchers observed, on several occasions, the van chauffeurs had to park a distance away from the delivery entrance due to vehicle-restricted areas or unavailable parking spaces. Therefore, cargo bikes have a great potential as a mode of delivery due to parking spaces. Cargo bikes have better access for goods deliveries, leading to more flexibility in terms of access to pedestrianized areas and bicycle paths, in comparison to vans, which are usually restricted to road networks. Thus, the handling of freight is easier and more efficient using cargo bikes due to the ability to pull up right outside, and pull away just as quickly without hindering customers.

6.6.1 Parking and Unloading

The measure of parking restrictions in the city center during the summer and autumn 2017 will enhance the success of implementing cargo bikes. Cargo bikes do not face challenges in terms of parking, while vans are restricted and have a risk of parking tickets. Thus, as proven in previous researches, cargo bikes are particularly effective in compact, congested towns and cities, and can often deliver more packages and documents in a day than their van-driving equivalent, even with the smaller payload requiring occasional returns to the depot

(Cyclelogistics, 2015; Iwan et al., 2015; Kamga & Conway, 2013; Navarro et al., 2016). In Norway, pedestrian streets often have goods deliveries before 11AM on weekdays and 9AM on Saturdays (Presttun, 2016). Chauffeurs often have to choose between not doing their job or violate traffic rules due to limited parking spaces. In the city centers, 74 percent of chauffeurs experiences that parking constitutes a problem for unloading and 8 of 10 often have to violate parking rules (Enehaug & Gamperiene, 2010). As previosly mentioned, cargo bikes do not suffer from this problem. Illustration 7 shows a typical example of a parking by a DHL Express van.

Illustration 7: Parking on sidewalk (photo by Anne Marthe Kjønnø, 2017)

6.6.2 Bicycle Infrastructure and Seasonality

In the case of Oslo, the City Counsel is continuously working to enhance the bicycle infrastructure – more bicycle lanes are being built and other new infrastructure is expected to reduce freight emission. Speed and travel time reliability can especially be improved when cargo bikes have access to preferential infrastructure like bus lanes and exclusive bicycle routes. Furthermore, cargo bikes could reduce travel distance by biking through one-way streets in the opposite direction, compared with the van alternative.

Oslo Bicycle Strategy for the period 2015-2025 has the goal to improve the bicycle opportunities in Oslo. The aim is to increase the share of daily travel by bicycle from 8 percent to 16 percent, as well as to increase Oslo residents' satisfaction with the city bicycle infrastructure (Urheim & Winsvold, 2016). Due

to various seasons and weather conditions in Norway, maintenance and operation of both roads and bicycle lanes are important to facilitate biking all year around.

6.7 SWOT

A SWOT matrix for cargo bikes (see Appendix 6) is conducted with the purpose of summarizing the theoretical background, and to give an overview of elements that impact the evaluation of DHL Express to implement cargo bikes to the vehicle fleet. The analysis is based on studies from other European cities on the use of cargo bikes in a distribution system.

6.7.1 Strengths and Weaknesses

Transport for London did a study on potential use of cargo bikes in London city center in 2009. They examined factors that were directly connected to the use of cargo bikes, and general perception and attitude to cargo bikes. The study resulted in a list of advantages and disadvantages by the use of cargo bikes in London, and was a mix of operational, human, urban, and environmental factors (Lenz & Riehle, 2013). Table 9 present a list of strengths and weaknesses using cargo bikes versus vans:

Description	Cargo Bike	Van
Purchase cost	+	-
Running cost	+	-
Parking costs and congestion charges	+	-
Speed in congestion charge area	+	-
Driver training	+	-
Low environmental impact	+	-
Security	+/-	+
Limited range and payload	-	+
Driver fatigue	-	+

Table 9: Advantages and disadvantages cargo bikes vs. vans (Lenz & Riehle, 2013)

Bogdanski (2017) studied cycle logistics solutions of the German parcel and express association. In this research, advantages and disadvantages of cargo bikes versus vans were listed (see Table 10):

Description	Cargo Bike	Van
Turn on site	+	-
Parking at delivery/pickup addresses	+	-
Search for parking space	+	-
Delivery/pickup in one-way streets	+	-
Shortcuts (infrastructure)	+	-
Shortcuts (traffic light)	+	-
Load capacity	-	+
Average speed	+	+/-
Duration of transportation cycle	-	+

Table 10: Pros and cons for cargo bikes vs vans (Bogdanski, 2017)

Figure 16 assesses the level of benefits for vans versus cargo bikes in a diagram. The higher the variable is placed on the axis, the better the benefit.
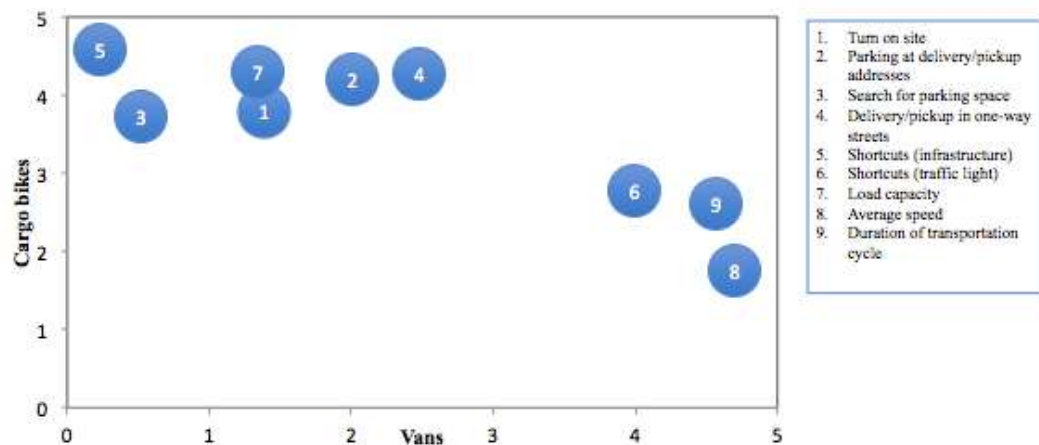
Figure 16: Assessment of benefits for vans versus cargo bikes

Cities across Europe can make good use of cargo bikes. The research from Cyclelogistics (2015) concluded that it is unrealistic for cargo bikes to replace all forms of motorized deliveries in urban areas, such as heavy goods deliveries. However, it is suggested that 25 percent of all commercial goods could be delivered with cargo bikes. The cost savings are significant, related to less fuel usage, lower maintenance costs, and much lower capital costs. There are significant reductions in air and noise pollution. All these benefits add value to the city and its population.

The mentioned studies above show that there are several advantages to changing a traditional system using vans with cargo bikes. The next section presents the opportunities and threats of implementing cargo bikes.

6.7.2 Opportunities and Threats

DHL Express experiences different barriers in terms of infrastructure, biking conditions, weather and routes in each of their operating countries. Hence, one specific decision-making model cannot be applied to prove that implementation of cargo bikes are effective in all countries. To date, the question of operational cost and productivity of a cargo bike versus a van has yet been answered in a Norwegian context.

Table 11 consists of barriers, opportunities and threats by implementing cargo bikes, which looks at lessons from the Netherlands (Balm, Ploos van Amstel, Hendriksen, & Sluijsmans, 2017).

Barriers	Opportunities	Threats
Cargo capacity (in weight) Cargo capacity (in volume)	Stricter policies regarding conventional vehicles	Competitors w/higher load capacity
Battery charging time	Development of environmental zones	Competitors w/low emissions (electric vehicles)
Availability charging infrastructure	Improvements on technical aspects	Pressure from critical deliveries
Range	Development of city hubs	Complexity due to weather on performance
Maintenance	Better cooperation in the sector	
Limited possibility to cool/freeze		
Position in public space		
Turning radius too large		
Inapplicable		

Table 11: Barriers and opportunities by the use of cargo bikes (Balm et al., 2017)

In the next section, expected impacts of implementing cargo bikes to the system are presented.

6.8 Expected Impacts

Experiences worldwide have acknowledged a number of benefits and drawbacks from using cargo bikes for urban deliveries. The extent to which these are realized depends on the local market, infrastructure and political constraint (Kamga &

Conway, 2013). The expected impacts of cargo bikes compared to vans for DHL
Express are summarized in Table 12 below.

Expected impacts	Increase (I), Decrease (D), or Varies Locally (V)
Operating Performance	
Travel speed	V
Delivery time - reliability	V
Delivery location - accessibility	I
Parking flexibility	I
Productivity	V
Operating Costs	
Labor	I
Fuel	D
Parking	D
Cargo bike purchase	D
Cargo bike maintenance	D
Other Impacts	
Driver's health	I
Driver's safety	V
Security of cargo bikes	V

Table 12: Expected impacts of cargo bikes vs. vans

6.9 Conclusion

This chapter has evaluated the cargo bike's potentials compared to their van-
driving equivalent by a qualitative comparison. High traffic congestion levels and
traffic emission are two among several influencing factors in the decision of
implementing cargo bikes to the system. The results from this analysis imply that
cargo bikes have the potential of reducing traffic congestion as well as emissions.
Consequently, the number of deliveries and pickups may increase. Cargo bikes
have better accessibility in terms of parking and unloading, thus, the handling of
goods deliveries is easier and more efficient compared to vans. Lastly, the average
speed in urban areas is expected to be similar for cargo bikes as for vans.
However, cargo bikes may face challenges in the delivery process due to load
capacity, bicycle infrastructure, and seasonality. In conclusion, the benefits are
expected to be overruling the corresponding drawbacks. Hence, the potential of
implementing cargo bikes as a mode of last mile logistics in the city center of
Oslo is considered to provide beneficial outcomes economically, environmentally
and socially.

82

Chapter 7:

FINAL

CONCLUSION

7.0 Final Conclusion

In this study of the freight delivery system by DHL Express, the analyses and findings have revealed that there is a potential for implementing cargo bikes to their vehicle fleet. This chapter provides the final conclusion of the Master thesis. Limitations and implications are discussed, suggestions for further research are presented, and the reminder of thesis is given.

7.1 Conclusion

The main purpose of the thesis was to investigate the potentials of last mile freight transport by implementing cargo bikes to DHL Express' vehicle fleet in the city center of Oslo. Furthermore, to evaluate the performance of cargo bikes as supplement for vans within a limited area, and its influence on productivity, service level, and environmental impact. The objectives of the thesis were to minimize total driving distance, hence transportation cost, compare service level, and environmental impact in terms of CO_2 emission. The thesis consisted of comparing the current system and the pilot project. Based on Gillet and Miller's Sweep Algorithm and Cheapest Insertion heuristic, a revised algorithm was developed to perform simulations for the two systems. The simulation method was programmed and coded based on the revised algorithm, a set of given inputs, historical data for one year, and KPIs. The simulation models gave results for a 10-month period of deliveries and pickups for both systems. The analysis of the results revealed that the pilot project is the most feasible solution. It has a higher delivery and pickup service level, hence it is able to serve more customers on-time. Implementation of cargo bikes leads to a reduction of number of vans, which results in a reduction of CO_2 emission by approximately 50 percent. The total productivity of the pilot project has increased compared to the current system.

A qualitative comparison of cargo bike's potentials in last mile delivery was performed based on interviews and previous studies. The results from the analysis concluded that cargo bikes have the potential to reduce traffic congestions and emission, in addition to handling goods more efficiently in terms of better accessibility to customers. However, by implementing cargo bikes in the vehicle fleet, DHL Express may face challenges in the delivery process due to lower load

capacity, bicycle infrastructure, as well as challenges related to topography and weather conditions.

This study has revealed that implementation of cargo bikes is a sufficiently good solution to the last mile logistics challenges of DHL Express. Based on the qualitative analysis and simulations results, this study can confirm that the three given hypotheses are true. Furthermore, to answer the research question, an implementation of cargo bikes has the potential to provide beneficial outcomes economically, environmentally and socially.

7.2 Limitations and Implications

The results given in the thesis do not reflect reality due to the assumptions made when generating the routes. Moreover, there were some limitations of the historical data given by DHL Express. First, it did not contain volume of packages, which had to be estimated. Available information consisted of average density measures that DHL Express uses to calculate dimensional weight. Based on weight from the dataset, volume of packages was estimated. This did not give exact volume measures, however, there was no other way to solve this problem. If volume and dimensions were given, the real measures could have been estimated by simulation. However, since the study uses the same formula for both systems to estimate volume, it is considered valid for comparison. Second, real driving distances between customers was not given in the dataset, and had to be estimated based on distances on Google Maps, which only gives approximate real distances. Lastly, order times for pickups also had to be estimated.

7.2.1 Further Research

The results of this thesis have provided interesting insights on the performance of DHL Express' last mile logistics service with cargo bikes and vans in the city center of Oslo. However, to make a fundament for evidence-based decision making focused on sustainable urban logistics, it is essential with further research addressing how different measures, such as incentives and regulations, affects a potential modal change towards cargo bikes effectively and efficiently.

The thesis has addressed and evaluated DHL Express' pilot project based on simulations and did not assess the real-life event and results. Hence, it would be interesting to see a more in-depth research of the pilot project by obtaining concrete performance data. In addition, interesting subjects would be to assess the

feasibility and level of productivity for cargo bikes in last mile logistics in Oslo with the emphasis on real-events, for example weather that affects biking conditions, delivery times, routes and traffic congestions. Successively, this could lead to possibilities for comparing the performance of LSPs, which enhances the perception of cargo bikes as delivery and pickup mode leading to sustainable city logistics.

The model of our study has been applied to a small sample of areas in one specific city, which possibly causes biased results. Thus, using the model to assess the competitiveness of cargo bikes in other areas or cities with different characteristics could be subject for further research. In addition, an interesting topic of study would be to implement cargo bikes to a broader area of Oslo with facility location of several micro depots. Another interesting subject would be to assess sensitivity by for example implementing additional cargo bikes and fewer vans in the pilot area.

Lastly, this thesis does not reflect the costs and spends incurred by DHL Express, such as purchasing, maintenance, insurance, wage, etc. Rather it has studied the cost efficiency related to level of productivity. Further investigations should include the financial analyses of vans versus cargo bikes, since they are essential and make up the basis for attracting private businesses to consider a modal shift. Factors such as insurance costs, registration costs, and legal expenses are factors that could be considered. The use of cargo bikes may incur high insurance costs as the packages being delivered are subject to higher risks of damage or theft and may therefore require higher costs for their insurance. A more in depth consideration of some benefits can be attained, for instance increases in revenue due to the attraction of a higher number of customers.

7.3 Reminder of Thesis

The thesis contribution was to provide new results regarding implementation of cargo bikes to the vehicle fleet, such that other LSPs in Oslo and Norway may learn from DHL Express' pilot project. The algorithm used for simulations was customized for this study and improved to fit the specific research problem. The results from this study may not have a direct impact on DHL Express' delivery system in practice. However, it may serve as a platform for analysis of existing cases. The study generated important knowledge related to a new transport mode

for last mile logistics that could be valuable for policy-makers, research institutions, and other LSPs, in a local and national context.

References

Aized, T., & Srai, J. S. (2014). Hierchical modelling of Last Mile logistic distribution system. *International Journal of Advanced Manufacturing Technology*(70), 1053-1061.

Angelelli, E., & Mansini, R. (2002). *The vehicle routing problem with time windows and simultaneous pick-up and delivery* (Vol. 519). Berlin: Springer.

Babulak, E., & Wang, M. (2010). Discrete event simulation: state of the art *Discrete Event Simulations*: InTech.

Balm, S., Ploos van Amstel, W., Hendriksen, B., & Sluijsmans, J. (2017). *Estimating the current, expected and potential market for cargo bikes.* Paper presented at the European Cycle Logistics Conference 2017, Vienna.

Basterfield, S., Juden, C., Wood, G., & Barner, E. (2011). *D2.1 Short History of Cargo Cycling - lessons to be learnt from present and future: Overview of the use of bicycles for goods deliveryin selected EU countries*. Retrieved from Cyclelogistics.eu:

Belfiore, P., Tsugunobu, H., & Yoshizaki, Y. (2008). Scatter search for vehicle routing problem with time windows and split deliveries. In T. Caric & H. Gold (Eds.), *Vehicle Routing Problem* (pp. 1-142). Vienna, Austria: In-Teh.

Bertrand, J. W. M., & Fransoo, J. C. (2002). Operations management research methodologies using quantitative modeling. *International Journal of Operations & Production Management, 22*(241-264).

Bochtis, D. D., & Sørensen, C. G. (2009). The vehicle routing problem in field logistics part I. *Biosystems Engineering, 104*(4), 447-457.

Bogdanski, R. (2017). *Cycle logistics solutions in the 2017 sustainability study of the German parcel and express association (BIEK).* Paper presented at the European Cycle Logistics Conference 2017, Vienna.

Browne, M., Allen, J., & Leonardi, J. (2011). Evaluating the use of an urban consolidation centre and electric vehicles in central London. *International Association of Traffic and Safety Sciences Research 35*, 1-6.

Bryman, A., & Bell, E. (2015). *Business Research Methods* (4th ed.). New York, USA: Oxford University Press.

Cattaruzza, D., Absi, N., Feillet, D., & González-Feliu, J. (2015). Vehicle routing problems for city logistics. *EURO Journal on Transportation and Logistics*, 1-29.

Chatterjee, A., & Cohen, H. (2004). *Accounting for commercial vehicles in urban transportation models.* (PhD), Cambridge Systematics, Inc., Massachusetts.

Chen, Q. (2014). *Sustainable Last-mile Solutions: Urban Freight Consolidation and Eco-routing Strategies.* UNIVERSITY OF ILLINOIS AT CHICAGO.

Choubassi, C. (2015). *An assessment of cargo cycles in varying urban contexts.* (MSc in Engineering), The University of Texas, Austin.

Clarke, G., & Wright, J. W. (1964). Scheduling of vehicles from a central depot to a number of delivery points. *Operations Research, 12*(4), 568-581.

Conway, A., Fatisson, P.-E., Eickemeyer, P., Cheng, J., & Peters, D. (2012). *Urban micro-consolidation and last mile goods delivery by freight-tricycle in Manhattan: Opportunities and challenges.* Paper presented at the Transportation Research Board 91st Annual Meeting.

Cordeau, J.-F., Desaulniers, G., Desrosiers, J., Solomon, M. M., & Soumis, F. (2000). *The VRP with Time Windows*. Montréal, Québec: GERAD.

Cordeau, J.-F., Gendreau, M., Laporte, G., Potvin, J.-Y., & Semet, F. (2002). A guide to vehicle routing heuristics. *Journal of the Operational Research Society, 53*, 512-522.

Cordeau, J.-F., Laporte, G., Savelsbergh, M. W., & Vigo, D. (2007). Vehicle routing. *Handbooks in Operations Research and Management Science, 14*, 367-428.

Cox, P., & Rzewnicki, R. (2015). Cargo bikes: Distributing consumer goods. *Cycling Cultures*, 130.

Cyclelogistics. (2015). *Cyclelogistic moving Europe Forward*. Retrieved from http://cyclelogistics.eu/docs/111/D6_9_FPR_Cyclelogistics_print_single_pages_final.pdf

Dablanc, L. (2011). Transferability of Urban Logistics Concepts and Practices from a Worldwide Perspective-Deliverable 3.1-Urban Logistics Practices–Paris Case Study. *Prepared for the European Commission. Lisbon: TURBLOG Consortium*.

Dablanc, L., Giuliano, G., Holliday, K., & O'Brien, T. (2013). Best practices in urban freight management: Lessons from an International Survey. *HAL*, 1-22.

Decker, K. D. (2012). Cargo cyclists replace truck drivers on European city streets. Retrieved from http://www.lowtechmagazine.com/2012/09/jobs-of-the-future-cargo-cyclist.html

Dekker, R., Bloemhof, J., & Mallidis, I. (2012). Operations research for green logistics - An overview of aspects, issues, contributions and challenges. *European Journal of Operational Research, 219*(3), 671-679.

Desrosiers, J., Dumas, Y., Solomon, M. M., & Soumis, F. (1995). Time constrained routing and scheduling. *Handbooks in operations research and management science, 8*, 35-139.

Deutsche Post DHL Group. (2016). Environment and solutions. Retrieved from http://www.dpdhl.com/en/responsibility/environmental-protection.html

DHL. (2015). DHL introduces Cubicycle, an innovative cargo bike for urban distribution, to its Netherlands operations [Press release]. Retrieved from http://www.dhl.com/en/press/releases/releases_2015/express/dhl_introduces_cubicycle_an_innovative_cargo_bike.html

DHL. (2016a). *First & Last mile logistics by bike*. Paper presented at the Express Forum, Hurdalsjøen Hotell og Konferansesenter. http://www.vegvesen.no/_attachment/1562599/binary/1137778?fast_title=08+Lastesykkel+i+praksis.pdf

DHL. (2016b). Vår organisasjon. Retrieved from http://www.dhl.no/no/om_oss/firma_portrett/var_organisasjon.html

Ducret, R., & Delaître, L. (2013). *Parcel Delivery and Urban Logistics-changes in Urban Courier, Express and Parcel Services: The French Case*. Paper presented at the 13th World Conference on Transport Research, Rio de Janeiro, Brazil.

Eaton, J. W. (2017). GNU Octave. Retrieved from https://www.gnu.org/software/octave/

El Hassani, A. H., Koukam, A., & Bouhafs, L. (2008). *A hybrid ant colony system approach for the capacitated vehicle routing problem and the capacitated vehicle routing problem with time windows*: INTECH Open Access Publisher.

Enehaug, H., & Gamperiene, M. (2010). *Nærtransportørens arbeidsdag - En undersøkelse blant sjåfører i Oslo, Bergen og Trondheim*. Retrieved from http://www.idebanken.org/innsikt/intervju/gode-ledere-hindrer.../afi-naertransport.pdf

Esteruelas, J. M. S. (2016). *An evaluation of the environmental impact reduction in the urban delivery logistics using trycicles: A case study in Portland, OR, USA*.

European Commission. (2014). *Living well, within the limits of our planet*. Retrieved from http://ec.europa.eu/environment/pubs/pdf/factsheets/7eap/en.pdf

Figliozzi, M. A. (2010). The impacts of congestion on commercial vehicle tour characteristics and costs. *Transportation Research Part E: Logistics and Transportation Review, 46*(4), 496-506.

Flügel, S., Fyhri, A., Hulleberg, N., Weber, C., & Ævarsson, G. (2016). Så fort sykler folk i Oslo. Retrieved from https://samferdsel.toi.no/forskning/sa-fort-sykler-folk-i-oslo-article33490-2205.html

Gevaers, R., Van de Voorde, E., & Vanelslander, T. (2011). Characteristics and typology of last-mile logistics from an innovation perspective in an urban context.

Gillett, B. E., & Miller, L. R. (1974). A Heuristic Algorithm for the Vehicle-Dispatch Problem. *Operations Research, 22*(2), 340-349.

González, E., Herrero, D., & León, J. (2015). *Assessment of environmental impact, economic and societal competitiveness*. Retrieved from PRO-E-BIKE: http://www.pro-e-bike.org/wp-content/uploads/2016/02/D-6-4-Assessment-of-environmental-impact-economic-and-societal-competitiveness_December-2015.pdf

Gopal, C., & Cypress, H. (1993). Integrated Distribution Management: Competing on Customer Service, Time, and Cost, Richard D. *Irwin, Burr Ridge, IL*, 1.

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global change and the Ecology of Cities. *Americal Association for the Advancement of Science, 319*(5864), 756-760.

Gruber, J., Ehrler, V., & Lenz, B. (2013). *Technical potential and user requirements for the implementation of electric cargo bikes in courier logistics services.* Paper presented at the 13th World Conference on Transport Research (WCTR).

Gruber, J., & Kihm, A. (2016). Reject or embrace? Messengers and electric cargo bikes. *Transportation Research Procedia 12*, 900-910.

Gruber, J., Kihm, A., & Lenz, B. (2014). A new vehicle for urban freight? An ex-ante evaluation of electric cargo bikes in courier services. *Research in Transportation Business & Management 11*, 53-62.

Hagen, J., Lobo, Z., & Mendonça, C. (2013). The Benefits of Cargo Bikes in Rio de Janeiro: A Case Study.

Halse, K. (1992). *Modeling and solving complex vehicle routing problems*. Technical University of Denmark.

Hillier, F. S., & Lieberman, G. J. (2010). *Introduction to Operations Research* (9th ed.). New York, USA: McGraw-Hill.

Ingalls, R. G. (2002). *Introduction to simulation: introduction to simulation*. Paper presented at the Proceedings of the 34th conference on Winter simulation: exploring new frontiers, San Diego, California.

Iwan, S., Thompson, R. G., & Macharis, C. (2015). *Application Of Genetic Algorithms In Optimizing The Logistics Network In An Urban Bicycle*

Delivery System. Paper presented at the Transportation Research Board 94th Annual Meeting.

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed Methods Research: A Research Paradigm Whose Time Has Come. *Educational Researcher, 33*(7), 14-26.

Kallehauge, B., Larsen, J., Madsen, O. B. G., & Solomon, M. M. (2006). Vehicle Routing Problem with Time Windows *Column Generation*: Springer US.

Kamga, C., & Conway, A. (2013). *Freight-Tricycle Operations in New York City*. Retrieved from http://www.utrc2.org/sites/default/files/pubs/Final-Freight-Tricycles-NYC.pdf

Karakikes, I. (2016). *Simulation Techniques for Evaluating Smart Logistic Solutions for Sustainable Urban Distribution*. Paper presented at the 16th International Conference "Reliability and Statistics in Transportation and Communication" Riga, Latvia.

King, D. A., Gordon, C. E., & Peters, J. R. (2014). Does road pricing affect port freight activity: Recent evidence from the port of New York and New Jersey. *Research in Transportation Economics 44*, 2-11.

King, R. (2013). Cargo bikes: last mile made easy. *Logistics & Transport Focus,* 42-45.

Knight, K., & Hofer, J. (1968). Vehicle scheduling with timed and connected calls: A case study. *Journal of the Operational Research Society, 19*(3), 299-310.

Koning, M., & Conway, A. (2016). The good impacts of biking for goods: Lessons from Paris city. *Case Studies on Transport Policy, 4*(4), 259-268.

Kumar, V. S., & Jayachitra, R. (2016). Linear Sweep Algorithm for Vehicle Routing Problem with Simultaneous Pickup and Delivery between Two Depots with Several Nodes. *Global Journal of Pure and Applied Mathematics, 12*(1), 897-908.

Laporte, G. (1992). The vehicle routing problem: An overview of exact and approximate algorithms. *European journal of operational research, 59*(3), 345-358.

Lenz, B., & Riehle, E. (2013). Bikes for Urban Freight? Experience in Europe. *Journal of the Transportation Research Board, 2379*, 39-45.

Leonardi, J., Browne, M., & Allen, J. (2012). Before-after assessment of a logistics trial with clean urban freight vehicles: A case study in London. *Procedia Social and Behavioral Sciences 39*, 146-157.

Leung, J. Y. T. (2004). *Handbook of Scheduling: Algorithms, Models, and Performance Analysis*. London: London : CRC Press.

Li, C., Loscher, K., Nagi, A., Sheerazi, H., Blair, K., Fonseca, S., & Millison, W. (2016). *GOING THE LAST MILE: Best Practices of Urban Freight Movement*. Retrieved from http://sustainability.ei.columbia.edu/files/2016/05/Tel-Aviv.pdf

Lin, C. K. Y. (2008). A cooperative strategy for a vehicle routing problem with pickup and delivery time windows. *Computers & Industrial Engineering, 55*, 766-782.

Lu, Q., & Dessouky, M. M. (2006). A new insertion-based construction heuristic for solving the pickup and delivery problem with time windows. *European Journal of Operational Research, 175*, 672-687.

Macharis, C., & Melo, S. (2011). *City distribution and urban freight transport: multiple perspectives*: Edward Elgar Publishing.

Maes, J., & Vanelslander, T. (2010). *The Use of Bicycle Messengers. An Option in the 2010 Supply Chain?* Paper presented at the European Transport Conference, 2010.

Maes, J., & Vanelslander, T. (2012). The use of bicycle messengers in the logistics chain, concepts further revised. *Procedia Social and Behavioral Sciences 39*, 409-423.

Maloni, M. J., & Benton, W. (1997). Supply chain partnerships: opportunities for operations research. *European journal of operational research, 101*(3), 419-429.

McCutcheon, D. M., & Meredith, J. R. (1993). Conducting case study research in operations management. *Journal of Operations Management, 11*(3), 239-256.

Merriam, S. B., & Tisdell, E. J. (2015). *Qualitative research: A guide to design and implementation*: John Wiley & Sons.

Midttun, K., Ødegaard, L. O., Flatheim, T., & Stridh, M. (2012). *Ring 1 - Kollektivfremkommelighet*. Retrieved from https://www.vegvesen.no/_attachment/401633/binary/688760?fast_title=Rapport+Ring+1+kollektivfremkommelighet.pdf

Min, H. (1989). The multiple vehicle routing problem with simultaneous delivery and pick-up points. *Transportation Research Part A: General, 23*(5), 377-386.

Mirshekarian, S., Celikbilek, C., & Süer, G. A. (2015). A Heuristic for the Vehicle Routing Problem with Tight Time Windows and Limited Working Times.

Mitroff, I. I., Betz, F., Pondy, L. R., & Sagasti, F. (1974). On managing science in the systems age: two schemas for the study of science as a whole systems phenomenon. *Interfaces, 4*(3), 46-58.

Montané, F. A. T., & Galvao, R. D. (2002). Vehicle Routing Problems with Simultaneous Pick-up and Delivery Service. *Operational Research Society of India, 39*(1), 19-34.

Montané, F. A. T., & Galvao, R. D. (2006). A tabu search algorithm for the vehicle routing problem with simultaneous pick-up and delivery service. *Computers & Operations Research, 33*, 595-619.

Morana, J. (2014). Sustainable Supply Chain Management in Urban Logistics. In J. Gonzalez-Feliu, F. Semet, & J.-L. Routhier (Eds.), *Sustainable Urban Logistics: Concepts, Methods and Information Systems* (pp. 21-35). Berlin, Heidelberg: Springer Berlin Heidelberg.

Munuzuri, J., Larraneta, J., Onieva, L., & Cortés, P. (2005). Solutions applicable by local administrations for urban logistics improvement. *Cities, 22*(1), 15-28.

Nagy, G., & Salhi, S. (2005). Heuristic algorithms for single and multiple depot Vehicle Routing Problems with Pickups and Deliveries. *European Journal of Operational Research*, 1-28.

Navarro, C., Roca-Riu, M., Furió, S., & Estrada, M. (2016). Designing new models for energy efficiency in urban freight transport for smart cities and its application to the spanish case. *Transportation Research Procedia, 12*, 314-324.

Newman, I., & Benz, C. R. (1998). *Qualitative-quantitative Research Methodology: Exploring the Interactive Continuum*. Illinois, USA: Southern Illinois University Press.

Nocerino, R., Colorni, A., Lia, F., & Luè, A. (2016). E-bikes and e-scooters for smart logistics: environmental and economic sustainability in pro-e-bike Italian pilots. *Transportation Research Procedia, 14*, 2362-2371.

Nordli, Ø. (2017). Fjerner all gateparkering i Oslo sentrum fra 1.juni. *Aftenposten*. Retrieved from http://www.aftenposten.no/osloby/Fjerner-all-gateparkering-i-Oslo-sentrum-fra-1-juni-613958b.html

NRK. (2017). Rapport: Oslo-borgere sitter mest i kø i Norden. Retrieved from https://www.nrk.no/ostlandssendingen/rapport_-oslo-borgere-sitter-mest-i-ko-i-norden-1.13389261

Nurcahyo, G. W., Alias, R. A., Shamsuddin, S. M., & Sap, M. N. M. (2002). Sweep Algorithm in vehicle routing problem for public Transport. *Jurnal Antarabangsa Teknologi Maklumat, 2*, 51-64.

Onwuegbuzie, A. J., & Leech, N. L. (2005). On Becoming a Pragmatic Researcher: The Importance of Combining Quantitative and Qualitative Research Methodologies. *International Journal of Social Research Methodology, 8*(5), 375-387.

Oslo Kommune. (2017). Bilfritt byliv. Retrieved from https://www.oslo.kommune.no/politikk-og-administrasjon/slik-bygger-vi-oslo/bilfritt-byliv/

Osman, I. H. (1993). Metastrategy simulated annealing and tabu search algorithms for the vehicle routing problem. *Annals of Operations Research, 41*(4), 421-451.

Pannirselvam, G. P., Ferguson, L. A., Ash, R. C., & Siferd, S. P. (1999). Operations management research: an update for the 1990s. *Journal of Operations Management, 18*(1), 95-112.

Pedersen, E. F. (2015). *KVU Oslo-navet: Byutvikling og bymiljø: Vedlegg til konseptanalyse*. Retrieved from https://brage.bibsys.no/xmlui/bitstream/handle/11250/2366580/Oslo-Navet Byutvikling og bymilj%C3%B8 vedlegg 14.pdf?sequence=1&isAllowed=y

Perboli, G., Rosano, M., & Gobbato, L. (2016). Decision support system for collaborative freight transportation management: a tool for mixing traditional and green logistics.

Pichpibul, T., & Kawtummachai, R. (2012). An improved Clarke and Wright savings algorithm for the capacitated vehicle routing problem. *ScienceAsia, 38*(3), 307-318.

Pichpibul, T., & Kawtummachai, R. (2013). A heuristic approach based on Clarke-Wright algorithm for open vehicle routing problem. *The Scientific World Journal*.

Presttun, T. (2016). Varelevering og sykkel i by. Retrieved from http://www.sykkelbynettverket.no/_attachment/1523279/binary/1131967?download=true

Quak, H., & Tavasszy, L. (2011). Customized solutions for sustainable city logistics: the viability of urban freight consolidation centres *Transitions towards sustainable mobility* (pp. 213-233): Springer.

Rizzoli, A. E., Montemanni, R., Lucibello, E., & Gambardella, L. M. (2007). Ant colony optimization for real-world vehicle routing problems. *Swarm Intelligence, 1*(2), 135-151.

Robinson, S. (2008). Conceptual modelling for simulation Part I: definition and requirements. *Journal of the Operational Research Society, 59*(3), 278-290.

Robinson, S. (2011). *Choosing the right model: Conceptual modeling for simulation.* Paper presented at the Proceedings of the 2011 Winter Simulation Conference, Warwick Business School.

Rundberget, A. N., Storsul, E., Wilhelmsen, F., & Osnes, S. (2016). *My bicycle is loaded with.* Retrieved from Oslo: http://www.vegvesen.no/_attachment/1521729

Russo, F., & Comi, A. (2012). City characteristics and urban goods movements: A way to environmental transportation system in a sustainable city. *Procedia Social and Behavioral Sciences 39*, 61-73.

Saenz, J., Figliozzi, M. A., & Faulin, J. (2016). Assessment of the Cargo Footprint Reductions of Tricycle Logistics Services. *Journal of the Transportation Research Board, 2570*, 48-56.

Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research Methods for Business Students* (5th ed.). Essex, England: Pearson Education Limited.

Savelsbergh, M. W. P., & Sol, M. (1995). The General Pickup and Delivery Problem. *Transportation Science, 29*(1), 17-29.

Schliwa, G., Armitage, R., Aziz, S., Evans, J., & Rhoades, J. (2015). Sustainable city logistics - Making cargo cycles viable for urban freight transport. *Research in Transportation Business & Management*, 1-8.

Schoemaker, Allen, Huschebeck, & Monigl. (2006). Quantification of Urban Freight Transport Effects I. *Best Urban Freight Solutions II*.

SSB. (2016). Transport med små godsbiler, 2014-2015. Retrieved from https://www.ssb.no/transport-og-reiseliv/statistikker/transpsg/hvert-5-aar/2016-03-11 - content

Statens vegvesen. (2015). *Trucker's guide for kjøring i Norge*. Retrieved from https://www.vegvesen.no/s/pdf/donnadiesel/no// - 1/z

Statens vegvesen. (2016). El-sykkel. Retrieved from https://www.vegvesen.no/kjoretoy/Eie+og+vedlikeholde/elkjoretoy/El-sykkel

Tako, A. A., & Robinson, S. (2012). The application of discrete event simulation and system dynamics in the logistics and the supply chain context. *Decision Support Systems(52*, 802-815.

Taniguchi, E., Thomson, R. G., Yamadi, T., & van Duin, R. (2001). City Logistics: Network Modelling and Intelligent Transport Systems. *Journal of Transport Geography, 10*(2), 158-159.

TOMTOM Traffic Index. (2017). Oslo Traffic Congestion Statistics. Retrieved from https://www.tomtom.com/en_gb/trafficindex/city/oslo

Toth, P., & Vigo, D. (2002). *The Vehicle Routing Problem*. Philadelphia, USA: Society for Industrial and Applied Mathematics.

Transport for London. (2009). *Cycle freight in London: A scoping study*. Retrieved from London, England:

Transportøkonomisk Instistutt. (2017). Om Transportøkonomisk institutt (TØI). Retrieved from https://www.toi.no/om-toi/category6.html

U TURN. (2015). *D1.1 Current transport Practices and Needs*. Retrieved from http://www.u-turn-project.eu/uploads/5/7/8/1/57812149/d1.1_current_transport_practices_and_needs_v1.0_final.pdf

Urheim, H. B., & Winsvold, E. (2016). *Oslostandarden for sykkeltilrettelegging*. Retrieved from Oslo: http://copenhagenize.eu/dox/oslo_standard.pdf

Verlinde, S., Macharis, C., Milan, L., & Kin, B. (2014). Does a mobile depot make urban deliveries faster, more sustainable and more economically

viable: results of a pilot test in Brussels. *Transportation Research Procedia 4*, 361-373.

Welch, C., & Piekkari, R. (2006). Crossing language boundaries: Qualitative interviewing in international business. *Management International Review, 46*(4), 417-437.

Wikipedia. (2017). Great Circle Distance. Retrieved from https://en.wikipedia.org/wiki/Great-circle_distance

Wilmsmeier, G., Johansson, L., & Jallow, D. (2015). The complex urban freight puzzle.

Winston, W. L., & Goldberg, J. B. (2004). *Operations research: applications and algorithms* (Vol. 3): Thomson Brooks/Cole Belmont.

Yin, R. K. (2009). *Case Study Reseach: Desin and Methods* (4 ed.). Thousand Oaks, CA: SAGE Publications.

Yin, R. K. (2014). *Case Study Research: Design and Methods* (5th ed.). Thousand Oaks, CA: SAGE Publications, Inc.

Appendices

Appendix 1 – Key Literature Reviewed for The Thesis Proposal

Author	City logistics	Last-mile logistics	Operations research	Transportation research	Electric bike	Cargo bike	VRP	Cost efficiency	Productivity	Environmental effect	Research Method	Results
Angelelli & Mansini (2002)			x				x	x	x		Quantitative, mathematical formulation	Exact algorithm
Conway, Fatisson, Eickemeyer, Cheng & Peters (2011)		x		x				x			Comparative case study	Decrease in overall costs by changing transport mode
Cordeau, Laporte, Savelsberg & Vigo (2007); Cordeau, Desaulniers, Desrosiers, Solomon & Soumis (2000); Belfiore, Tsugunobu & Yoshizaki (2008)			x				x	x			Quantitative, mathematical formulation	Optimal algorithms
Dablanc, Giuliano, Holliday & O'Brien (2013)	x	x								x	Qualitative study	Strategies: last-mile, environment, trade node
Gillett & Miller (1974)			x				x				Quantitative, mathematical formulation	Sweep algorithm
Gruber, Kihm & Lenz (2014)	x			x	x			x			Empirical study (descr. stat. met.) Case study	Messengers positive to change of mode
Hagen, Lobo, Mendonca (2013)					x			x		x	Case study	Beneficial regarding emissions, urban space and economic activity
Kamga and Conway (2013)	x	x				x		x		x	Case study in NYC	Cargo bikes contributes to safety, little emission, faster speed, lower costs
Koning and Conway (2016)	x	x			x	x				x	Case study in Paris	Quantification of externality savings from growing cargo bikes
Leonardi, Browne & Allen (2012); Browne, Allen & Leonardi (2011)				x						x	Case study/Trial	Decrease in total distance/CO2 emissions
Maes & Vanelslander (2012)		x				x		x			Simulation	Cargo bikes were a viable alternative for vans
Montané & Galvao (2002)			x				x				Mathematical formulation	Heuristic procedures
Nagy & Salhi (2005)			x				x	x			Mathematical formulation	Heuristic procedures
Navarro, Roca-Riu, Furió and Estrada (2016)	x	x		x		x		x	x	x	Case study in Spain	Cost and CO2 savings, reduced distance(km)
Russo & Comi (2012); Russo & Comi (2010)	x									x	Case study	Classification of measures on the subject
Saenz, Figliozzi & Faulin (2016)		x		x		x				x	Case study in Portland, Oregon	Reduced CO2 emissions
Savelsbergh & Sol (1995)			x	x			x				Mathematical formulation	Exact algorithm
Schliwa, Armitage, Aziz, Evans & Rhoades (2015)	x			x		x				x	Qualitative study	New typology on the subject
Taniguchi, Thomson, Yamada, van Duin (2001)	x			x						x	Optimization models	Effective freight system
Verlinde, Macharis, Milan and Kin (2014)	x	x		x	x			x	x	x	Case study in Brussel	Reduced emission and punctuality of deliveries. More expensive than the original concept
Kjenne & Pham (2017)	x	x	x	x		x	x	x	x	x	Case study in Oslo, simulation, minor contribution to algorithm	Increased productivity, reduced CO2 emissions, increased service level

95

Appendix 2 – Mathematical Formulation

Based on Angelelli and Mansini's VRPSPDTW (2002):

Indices

i, j indices for nodes (customers). $i, j = 1, ..., N$

k index for vehicles. $k = 1, ..., K$

Parameters

n number of nodes (customers)

K number of routes or vehicles

V set of customers/fleet of homogeneous vehicles, V=1,…,v

c_{ij} distance between customer i and j (travel time/cost), $c_{ij} = c_{ji} \; \forall i, j \in N$

d_i amount (volume) of delivery demand of node i during a shift

p_i amount (volume) of pickup demand of node i during a shift

Q total vehicle capacity

Set of indices

D the set of delivery nodes (customers)

P the set of pickup nodes (customers)

L $D \cup P$

Decision variables

$X_{ij}^k = \begin{cases} 1, & if \; vehicle \; k \; drives \; directly \; from \; i \; to \; j \\ 0, & otherwise \end{cases}$

D_i^k amount (volume) of remaining deliveries carried by vehicle k when departing from customer i

P_i^k amount (volume) of collected pickup quantities carried by vehicle k when departing from customer i

T_i^k starting time of service of vehicle k at customer i

A path P is feasible if, for each $s = 1, ..., p$, the following conditions hold:

$$a_{i_s} \leq T_{i_s} \leq b_{i_s} \tag{1}$$

$$\sum_{k=1}^{s} p_{i_k} + \sum_{k=s+1}^{p} d_{i_k} \leq Q \tag{2}$$

where $T_{i_s} = max\{a_{i_s}, T_{i_{s-1}} + t_{i_{s-1}, i_s}\}$ indicates the time service started at node i_s.

The problem can be formulated as follows:

$$Minimize \sum_{k \in K} \sum_{(i,j) \in A} c_{ij} X_{ij}^k \tag{3}$$

subject to:

$$\sum_{k \in K} \sum_{j \in V} X_{ij}^k = 1 \qquad\qquad \forall i \in N \tag{4}$$

$$\sum_{i \in V} X_{ip}^k = \sum_{j \in V} X_{pj}^k \qquad\qquad \forall p \in N, \forall k \in K \tag{5}$$

$$\sum_{j \in N} X_{0j}^k \leq 1 \qquad\qquad \forall k \in K \tag{6}$$

$$\sum_{i \in N} X_{i,n+1}^k = \sum_{j \in N} X_{0j}^k \qquad\qquad \forall k \in K \tag{7}$$

$$D_i^k + P_i^k \leq Q \qquad\qquad \forall i \in V, \forall k \in K \tag{8}$$

$$D_{n+1}^k = 0 \qquad\qquad \forall k \in K \tag{9}$$

$$D_0^k = \sum_{i \in N} \sum_{j \in N} X_{ij}^k d_i \qquad\qquad \forall k \in K \tag{10}$$

$$P_{n+1}^k = \sum_{i \in N} \sum_{j \in N} X_{ij}^k p_i \qquad\qquad \forall k \in K \tag{11}$$

$$P_0^k = 0 \qquad\qquad \forall k \in K \tag{12}$$

$$X_{ij}^k\left(P_i^k + p_j - P_j^k\right) = 0 \qquad \forall i, j \in V, \forall k \in K \qquad (13)$$

$$X_{ij}^k\left(D_i^k + d_j - D_j^k\right) = 0 \qquad \forall i, j \in V, \forall k \in K \qquad (14)$$

$$X_{ij}^k\left(T_i^k + t_{ij} - T_j^k\right) \leq 0 \qquad \forall i, j \in V, \forall k \in K \qquad (15)$$

$$a_i \leq T_i \leq b_i \qquad \forall i \in V, \forall k \in K \qquad (16)$$

$$D_i^k \geq 0 \qquad \forall i \in V, \forall k \in K \qquad (17)$$

$$P_i^k \geq 0 \qquad \forall i \in V, \forall k \in K \qquad (18)$$

$$X_{ij}^k \in \{0,1\} \qquad \forall i, j \in V, \forall k \in K \qquad (19)$$

(2) ensures that total pickup and total delivery does not exceed total capacity

(3) is the objective function, which minimizes the total travel distance, travel cost or travel time of the routes

(4) implies that every customer must be visited once and only once

(5) guarantees that the vehicle entering/exiting each customer is the same

Notice that:

$$\sum_{k \in K} \sum_{i \in V} X_{ij}^k = 1 \qquad j \in N \qquad (20)$$

which is normally coupled with constraint set (4) in the assignment problem are redundant and therefore ignored.

(6) and (7) imply that a vehicle is used at most once, and force the route of each vehicle to start and end at the depot

(8) limit the maximum amount of freight on vehicle k, when it departs from node i, and is always lower than the vehicle capacity

(9) and (11) guarantee that the returning vehicles to the depot have fulfilled all deliveries, and brought back all pickups

(10) and (12) denotes that each vehicle leaves the depot fully loaded, while the pickup load is zero

(13), (14), and (15) means that each visited customer has been serviced either a pickup or a delivery, and the service time for each customer cannot be negative

(1) and (16) impose the time window

(17) ensure that vehicle k is loaded with remaining deliveries when departing from customer i

(18) ensure that vehicle k is loaded with collected pickup when departing from customer i

(19) the decision variable is a binary variable

Appendix 3 – Questionnaire to Chauffeurs of Vans

1. **Which areas does your route cover?**

   Van A:

   Majorstuen, small part of Frogner, and Grünerløkka

   Van B:

   Solli plass, Frogner, and Skøyen

2. **What is the average time spent on delivery and pickup of one package?**

   Van A:

   It is relatively fast, 2-3 minutes per stop.

   Van B:

   It is relatively fast, average 2 minutes per delivery/pickup.

3. **Is it possible to deliver and pickup simultaneously?**

   Van A:

   Yes, we continuously try to do match this, but it is not always possible. We try to pickup packages to be collected in the same area as we deliver packages.

   Van B:

   Yes, it is possible. The driver strives to achieve this - to pickup and deliver packages in the same areas. However, due to time congestion, before-12 deliveries can be a bit difficult. Often, the driver gets a call after leaving the area and must therefore return later (this also applies to after-12 deliveries).

4. **What do you do if there are more packages than capacity of the van?**

   Van A:

   Then we have to give away these packages to other drivers who have spare capacity. Packages should be delivered the same day they arrive at the terminal.

Van B:

These are situations that need to be considered whether the goods should be loaded in trucks instead, or use extra vans.

5. **What happens if you fail to deliver all packages, for example, if you receive an additional delivery?**

    Van A:

    First, we check whether we have spare capacity to deliver the additional package, otherwise we have to give the delivery to another chauffeur that has the capacity to take it.

    Van B:

    If drivers fail to deliver all packages/documents, they must be scanned as "non-delivered" and delivered the next day. But this should to a high degree be avoided. This has not happened to me during the past year.

6. **Size and weight of the packages: Are there any deviations with regard to order information and what is being collected?**

    Van A:

    Yes it may be.

    Van B:

    Yes, it happens very often. We get to know the size and weight of pickups to a certain extent. It was a case where 0kg was given on the package, but when I was to pick it up it was 15kg.

7. **How do you experience the working conditions in terms of pickups and deliveries?**

    Van A:

    It is stressful. I usually do not have time for lunch breaks.

    Van B:

    The delivery conditions are very stressful, especially in the case of before-12-deliveries. There is a lot of running, and little time for lunch break. The

drive is quite twisting at the start of the trip due to before-12-deliveries. There is lots of stops and waiting because of cyclists and pedestrians, which may be a bit stressful.

8. **Does the car often come into repair? What do you do if the car is not available as a result of this?**

Van A:

Usually only regular service, if you do not get into an accident. As drivers own the cars themselves or leases, they have to pay for damage etc. themselves.

Van B:

It is usually regular or routine services. It happens that there may be bumps and such on the car that causes it to be on service, but it is not often. The driver must rent a car if the car is at the workshop over a longer period of time, and it will be a cost to the driver.

9. **What do you do if there is no (legal) parking available?**

Van A:

Then I find a safe parking spot that is no danger to anyone. I try to avoid parking in front of crossings and pedestrian crossings that blocks the sight of other drivers/pedestrians.

Van B:

Then I have to find another parking solution, for example in the middle of the road or on the sidewalk. As long as I do not block traffic or pose danger to other cyclists, motorists or pedestrians.

10. **Have you experienced to get fines for illegal parking? In such cases, which areas/places does it usually take place?**

Van A:

If the car is properly parked, even if it is illegal, it will usually be just fine. But there is difference between municipal and private parking guards. Municipalities gladly explain to the driver that legal parking is required, while private parking carriers print fines. We try to avoid illegal parking

where it is possible. If you get a fine then the chauffeur himself has to pay for this. However, vans used for distribution of goods can stand up to 20 minutes parked, even in the middle of a street (not in tram tracks).
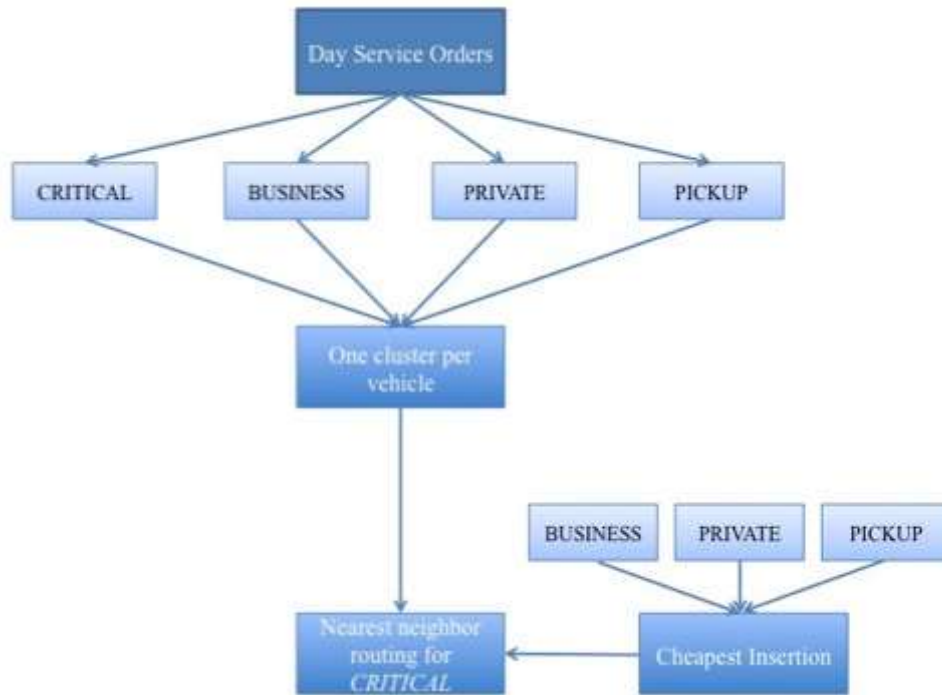
Van B:

As long as the parking does not pose a special hazard, it usually goes well. Parking guards usually show discretion and accept explanations. It is common to get a fine if the parking is too close to pedestrian crossing, but this is something that is avoided.

Appendix 4 – List of Meetings and Attendance

Date	Attendees	Place	Main objective	Length
20.09.16	JA, KF, AMK, DTP	TØI head office	Initial meeting, discussing potential themes/cases	60 min
22.09.16	MS, AMK, DTP	BI	Discussing two alt. themes	45 min
20.10.16	MS, AMK, DTP	BI	Choosing theme	15 min
05.01.17	MS, AMK, DTP	BI	Discussing preliminary thesis report	60 min
12.01.17	MS, AMK, DTP	BI	First draft prelim.	1h 30 min
20.01.17	JA, KF, TØ, AMK, DTP	TØI head office	Update on progress	30 min
02.02.17	MS, AMK, DTP	BI	Brief planning before meeting with TØI, DHL, Oslo municipality, Bymiljøetaten and Vegdirektoratet	15 min
03.02.17	JA, KF, TØ, TP, HJ, AA, JK, LJA, SO, AMK, DTP	Vegdirektoratet head office	Update on progress and orientation from DHL and Oslo municipality, work program from TØI	2h 30 min
07.02.17	JA, KF, TØ, AA, AMK, DTP	TØI head office	Discussing data	1h 30 min
13.02.17	MS, MA, AMK, DTP	BI	Discussing meeting report from feb. 3rd	1h 15 min
14.03.17	KF, TØ, AMK, DTP	Berger/Oslo	Attending delivery route	5h
20.03.17	MS, AMK, DTP	BI	Update from delivery route and simulation	30 min
10.05.17	MS, MA, AMK, DTP	BI	Discussing research design and simulation	1h 15 min
18.05.17	MS, AMK, DTP	BI	Discussing problem and method	1 h
01.06.17	KF, TØ, AMK, DTP	TØI head office	Update on progress	
09.06.17	MS, AMK, DTP	BI	Discussing method and data	1h 30 min
28.06.17	MS, AMK, DTP	BI	Discussing method and data	50 min
03.08.17	MS, MA, AMK, DTP	Skype	Discussion of generating the routes	35 min
03.08.17	MS, AMK, DTP	BI	Algorithm and real distance measurement	45 min
15.08.17	MS, AMK, DTP	BI	Comments 1st draft	1h 20 min
18.08.17	MS, AMK, DTP	BI	Discussing results test case	50 min
22.08.17	MS, AMK, DTP	BI	Discussing simulation results	40 min
23.08.17	MS, AMK, DTP	BI	Final discussion on simulation results	1h 30 min

Name	Initial	Organization/Role
Anders Aasgaard	AA	DHL Express
Anne Marthe Kjønnø	AMK	BI - Master student
Diem Tran Pham	DTP	BI - Master student
Helge Jensen	HJ	Bymiljøetaten Oslo
Jardar Andersen	JA	TØI - Chief Research Engineer
Jørn Kveseth	JK	DHL Express
Mehdi Sharifyazdi	MS	BI - Professor
Meisam Ashraf	MA	Phd in Mathematics/Programmer
Karin Fossheim	KF	TØI - Researcher
Liv Jorun Andenes	LJA	Bymiljøetaten Oslo
Simon Ohlin	SO	Bymiljøetaten Oslo
Tale Ørving	TØ	TØI - Researcher
Toril Presttun	TP	Statens Vegvesen

Appendix 5 – Revised Algorithm

Appendix 6 – SWOT matrix

Strengths
- Cost reduction (purchasing/running/parking)
- Low environmental impact
- No congestion charges
- Speed in congestion charge area
- Driver training
- Flexibility (accessibility/parking/one-way streets/turn on site)
- Shortcuts (infrastructure/traffic ligh
- High average speed

Weaknesses
- Load capacity (weight/volume)
- Turning radius too large
- Infrastructure and biking conditions
- Inapplicable for some types of deliveries/pickups
- Driver fatigue and security

SWOT

Opportunities
- Stricter policies regarding conventional vehicles
- Development of environmental zones
- Improvements on technical aspects
- Development of city hubs
- Better cooperation in the sector

Threats
- Competitors that offer higher load capacity and low emissions, such as electric vehicles
- Pressure from critical deliveries
- Complexity in terms of weather on performance