Sustainable solutions in first and last mile logistics: potential benefits and barriers

Auteur : Dupont, Maxime

Promoteur(s) : Paquay, Célia

Faculté : HEC-Ecole de gestion de l'Université de Liège

Diplôme : Master en sciences de gestion, à finalité spécialisée en global supply chain management

Année académique : 2021-2022

URI/URL : http://hdl.handle.net/2268.2/14552

SUSTAINABLE SOLUTIONS IN FIRST AND LAST MILE LOGISTICS: POTENTIAL BENEFITS AND BARRIERS

Master thesis by
Maxime DUPONT
For the purpose of obtaining a Master’s degree in Management with a specialization in Global Supply Chain Management
Academic year 2021/2022

Jury :
Supervisor :
Célia PAQUAY
Reader :
Manisha ANAND

Acknowledgements

First, I would like to express my greatest thanks to my thesis supervisor, Ms. Paquay, for her guidance throughout the writing of this thesis and for her valuable insights.

I would also like to express my gratitude to the various people who accepted to be interviewed and took the time to answer to my questions for the purpose of this thesis, although their names are not mentioned for confidentiality reasons.

Lastly, I would like to thank my family, as well as my friends and classmates, for supporting me during this period and proofreading my work.

Table of contents

1 List of abbreviations

B2B: Business-to-business

B2C: Business-to-customer

CL: City logistics

CO_2: Carbon dioxide

CVRP: Capacitated vehicle routing problem

EU: European Union

EV: Electric vehicle

FM: First mile

FML: First mile logistics

FMLM: First mile – last mile

FRT: Freight rapid transit

GHG: Greenhouse gas

ICE: Internal combustion engine

KPI: Key performance indicator

LCA: Life cycle assessment

LM: Last mile

LML: Last mile logistics

MILS: Metro-integrated logistics systems

PP: Pickup point

PRT: Personal rapid transit

RL: Reverse logistics

TCO: Total cost of ownership

UCC: Urban consolidation center

2 Introduction

Last mile logistics (LML) is a very researched subject as it is considered the least efficient part of the supply chain, due to its complexity (Bosona, 2020). It is often fragmented and uncoordinated. LML often takes place in very dense urban areas, with a high flow of vehicles. Moreover, each delivery corresponds to an individual customer and has to be transported to a different address, which means the destinations are often very scattered (Macioszek, 2018). This leads to a high number of stops, which further lowers the speed to delivery and increases travel time, leading to a decrease in cost efficiency (Nocera et al., 2020).

A big part of the transportation costs comes from the final delivery to the customers. LML accounts for up to 28% of the total delivery cost (Cardenas et al., 2017; Ranieri et al., 2018).

But the first mile of logistics (FM) also becomes more and more complex due to the growth of e-commerce marketplaces, which increases the fragmentation of pickup volumes. Yet this part of first mile- last mile logistics (FMLM) hasn't been as studied as the last mile, especially regarding sustainability.

The aim of this research is to highlight several solutions that can potentially improve the sustainability of the first and last mile logistics and identify the potential benefits and barriers to its implementation. Another objective is to verify if these concepts used in the last mile can also be applied to the first mile pickup. These research questions will be answered by analyzing the literature and the results from several qualitative interviews with logistics providers.

First, the context will be laid out in the next section. The causes and consequences of the urban freight transportation increase will be presented. The concept of sustainability will be defined and several reasons for companies to improve the sustainability of their logistics will be listed. The concept of first and last mile logistics will also be defined.

Afterwards, the methodology of this thesis, which consists of a literature review and qualitative interviews, will be described.

Then the results of the literature review and the qualitative interviews will be presented. The KPIs validated and complemented by the interviews will be summarized and classified in a table. The different solutions that were identified will be described, and the benefits and barriers of each concept will be listed and linked to the KPIs that were previously presented. These solutions include crowdshipping, parcel lockers, urban consolidation centers (UCCs), passenger/freight integration, electric vehicles (EVs) and cargo bikes. These results, obtained through the literature research and interviews with logistics providers, will be presented in a table and discussed in the following section.

Finally, the conclusion will briefly summarize the results, present the limitations of this thesis, and suggest some paths for future research.

3 Developments

3.1 Theoretical framework

Before identifying the KPIs and some solutions used to improve the sustainability of the first and last mile, the context will be introduced. We will briefly analyze the causes of the urban transportation increase and the consequences it can bring. Then an explanation of first and last mile logistics will be presented to better understand these parts of freight transportation.

The concepts of sustainability and sustainable transportation will also be presented, then we will analyze the different reasons why a company would be encouraged to adopt sustainable solutions in the first and last mile of logistics.

3.1.1 Causes of urban freight transportation increase

Several causes can be identified to explain the increase of freight flows in urban areas.

First, the growth of Internet and the development of e-commerce greatly increased urban freight transportation. Online shopping increased tremendously during the pandemic period in 2020 and 2021, and is likely to keep growing (Sahay & Wolff, 2021). Typically, e-commerce companies outsource the freight transportation to logistics providers. These logistics providers collect the parcels from various retailers, consolidate the deliveries and perform the last mile deliveries (Visser et al., 2014). According to the World Economic Forum, the growth of e-commerce could generate “36% more delivery vehicles in inner cities by 2030” (Sahay & Wolff, 2021, p. 3).

Furthermore, customer expectations are also getting stricter (for example, customers expect quick or same-day delivery). The trend of instant deliveries (or “quick commerce”), where businesses emphasize on the speed of delivery, is growing. These strict requirements cause an increase in the fragmentation of orders, which generates more traffic flows (Krechetova, 2021; Nocera et al., 2020).

Other factors also participate in this increase of urban freight, such as globalization, urbanization and the growth of the population (Bosona, 2020). Urbanization is still progressing in the EU and this trend will likely continue in the future, further increasing the density in urban areas and the need for urban freight transportation (Bergmann et al., 2020; European Environment Agency, 2020). According to estimations, 70% of the world population will live in cities by 2050 (Boysen et al., 2021).

3.1.2 Consequences of urban freight transportation increase

The negative externalities caused by the growth of urban freight, such as traffic congestion and greenhouse gas (GHG) emissions, are getting more and more visible (Krechetova, 2021). These externalities can be defined as indirect costs generated when the activity of a stakeholder impacts another group of stakeholders. In the case of transportation, these externalities include, for example, air and noise pollution, climate change, road accidents and infrastructure overuse (Ranieri et al., 2018).

In 2017, the transport sector (including air transport) accounted for 24.6% of total emissions in the EU. These GHG emissions are the main factor responsible for the climate change. The transport sector generates many other negative externalities in cities, such as congestion and noise pollution, which can have an impact on human health (European Environment Agency, 2020). In 2016, the total cost of externalities in the transport sector in the EU (excluding air and maritime transport) was estimated at €841 billion (5.6% of the EU-28 gross domestic product) (European Environment Agency, 2020).

Moreover, the growing number of trips will also generate more road accidents (Krechetova, 2021). In 2016, about 38% of road fatalities in the EU happened in urban areas (European Environment Agency, 2020).

Due to the growth of urban transportation, the need for transport infrastructure is also increasing and taking up space. This expansion leads to a higher fragmentation of land, bringing negative consequences to the environment. The land fragmentation caused by the transport infrastructure "alters the quality and connectivity of habitats and can create physical barriers to the movement of plants and animals between habitats" (European Environment Agency, 2020, p. 24). Furthermore, an increase of vehicles in traffic also means more infrastructure wear and tear (Ranieri et al., 2018).

With the growth of urban freight also comes an increased demand for labor: more drivers are needed to complete the deliveries. This new demand can be partially met by new solutions such as crowdshipping, which uses non-professional individuals to perform the last mile. However, this new type of business model is bringing concerns about the social protection of employees (Krechetova, 2021). This concept will be presented in more details later in this thesis.

3.1.3 Sustainable transportation

As urban freight transportation is increasing, companies are putting more sustainable first/last mile solutions in place to mitigate the negative externalities (Hu et al., 2019). Logistics providers tend to increase the use of lighter vehicles for urban logistics (Oliveira et al., 2017). We can also observe a growing interest in sustainable urban transport research, as the number of studies about solutions to improve sustainability in City Logistics (CL)[1] have greatly increased this past decade (Hu et al., 2019).

[1] Both city logistics and LML involve the transportation of freight in urban areas, but CL has a broader scope and is focused on the interactions between stakeholders (Cardenas et al., 2017; Visser et al., 2014). LML is considered as a part of city logistics (CL). The objective of this area of research is "improving the quality of life of the citizens"(Cardenas et al., 2017, p. 14).

3.1.3.1 Definition

Sustainable development can be defined as meeting "the needs of the present without sacrificing the ability of future generations to do the same" (Goldman & Gorham, 2006, p. 2). The objective is to achieve sustainability goals related to three aspects: economic, environmental, and social. Sustainable transport applies these goals to logistics. These three aspects of sustainability can be measured by several indicators, which will be presented later in this work. Sustainable urban transport aims at, notably, protecting human health and ecosystems, and limiting the negative externalities generated by transportation, such as GHG emissions, air and noise pollution (Goldman & Gorham, 2006). The concepts of sustainability and sustainable transportation are defined in more details by Goldman and Gorham (2006).

3.1.3.2 Motivations for improving sustainability

Various reasons can incite companies to adopt more sustainable solutions in logistics. These motivations can be internal (from inside the company) or external (outside the company, linked to other stakeholders) (Lozano, 2015).

For instance, increasing the cost efficiency (thus the profits) is an internal reason for the adoption of more sustainable solutions (Lozano, 2015). The typical last mile delivery, where the goods are delivered at the customer's home (also called attended delivery), is very costly and has a high delivery failure rate. These costs could be dramatically reduced by implementing more efficient solutions, such as parcel lockers (which will be discussed in a later section), where the delivery failure rate is usually lower (Bosona, 2020).

The ethical obligation to improve the company's sustainability can be seen as a strong internal driver as well (Lozano, 2015).

On the other hand, customer expectations are an important external motivation (Lozano, 2015). Consumers buy more categories of products online than a few years ago, such as clothes, food, home appliances or furniture (Ranathunga et al., 2021). Furthermore, customers become more and more conscious of the environmental impact of e-commerce. According to the World Economic Forum, environmental reasons are cited by 56% of millennials when an alternative to attended delivery is chosen, and "more than half of consumers say they are conscious of environmental issues in e-commerce" (Sahay & Wolff, 2021, p. 10).

In addition to the increasing customer awareness, local authorities tend to impose new legislations encouraging logistics providers to implement more sustainable solutions. For example, vehicle restriction measures like low-emission zones would incite businesses to use more environmentally friendly vehicles, like electric vehicles (EVs) (Boysen et al., 2021; Hu et al., 2019).

Brand image can be another external driver for the implementation of sustainable FMLM solutions (Lozano, 2015). The last mile delivery especially is highly visible as it usually happens in very populated areas (in the city center). The use of alternative vehicles (such as bikes) could have a positive effect on the company's image (Visser et al., 2014).

Several other reasons can be found in the literature. Lozano (2015) studied the internal and external corporate sustainability drivers in more details.

3.1.4 First and last mile logistics: typology

In order to better understand what is considered as the first and last mile of logistics, a definition will be provided for these two concepts.

3.1.4.1 First mile logistics

First mile logistics (FML) is the part of logistics related to the collection of parcels. However, the definition of "first mile" can vary greatly depending on the point of view. For a manufacturer, it is the segment where the materials enter the supply chain. From the logistic provider point of view, it is the part of the delivery where the goods are collected from the manufacturer (or at a warehouse), then stored at an intermediate stop (it can be a regional warehouse, a consolidation center,…) (Krechetova, 2021). In this thesis, we will mostly focus on the logistics provider's point of view.

Figure I represents a simplified version of the first mile – last mile structure.

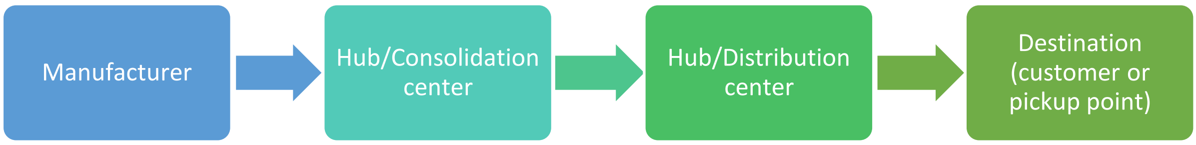

Figure I. First mile – last mile logistics structure (source: own composition based on Bosona (2020))

Typically, the goods are first collected from the supplier, then stored and consolidated in a hub. There can be a long-haul transportation between the consolidation center and another hub closer to the end destinations of the packages. This long-haul segment is usually done using heavier vehicles (such as trucks) and can be identified by a higher speed and shorter travel time compared to the first and last mile (Bosona, 2020; Nocera et al., 2020). After this long-haul segment begins the "last mile", where the goods are deconsolidated in the distribution center, reloaded in generally smaller vehicles, then shipped to the final delivery point (Krechetova, 2021; Oliveira et al., 2017).

3.1.4.2 Last mile logistics

Last mile logistics (LML) is the part of logistics dedicated to the last mile delivery. It is the delivery of the products to the end customer or to the end destination. It is the last step (or "leg") of the supply chain. The term "last mile" was first used by cable TV companies in the telecommunication sector, back when the technology was growing and each individual household had to be connected to the cable television system (Nocera et al., 2020).

The term LML is often used to define home deliveries in a "business-to-customer" (B2C) context. But it can also include "business-to-business" (B2B) deliveries (to restaurants or retail stores, for example) (Cardenas et al., 2017).

The destination may be the final user's location or a pickup point, such as a parcel locker. In that case, the last part of the LM is accomplished by the customer (Cardenas et al., 2017; European Environment Agency, 2020).

3.1.4.3 First mile – last mile structure

On figure II, we can see a schema representing the first mile – last mile (FMLM) structure. As mentioned before, the transportation of freight can be divided into three parts: FM, long-haul and LM segment.

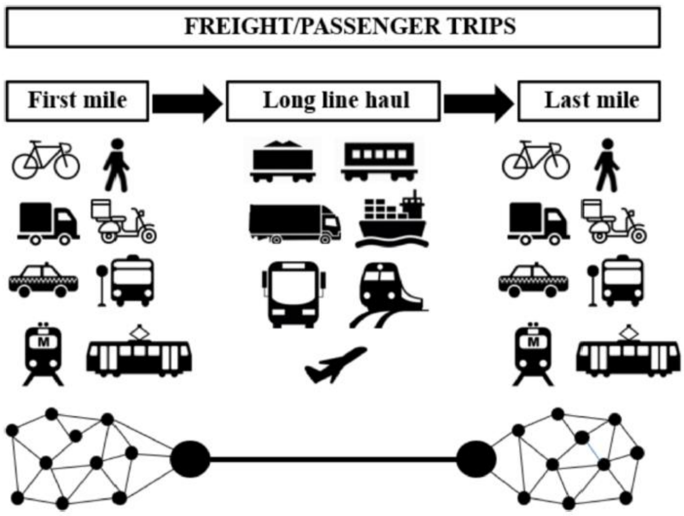

Figure II. Simplified FMLM schema (source: (Nocera et al., 2020, p. 6))

As we can see on figure II, the first mile pickup follows a "hub-and-spoke" network: the goods are collected from multiple sources then shipped to a sorting center (Ballare & Lin, 2020). The first and last mile logistics have a "many-to-one" and a "one-to-many" structure, respectively. Between these two segments is the long-haul transportation (Nocera et al., 2020).

FMLM can be applied to passenger or freight transportation. In this work, we will mainly focus on freight transport. FML and LML could also use a different mode of transportation, like maritime or air transport (by using drones, for example). In this thesis, we will only focus on road transport as this is the main mode responsible for externalities caused by deliveries in urban areas (Bosona, 2020; Ranieri et al., 2018).

3.2 Methodology

Now that the context has been presented, the methodology used in this thesis will be described in this section.

First, research in the literature was needed to identify the commonly used KPIs to measure the efficiency of FMLM solutions in a sustainability point of view. Another objective of the documentary research was to identify several potential solutions that could improve the sustainability of the

FMLM. The potential benefits and barriers of these concepts have been identified by studying which KPIs are impacted by each solution.

After the literature review, several interviews with logistics companies were carried out to validate the results obtained during the literature research stage, and to identify other potential solutions that could improve the sustainability of FMLM. This analysis has been conducted in the form of qualitative interviews with logistics companies that perform the first and/or last mile of delivery.

The interviews were semi-structured: for that purpose, an interview guide has been elaborated, and consisted of open questions based on what was highlighted during the literature review. This list served as a guide only: some questions were added or deleted after each interview, and more emphasis was put on a specific solution implemented by a company if it seemed promising. The objective of these semi-structured interviews was to keep a natural flow of conversation and bring up new ideas that were not identified during the literature research.

First, some questions briefly inquired about the context of the company. Then the question focused on the KPIs that are used, the solutions that were implemented or considered, how it was implemented (or why it wasn't) and what were the benefits and barriers of each of these solutions. The objective of these interviews was also to verify if these concepts used in the LML could be applied to the FML as well.

3.3 <u>Results</u>

3.3.1 Qualitative interviews

3.3.1.1 Interview guide's content

Like mentioned previously, the qualitative interviews were semi-structured, and an interview guide was elaborated. The questions were open and based on the literature review, as the objective of the interviews was to validate and complement the results obtained during the documentary research.

First, a summary of the qualitative interview's objectives was elaborated to remind the interviewees of the subject at the beginning of each interview. Then the interview itself would begin, using the list of questions as a guide.

These open questions were divided into three main sections. The guide was structured as follows:

- Context: some questions are asked to check if the company is familiar with the concept of sustainability, if it is specialized in FM, LM or both… It includes questions about the fleet of vehicles and other questions linked to the context;
- KPIs: questions about the most used indicators linked to sustainability;
- Solutions: questions about what was implemented at the company, what were the impacts of these solutions and the obstacles to its implementation…

The guide was adapted after each interview. The final model of the semi-structured interview guide can be found in appendix n°1.

3.3.1.2 Selection and profile of the interviewed companies

Several meetings with various logistics companies were organized. The companies targeted were logistics providers active in Europe, that are active in the first and/or last mile of logistics. Most companies were selected by carefully reviewing logistics providers that are members of "Logistics in Wallonia", which is an innovation cluster for the logistics sector in the region of Wallonia, in Belgium[2]. An important objective of "Logistics in Wallonia" is the improvement of sustainability in logistics. This cluster has a network of more than 350 members (Logistics in Wallonia, 2020).

Table I is an overview of the companies interviewed. For confidentiality reasons (some data that was gathered is sensitive, such as plans to collaborate with transport operators or cities), the names of the companies are not mentioned.

Table I. List of the interviewed logistics providers (source: own composition)

Company	Person of contact (occupation)	Area of activity	Main solutions implemented	Group
Company 1	Continuous Improvement Officer	Europe	Electric vehicles, cargo bikes	A
Company 2	Sourcing Manager	Europe	Electric vehicles, alternative fuel vehicles (natural gas)	A
Company 3	Operational manager	Europe	Electric vehicles	A
Company 4	Circular Business Designer	Europe	Electric vehicles, alternative fuel vehicles, cargo bikes	A
Company 5	Project manager	France	Electric vehicles, urban consolidation centers	A
Company 6	Founder	Belgium, Luxembourg	Electric vehicles, cargo bikes	B
Company 7	Operational manager	Belgium	Cargo bikes	B
Company 8	Co-founder	Belgium	Cargo bikes	B

[2] More information on the cluster and the list of members can be found at: https://www.logisticsinwallonia.be/en

The interviewed companies can be divided into two groups, based on the similarities of the results and the size of the company. Group A typically consists of bigger companies, which are active on a large area and are using similar solutions, with a focus on electric vehicles. Group B consists of smaller and local companies, with a focus on cargo bikes.

In the following sections, a summary of the results will be presented: first the most used KPIs will be identified, then each solution highlighted during the literature research or the interviews will be discussed.

3.3.2 Key performance indicators

To be able to evaluate the efficiency of a potential solution for the FMLM, it seems important to first identify some KPIs related to the economic, environmental, and social aspect of sustainability.

These indicators of performance can also be useful for studying the impact of each solution on the sustainability of logistics and for comparing them.

First, an analysis in the literature was performed to identify and classify these KPIs. Then the results from the interviews were used to validate the findings and establish a list of the most used and relevant KPIs in the field. These indicators can be classified based on the three aspects of sustainability (economic, environmental and social).

3.3.2.1 Economic

- Distance traveled (in kilometers): total distance traveled to accomplish the deliveries (or the collection). The distance from a depot and distance between stops have an influence on logistic costs (Bosona, 2020). The distance traveled per parcel can be reduced by making more deliveries (or pickups) per trip (Visser et al., 2014). Routing problems (such as the milk run problem) can be used to reduce distance and costs (Cardenas et al., 2017). This indicator can belong to the environmental and social categories as well, as it can influence other KPIs, such as CO_2 emissions and air pollution (European Environment Agency, 2020; Visser et al., 2014).

- Cost per delivery: the cost can be calculated based on the delivery time and distance traveled (Nocera et al., 2020). Many other factors can affect the cost, like the number of stops per trip (in average), the delivery success rate (a failed delivery attempt generates an extra cost), the density of the delivery area (the cost per delivery decreases if the density increases), the vehicle used (Nocera et al., 2020)…

- Delivery time: it is the total time needed to carry out the deliveries (route): it includes the travel time (the time needed to actually travel the route), waiting time (like parking) and the loading/unloading time (Savelsbergh & Sol, 1995). This indicator is closely related to the delivery distance and cost: a long delivery time increases the delivery costs. The delivery time can be impacted during the last mile delivery by problems in the urban areas such as congestion (Nocera et al., 2020). Stopping/parking time also influences logistic costs (Bosona, 2020). A long delivery time can negatively impact the customer satisfaction as well (Bosona, 2020).

- Number of transshipments: this number is higher if, for example, an additional hub is used. It generates additional costs, like labor-related expenses (Nocera et al., 2020).

- Load factor (or vehicle capacity usage): it is often low in LM logistics, and thus not cost-effective (and generating more vehicle trips). In order to quickly respond to the demand, logistics providers often perform deliveries without using the full capacity of their vehicles (Nocera et al., 2020). This KPI can be classified as an environmental and social indicator as well, since it influences the vehicle flows.

- Customer satisfaction/inconvenience: different ways to measure the customer satisfaction and inconvenience exist. Models can be based on factors such as the pickup delay (the difference between the desired pickup time and the effective pickup time) or the delivery delay (Savelsbergh & Sol, 1995). According to several interviewed companies, the delivery failure rate can also determine the satisfaction (a failed delivery attempt can lead to customer dissatisfaction).

- Delivery success and failure rate: a failed delivery can have a big impact on the delivery time and cost. This rate can also have a major impact on CO_2 emissions. According to Dell'Amico and Hadjidimitriou (2012), a 10% failure rate can increase CO_2 emissions by 15%, while a 30% failure rate can increase emissions by 45%. This increase can go up to 75% for a 50% failure rate (Dell'Amico & Hadjidimitriou, 2012). Researchers mention that 12% of deliveries fail and have to be redelivered, and 2% of the products are never successfully delivered (Visser et al., 2014). Many delivery failures are due to the delivery time window (like a small time gap or lack of information) (Bosona, 2020). Unattended delivery methods such as parcel lockers have a higher successful delivery rate than attended delivery (Bosona, 2020). Parcel lockers will be further described in a later section. We can consider this indicator as environmental and social as well, due to its influence on costs, customer satisfaction and polluting emissions.

3.3.2.2 Environmental

- CO_2 emissions: CO_2 is a greenhouse gas contributing to climate change. In the EU, the transport sector accounted for 24,6% of the total GHG emissions in 2017. Road transport accounted for 71.7% of the total emissions in this sector (European Environment Agency, 2020). Many factors can influence the CO_2 emissions, like the distance traveled by the vehicle (closely related KPI), the type of vehicle (lighter, more fuel-efficient vehicles generate fewer emissions) and energy used (using electricity or biofuel can cause less CO_2 emissions per unit consumed than petrol) (Visser et al., 2014).

- Energy consumption: the quantity of energy (petrol, diesel, electricity…) consumed by the vehicle. Energy efficiency is another indicator closely related to this KPI: it can be increased by minimizing the energy consumption of the fleet. The scheduling of the collection/delivery route can have a big impact on the energy consumption (and thus the delivery cost). Real-time scheduling models can be used to minimize the energy consumption of the fleet, thus improving energy efficiency (Bányai, 2018). This indicator is related to other KPIs such as the CO_2 emissions (Visser et al., 2014).

3.3.2.3 Social

- Noise pollution (or noise level): the biggest source of noise pollution in cities is road traffic. The noise pollution can negatively impact the quality of life and long-term exposure contributes to high stress levels, sleeping issues, heart diseases and metabolic system issues. Wildlife is also impacted by high noise levels (European Environment Agency, 2020). Thus this indicator is related to the environmental aspect as well. This indicator in particular was not measured by the interviewed companies.

- Air pollution (or air quality): air pollution can cause health issues: in the European Union (EU), it is considered the "most important environmental cause of premature death" (European Environment Agency, 2020, p. 22). Many EU citizens still live in areas where the air pollution concentration doesn't meet the EU's air quality standards, nor the World Health Organization guidelines (European Environment Agency, 2020). Air pollution is also closely related to the environmental aspect. This indicator was not measured by the interviewed companies but was considered when implementing some sustainable logistics solutions, such as cargo bikes.

- Level of collaboration/engagement of stakeholders: as we will observe later, several FMLM solutions require a high level of collaboration between various stakeholders (Akgün et al., 2020). However, no precise method to measure the level of collaboration was found in the literature or the qualitative interviews.

- Employee satisfaction: this indicator can include different aspects such as the working conditions or the stress level, and can be used to compare different logistical solutions. For example, cargo bikes can improve the employees' working conditions since parking restrictions are less strict compared to conventional vehicles (Bosona, 2020).

We can observe that many KPIs can also be classified under several categories, and most of these indicators are interrelated: any impact made on one KPI can in turn have an influence on several other ones.

Below is a table that summarizes the KPIs identified during the literature research (table II). The indicators are classified based on the three aspects of sustainability, but it is possible to use a different method of classification.

Table III is an example of a different classification. In this table, the KPIs are classified based on which stakeholder the indicator is focused on. The stakeholders can be divided into three categories: the businesses (the logistics providers performing the FMLM), the customers, and other stakeholders (like the citizens, employees and the city administration), who are also affected by the transportation of freight (and its negative externalities).

Table II. Sustainability KPIs identified in the literature (source: own composition)

<table>
<tr><th>Economic</th><th>Environmental</th><th>Social</th></tr>
<tr><td colspan="3">• Distance traveled (MINIMIZE)
• Load factor (MAXIMIZE)
• Delivery failure rate (MIN)</td></tr>
<tr><td colspan="2">• Energy consumption (MIN) / energy efficiency (MAX)</td><td></td></tr>
<tr><td></td><td colspan="2">• Noise pollution (MIN)
• Air pollution (MAX)</td></tr>
<tr><td>• Delivery cost, cost per delivery (MIN)
• Customer satisfaction/inconvenience (MIN)
• Delivery time (MIN)</td><td>• CO_2 emissions (MIN)</td><td>• Employee satisfaction (MAX)
• Level of collaboration/engagement of stakeholders (MAX)</td></tr>
</table>

Table III. Another classification of the KPIs (source: own composition)

Focus on the business	**Focus on the customer**	**Other affected stakeholders: citizens, city administration, employees**
• Distance traveled (MINIMIZE) • Delivery cost, cost per delivery (MIN) • Delivery time (MIN) • Load factor (MAX) • Energy consumption (MIN) / energy efficiency (MAX)	• Customer satisfaction/inconvenience (MIN) • Delivery failure rate (MIN)	• CO_2 emissions (MIN) • Air pollution (MAX) • Noise pollution (MIN) • Level of collaboration/engagement of stakeholders (MAX) • Employee satisfaction (MAX)

A summary of the KPIs used by the companies interviewed (in both groups, A and B) can be useful to identify which are the most used indicators in practice. Here is a list of the main KPIs identified through the interviews:

- CO_2 emissions per ton delivered/km traveled: this indicator gives the ability to companies to compare different FMLM solutions;
- CO_2 saved per km traveled: the CO_2 saved can be calculated by comparing the emissions of a FMLM solution with the average emissions of a motorized vehicle (like a diesel van);
- Delivery success rate and failure rate (in %): failed attempts are often caused by a lack of information about the customer (what is the time window, the destination…);
- Kilometers (km) traveled in total;
- Km traveled per delivery: the lower it is, the more cost-efficient it becomes (since the density of destinations is higher);
- Energy consumed;
- Load factor in m^3 and kg;
- Number of packages delivered per hour/month;
- Number stops per trip/month: this indicator can be impacted by the type of customer. For example, big retailers constitute one stop but the volume to deliver is typically bigger compared to individual customers;
- Average delivery time;
- Number of breaks, dysfunctions: mostly used by cargo bike companies (in group B). The geography of the land and quality of the road have a great impact on this indicator. It can be mitigated by providing safe riding training to employees, using high-quality bikes, reducing the load…;
- Employee comfort and satisfaction;
- Customer satisfaction rate (can be estimated by analyzing online surveys…).

Using these results to complete the literature review, we can come up with a summary of relevant KPIs that are commonly used in practice to measure the sustainability of FMLM (see table IV):

Table IV. Relevant Sustainability KPIs identified through the literature research and qualitative interviews (source: own composition)

<table>
<tr><th>Economic</th><th>Environmental</th><th>Social</th></tr>
<tr><td colspan="3">• Distance traveled: km traveled in total or per delivery
• Load factor (vehicle capacity usage) in m^3 and kg
• Delivery failure rate</td></tr>
<tr><td colspan="2">• Energy consumption</td><td></td></tr>
<tr><td>• Number of breaks</td><td></td><td>• Number of breaks</td></tr>
<tr><td>• Number of stops per trip/month
• Number of parcels delivered per hour/month
• Cost per delivery/parcel delivered (in €)
• Customer satisfaction (%)
• Delivery time (average time to deliver a parcel)</td><td>• CO_2 emissions: per parcel, ton delivered or per km
• CO_2 emissions saved per km</td><td>• Employee satisfaction</td></tr>
</table>

Externalities such as noise and air pollution were not included as it wasn't measured in practice by the companies. The level of collaboration between stakeholders was also often mentioned, but no method to measure it was found in the literature or by analyzing the qualitative interviews.

Some KPIs can be measured in different ways. For example, CO_2 emissions can be expressed as the emissions generated by parcel delivered, or the emissions saved per kilometer. The load factor can be measured in both cubic meters and kilograms.

We can also observe that several KPIs have an influence on all three aspects of sustainability. For example, the distance traveled could be considered as an economic (since it impacts the delivery cost), environmental and social indicator (a longer delivery distance generates more GHG emissions and air pollution) (European Environment Agency, 2020; Visser et al., 2014).

The following sections will focus on different solutions put in place by logistics providers to improve some of those indicators. These solutions include crowdshipping, parcel lockers, electric vehicles, cargo bikes, urban consolidation centers and passenger/freight transport integration. Each solution can have an influence on a different set of KPIs.

3.3.3 Crowdshipping

Crowdshipping consists in outsourcing the last mile delivery of the goods to local and non-professional individuals, also called "crowd drivers" (Perboli et al., 2021). This solution is part of the shared mobility economy: the principle is that the access to transportation services is shared between people (Qi et al., 2018).

The crowdshippers can choose their own means of transportation to deliver the goods or use public transportation (or a combination of different modes) (Simoni et al., 2020). For example, it can be an individual passing by the area of delivery by car and willing to make a detour. The crowdshippers often take the order using a digital platform. This platform serves as a meeting place between the companies and the crowdshippers (Comi & Savchenko, 2021). This concept is sometimes called "uberization" of the delivery, since it is similar to ridesharing services such as Uber (Krechetova, 2021).

Simoni et al. (2020) make the distinction between car-oriented and public transit-oriented crowdshipping. In the public transport-oriented type, the passenger picks up the parcel at a depot/locker situated near the railway or metro station, performs the delivery by public transport, then covers the rest of the distance on foot. In the car-oriented type, the driver picks up the package at a pickup point (a parcel locker or a store, these concepts will be defined in the next section) outside the city, then uses their own car to perform the last mile.

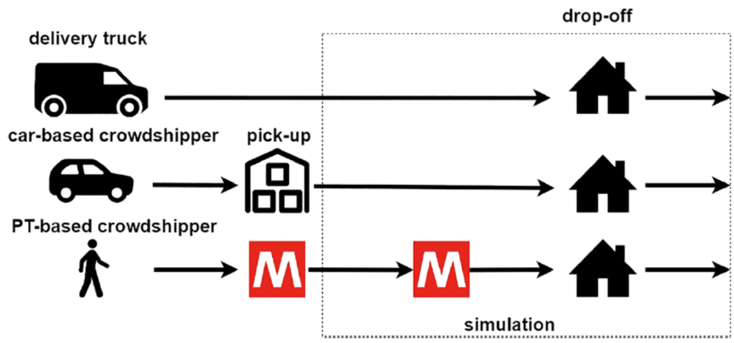

Figure III. Traditional delivery and two different crowdshipping delivery systems (source: (Simoni et al., 2020, p. 9))

3.3.3.1 Benefits

An economic benefit is that logistics providers would need a smaller fleet of vehicles (since crowdshippers use their own vehicle), which means investments in vehicles are greatly reduced (Qi et al., 2018). Thus crowdshipping can be considered as a complementary solution to a traditional, professional delivery fleet: packages that were not taken care of by crowdshippers could be delivered by the professional fleet (Gdowska et al., 2018). This system can bring additional flexibility to logistics providers: in case the quantity of parcels to deliver increases, crowdshippers can be used instead of increasing the delivery fleet (Na et al., 2021).

Moreover, the delivery costs can be reduced thanks to an efficient use of the workers' idle capacity, a decreased number of delivery trips and a cheaper workforce (Simoni et al., 2020).

Crowdshipping could also bring other benefits such as a reduction of the distance traveled and thus in the CO_2 emissions (Hu et al., 2019; Na et al., 2021; Punel & Stathopoulos, 2017).

3.3.3.2 Barriers

Like mentioned previously, this solution can provide flexibility for workers and the companies. This type of job is often called "on-demand" or "gig", as the workers can choose their schedule and work at the time that is most convenient for them. From a social point of view, this solution could bring societal benefits by helping in reducing unemployment (Na et al., 2021). However, the workers' status is often closer to entrepreneurship compared to a regular employee contract. For this reason, this type of work could create social inequalities: the workers often get less benefits and social protection than in a more traditional contract, like health insurance or unemployment protection (Krechetova, 2021). Several companies (n°4,6 and 8) also mentioned the ethical and social problems brought by the gig workers' status. The workers are not under a traditional contract and are less socially protected than regular employees. Companies would need to be careful about social issues when considering this solution.

Moreover, the efficiency of this solution greatly depends on the availability of crowdshippers (Ballare & Lin, 2020). For this solution to be effective, a sufficient number of workers would need to be attracted to attain a "critical mass". Otherwise, the quality of the deliveries could be negatively impacted by the lack of workers, and the number of customers would decrease. However, a critical mass of customers is also needed in order to attract more workers (Qi et al., 2018). The difficulty to attract crowdshippers was brought up by some companies (n°4 and 6), mainly due to the competition with other platforms, such as Deliveroo or Takeaway, that have a similar business model based on gig workers. Thus there might not be enough workers to organize all the deliveries. Moreover, it could be difficult to coordinate the crowdshippers' trips when the goods have to be delivered during a specific time window.

Trust building issues can also arise between the logistics operator, the crowdshipper and the customer, since the packages are transported by local and non-professional individuals (Qi et al., 2018). This was mentioned by an interviewee (n°6). There were trust issues between the company and the crowdshippers as there was the concern that parcels might get "lost" in transit.

Qi et al. (2018) also found that the scalability of such a solution is challenging: the cost efficiency tends to decrease when delivery demand increases. This means that crowdshipping could only be more cost-efficient than traditional delivery (a professional vehicle fleet only) as long as the demand doesn't reach a certain limit. It can be explained by the wage payment difference between truck drivers and shared mobility drivers: truck drivers are paid proportionally to the delivery distance, while crowdshippers are paid per gig. For this reason, the total wage tends to increase faster for crowdshippers than for truck drivers as the number of trips increases (Qi et al., 2018).

Moreover, according to the same researchers, there might be no significant change in GHG emissions between traditional and shared mobility delivery using cars. Cars, often used for crowdshipping, have a lower emission rate than trucks and vans, but the loading capacity is lower so more trips are needed to fulfill the deliveries (and thus the distance traveled and energy consumption increase) (Qi et al., 2018).

To conclude, the benefits of this solution are still vague as it depends on many factors: which means of transportation did the crowdshipper use, what is the additional distance caused by the detour (Simoni et al., 2020)… The choice of mode especially can have a large impact on the potential benefits (Punel & Stathopoulos, 2017). Crowdsourced deliveries by car could even generate a higher negative impact on traffic and emissions than traditional deliveries. The negative externalities are also higher if the drivers make dedicated delivery trips, thus it can be difficult to evaluate the sustainability of such a solution (Simoni et al., 2020).

These results obtained through the literature seem to be confirmed by the qualitative interviews. Crowdshipping is not used by any company interviewed at the moment. Some interviewees (n°4 and 6) have done some testing to try to implement this solution as it can bring many benefits, like a potential reduction in delivery costs. However, several obstacles were encountered during the testing, like the ethical issues and the difficulty to attract enough crowdshippers. There were many uncertainties and the companies decided not to pursue this solution.

3.3.4 Parcel lockers

Parcel lockers are unmanned collection points. These lockers (also called bentobox and parcel stations in the literature) are often located in strategic points like in shopping malls, residential area and other locations relatively close to the customers (Dell'Amico & Hadjidimitriou, 2012; Visser et al., 2014). An example of this solution is DHL's network of automated parcel lockers, in Germany (Ballare & Lin, 2020).

Instead of delivering the parcels to each individual customer, logistics providers can store these packages in parcel lockers. The customers can collect their parcels when it is convenient for them (meaning they are the ones that perform the last leg of delivery) (Cardenas et al., 2017). The location of the parcel lockers is an important factor for the efficiency of this solution. It can have an impact on many KPIs, such as the delivery costs and emissions (Na et al., 2021).

Parcel lockers can be seen as a type of pickup point (PP). Pickup points are alternative delivery destinations where the customer can collect their package. There are two different types (Visser et al., 2014):

- Parcel service points, which are staffed and are often located in convenience stores or supermarkets. These are the most common type;
- Parcel lockers, which we will be our focus in this work.

Pickup points are also used in combination with attended delivery: it can be an alternative delivery destination in case home delivery failed (Visser et al., 2014).

Another innovative variation of parcel lockers is the modular bentobox: modules (trolleys) containing drawers of different sizes can be removed from the bentobox, then are filled with the packages at a depot. Once the module is filled up, it is transported and put back into the fixed part of the bentobox system. Thus, the transporter only needs to make one stop to deliver all the packages contained in the module. According to models, this solution could decrease failed deliveries and delivery time (thus reducing emissions) (Dell'Amico & Hadjidimitriou, 2012). A company in particular (n°6) is testing another variation of parcel locker: a mobile pickup point system. This mobile parcel locker will move around the city during the day, and the customers can come and pick up the packages at the most convenient time and location for them. This solution has already been tested once before but wasn't successful. One problem is that at least one person needs to manage the mobile pickup point, which generates additional costs. Mobile parcel lockers, specifically autonomous lockers, have been studied in the literature as well. The main advantage of this solution is that it can reach more customers compared to stationary lockers. Thus the number of lockers could be reduced (Boysen et al., 2021).

Parcel lockers are seen as an interesting solution for many interviewees (in both group A and B). It can be used as the main delivery method, but it is also seen as an alternative to attended delivery if the first delivery attempt has failed, in order to reduce costs. Several companies (in group B) are considering a collaboration with big operators such as Bpost, that already have a wide network of parcel lockers.

These lockers can also be used in reverse logistics (RL) to collect the parcels to be returned (Bell, 2021). In RL, the flow of goods is reversed: the objective is to collect the goods from its end customer and return them to the supplier. The segment where the goods are collected from its individual users is known as the first mile of reverse logistics (Jäämaa & Kaipia, 2022). A company (n°4) added that they can deliver packages to the parcel lockers, and at the same time collect the parcels that have to be returned, thus integrating both flows of goods.

3.3.4.1 Benefits

There are several advantages compared to traditional attended delivery. One benefit is that the customer isn't forced to wait at home to receive the package and can collect it at a time that is most convenient for them (Bell, 2021).

By delivering the goods to a parcel locker, the carrier can consolidate the deliveries much more easily: this can increase the cost efficiency and lower the delivery time and distance per delivery, meaning fewer emissions and congestion (Visser et al., 2014). Moreover, this decreased delivery distance can allow the use of lighter and less polluting vehicles (such as electric vehicles) more easily, further reducing CO_2 emissions (Dell'Amico & Hadjidimitriou, 2012). Based on the results of the qualitative interviews, consolidation often appeared as a main benefit of parcel lockers: instead of delivering each shipment to individual end customers, the parcels can be dropped off at a single location.

Moreover, the failed delivery attempt rate can decrease significantly: in attended deliveries, if the customer isn't present and the package doesn't fit the mailbox, the carrier has to attempt delivery a second time. There is no such problem in the case of a pickup point (Ballare & Lin, 2020; Visser et al., 2014). Several companies (n°4 and group B) that were interviewed mentioned this benefit as a main reason why this solution is interesting for them, as an improved delivery success rate can also increase the customer satisfaction.

Furthermore, as opposed to attended delivery, there is no time window restriction. Strict time windows for home delivery can make the planning of trips complex, and is often the source of failed delivery attempts. In the case of parcel lockers, the packages can be delivered to the lockers at any time during the day (Bell, 2021). Thus it can also allow for night-time/off-peak hours deliveries, which brings many benefits, such as a reduction in delivery time and energy consumption (Hu et al., 2019).

3.3.4.2 Barriers

One barrier of this solution is that its financial viability depends on whether the volume of goods to be delivered is high enough. Parcel lockers need to be filled up to a certain volume in order to be effective (for the consolidation to bring a positive impact) (Visser et al., 2014). Moreover, based on some results obtained through the qualitative interviews (by companies 1 and 7), the type of good to transport also greatly influences the attractiveness of such a project. Several examples were mentioned. Goods like furniture to assemble usually constitute large and heavy parcels, which might not fit in the lockers. Lockers can't be used for home appliances that need to be installed at the customer's home, like a dishwasher. For companies that often deliver food products or prepared meals (mainly group B), the concern of food conservation was also mentioned.

Deliveries to parcel lockers can also influence the final consumer on the choice of mode of transportation. For example, the car might be chosen instead of public transportation to collect the parcel on the way to work. This can have a direct impact on emissions and congestion (Visser et al., 2014). This potential barrier was brought up during the qualitative interviews (notably by company 8): the positive effect on traffic brought by parcel lockers can be offset if the end customer picks up the package using their own vehicle, especially if the only reason for the trip is the collection of the package.

According to Lemke et al. (2016), the effectiveness of this solution also depends on the support of different stakeholders on top of the logistics providers: the customers, the owner of the land where the parcel lockers could be set up and the local authorities (the city administration). In particular, the city has to collaborate with the logistics providers at the early stages of the project (to select the locations of the lockers for example) (Lemke et al., 2016).

3.3.5 Electric vehicles

Electric vehicles (EVs) are the solution that came into discussion the most during the interviews (in both groups A and B). This section mostly covers light electric vehicles such as cars and vans. Electric cargo bikes will be treated separately in the following section.

For many interviewed companies (in group A), electrification of the vehicle fleet is a big focus to achieve sustainability in the FMLM. For example, according to a sustainability report by DHL, 13% of the group's fleet uses alternative energy: electricity is especially used for short-distance trips (such as pickups and the last mile), while other sources of energy are used for long-haul transportation (Deutsche Post DHL Group, 2020). This can be explained by the typically lower autonomy of EVs, making these vehicles less interesting for long-distance trips (Lebeau et al., 2013).

Based on the qualitative interviews, electric vehicles also seem to be used for the first mile by some companies (n°5 and 6), although the focus tends to be on the LM. One company (n°6) made plans for a special kind of "green hub" for the FM. This hub would produce its own electricity with solar panels and would be equipped with fast-charging stations. Electric trucks and vans performing the FM would stop by the green hub to drop off goods that need to go to town. The vehicles would recharge the batteries there before leaving to finish its trip.

Besides electricity, other alternative energies were often considered by the logistics operators (like company 2), such as liquefied natural gas, but electricity seems to be the core focus of many companies.

3.3.5.1 Benefits

For all the interviewees using EVs, one of the main reasons for implementing this solution is the decrease of CO_2 emissions, compared to a "traditional" fleet consisting of internal combustion engine (ICE) trucks and vans. To evaluate the efficiency of the electrification of their fleet, several companies use the CO_2 emissions saved (compared to a traditional vehicle) as a KPI. This can be confirmed by the literature. EVs have a lower environmental impact than traditional vehicles (Lebeau et al., 2013). The use of EVs has been shown to be a strategic tool for reducing oil dependency, emissions and other negative externalities (Nocera et al., 2020; Oliveira et al., 2017). Siragusa et al. (2022) performed a life cycle assessment[3] (LCA) for a diesel and an electric van. They found that EVs can reduce GHG emissions by up to 17% for a traveled distance of 20 km per day (compared to a diesel vehicle). This decrease can reach 54% for a daily traveled distance of 120 km.

Based on the interviews (notably companies 1 and 4), another reason for the choice of this solution is the need for a large load capacity: other lighter vehicles, such as cargo bikes (which will be

[3] The life cycle assessment (LCA) is a method used to assess the environmental impacts of a solution during its life cycle (production of the vehicle and energy, consumption of energy, disposal…) (Siragusa et al., 2022).

discussed in the next section), often have a limited capacity compared to traditional trucks and vans. A larger capacity can make deliveries more efficient by reducing the number of trips and thus the total distance traveled. This can be verified in the literature: EVs used for deliveries (like vans) have a similar capacity compared to their internal combustion engine counterparts (Siragusa et al., 2022). Cargo bikes, on the other hand, can be limited by a low capacity, in weight and dimensions (Oliveira et al., 2017).

Furthermore, EVs are not restricted by local policies imposed on ICE vehicles in the city center. This can be verified in the literature. As mentioned before, local authorities tend to focus on the reduction of traffic congestion, accidents and air and noise pollution (Nocera et al., 2020). Local policies are generally used by authorities to lower the congestion and the air pollution in the city center, and to encourage the use of more sustainable solutions (Bosona, 2020; Boysen et al., 2021). For example, the city of Milan, in Italy, imposes a road toll to vehicles entering the city center (€3 for a diesel van). However, this toll doesn't apply to EVs, which lowers its delivery costs (Siragusa et al., 2022). All interviewees using EVs (and cargo bikes) seem to agree that this trend of restricting ICE vehicles in the city center will continue.

Another advantage that wasn't mentioned during the interviews is that EVs generate less noise pollution, which allows for night deliveries in the city center (Bosona, 2020). This can bring several benefits, such as the reduction of the delivery time and the energy consumption (Hu et al., 2019).

3.3.5.2 Barriers

However, the efficiency of electric vehicles has to be nuanced. As pointed out in some interviews (notably by company 4), the sourcing of electricity used to "feed" these vehicles can come from various sources. The electricity used would need to be produced by "green" sources for the impact to be the most positive. The literature also mentions that the amount of GHG emissions created by EVs depends on the mix of electricity used (as the GHG emissions produced by EVs come from the generation of electricity) (Siragusa et al., 2022).

The need for recharging infrastructure is a barrier that is mentioned in the literature (Bosona, 2020; Oliveira et al., 2017). The initial investment is also higher since EVs have a greater purchasing cost than ICE vehicles. However, the operating costs of EVs are lower compared to traditional vehicles (Bosona, 2020; Lebeau et al., 2013; Nocera et al., 2020). This means that the total cost of ownership[4] (TCO) for EVs tends to be lower than for traditional vehicle after a certain amount of time.

[4] The TCO includes the owning costs (like the purchasing cost and registration fee), operating costs (like the energy consumption) as well as holding costs (such as assurance and depreciation) (Siragusa et al., 2022).

Nonetheless, it can be difficult to make generalizations as the TCO depends on many factors, like the incentives policies put in place in the area, the distance traveled and costs in energy (Siragusa et al., 2022)… The costs were identified as a barrier by several interviewed companies (n°1, 2 and 4) as well. Investments were required on top of the purchasing cost, to build infrastructures such as charging stations in the company's central hub.

Several companies (n°4, 5 and 6) stated that EVs typically have a lower autonomy than traditional vehicles, which can pose problems for planning the delivery trips. Indeed, the low autonomy of EV and the long charging time of the battery are barriers that are mentioned in the literature (Lebeau et al., 2013). However, this barrier can be nuanced: this limitation might not appear in cases where the vehicle autonomy in km is greater than the daily distance traveled (Siragusa et al., 2022). One company (n°6) mitigated this problem by setting up additional hubs: instead of coming back to the central hub after the deliveries, EVs can stop at a closer hub, where the batteries can be recharged. This can save the time to travel back to the central distribution center and allow the vehicles to make more deliveries in a day. However, setting up new hubs requires an investment and generates new costs (due to the additional transshipment operations, rent…). According to the company interviewed, the addition of a hub is still cost-effective nonetheless, and brings other benefits such as a reduction of CO_2 emissions (due to the reduction of the total distance to travel). Lebeau et al. (2013) studied the use of a consolidation center (a hub close to the city center) in combination with EVs. They found that the battery autonomy wasn't a barrier as a single charge during the night is enough to perform the daily deliveries.

3.3.6 Cargo bikes

Another solution that is used by many interviewed companies (companies 1, 4 and group B) is the delivery by bike.

Several types of cargo bikes can be used, depending on the volume of parcels to transport.

Figure IV. Example of a cargo bike with 3 wheels (source: (Treebike, 2022))

Some companies (company 1 and group B) have a fleet consisting of several types of bikes to complete the deliveries depending on the volume and weight to deliver. Cargo bikes typically have a container in front or behind the driver. For a bigger capacity, an independent trailer can be attached to some types of bikes, that can easily fit pallets (up to 3 EU pallets and 200 to 250 kg). Many bikes are also electrically powered and often have at least 3 wheels for a better stability.

Figure V. Another type of cargo bike (source: (Deutsche Post DHL Group, 2020))

Based on the interviews (from company 1 and group B), trucks and/or vans typically deliver the goods to a central hub near the city center. The parcels received at the hub are consolidated, then dispatched to the city center via cargo bike. There might be an additional transshipment if the packages are delivered to a micro-hub in the center before the final delivery (this concept will be addressed later in this section).

According to companies specialized in delivery by bike (group B), the demand (for transportation by bike) mostly exists for the LM. Technically, bikes can be used for the FM if the points of collection are not too far from the central hub where the goods are dropped off. But collection is mostly performed by motorized vehicles for practical reasons:

- Motorized vehicles are more cost-effective as the distance can be long, more than in the case of LML;
- The goods to collect are often more voluminous, heavier and are packaged into pallets. Containers attached to the bike can transport pallets, but the capacity is limited compared to a van or a truck.

Based on the interviews (notably group B), the FM activities of such a solution mostly concern the collection of goods for the reverse logistics. The goods are collected in the city center by bike, then are returned to the central hub in the outskirts of the city. From there, trucks come to collect the packages to be returned and perform the last part of the reverse logistics. According to the logistics providers (group B), this first leg of reverse logistics is very similar to LM delivery since it is subject to the same constraints (same restrictions in the city center, similar volume/size of the parcels…).

These reverse logistics activities are integrated with the LM deliveries (according to group B): cargo bikes are dispatched from the main hub to deliver the packages, and a few stops are added to the route to collect the goods to be returned. Trucks and other motorized vehicles that drop off the parcels to deliver to the central hub are also used for taking back the packages to be returned. According to one of the companies (n°8), the difficulty is the complexity added by combining these

2 parts of logistics/collection to LM deliveries. They often need to integrate several requests from several clients to be efficient, which is potentially complex.

3.3.6.1 Benefits

Delivery (or collection) by cargo bike can bring several benefits. Studies in the literature show that the use of bicycles and tricycles can reduce CO_2 and other GHG emissions (Bosona, 2020; Oliveira et al., 2017). One of the main benefits mentioned by all the companies using this solution is that performing the LM by bike can allow for CO_2 neutral deliveries. However, for electrically assisted bikes, the amount of GHG emissions generated depends on the mix of electricity used (like for EVs) (Siragusa et al., 2022).

All companies using this solution also emphasized on the legislation aspect: bikes are not as much restricted in the city center (by parking constraints or low-emission zones, for example) as regular cars or vans. As mentioned previously, local authorities tend to put in place policies with the objective of encouraging the use of more environmental-friendly solutions (Boysen et al., 2021). Several companies (group B) explained that cities are getting more welcoming of such solutions, and legislation is getting stricter for regular motorized vehicles, making them increasingly impractical over time. It is easier for bikes to move within the city center and park, which can bring considerable gains of time and allow a quicker delivery time per parcel. The literature mentions a reduced parking time as well, since it can park at more locations than traditional vehicles, such as the sidewalk (Bosona, 2020). Moreover, bikes can avoid heavy traffic and shorten the delivery distance by using specific paths that traditional vehicles can't access, such as bike lanes and urban areas where motorized vehicles are prohibited. This can lead to a decreased delivery time and energy consumption (for electric bikes) (Bosona, 2020; Fikar et al., 2018; Oliveira et al., 2017).

The congestion level can also be reduced since bikes can use specific paths and avoid traffic. This can reduce costs and emissions: a high congestion level leads to time loss (and thus economic costs), uncertain delivery time and higher GHG emissions (Bosona, 2020; European Environment Agency, 2020; Oliveira et al., 2017).

Social benefits like increased employment and better health (by reducing environmental and noise pollution) are also highlighted in the literature (Bosona, 2020; Oliveira et al., 2017). Moreover, using bikes can increase the working conditions by having less parking problems (Bosona, 2020).

3.3.6.2 Barriers

The low autonomy is a constraint that can limit the delivery range of bikes (Fikar et al., 2018). Companies (group B) pointed out that cargo bikes cannot go as far as traditional motorized vehicles due to the limited capacity of the battery and the fact that the bike is partly human powered. To be effective, cargo bikes usually make trips within a limited radius around the central hub, as deliveries too far from the hub might not be cost-efficient.

The effectiveness of this solution can be greatly impacted by the geography and infrastructure in the city (Schliwa et al., 2015). For example, bikes can have difficulties when riding on a steep slope (Bosona, 2020). Logistics providers that use this solution also mentioned that steep streets, for example, are not very adapted for cargo bikes, and that a bad infrastructure (lack of bicycle paths, paved roads…) increases the risk of accident and breakage. One company in particular (n°6), which makes some deliveries by cargo bike in some cities in Belgium, insisted on the influence of the city's geography. According to them, cargo bikes are more efficient in cities like Gent and Antwerp, where the land is quite flat. Other cities like Liège and Brussels have more (and steeper) slopes, consuming the bike's battery faster and making the deliveries less efficient.

Some companies (notably company 1) reported that the cost of delivery by truck and van is slightly lower due to some factors such as the bigger capacity, range of action… that can increase the cost efficiency. The lower capacity of bikes and the higher weight and dimension constraints can be found in the literature (Oliveira et al., 2017; Schliwa et al., 2015). Nonetheless, the interviewed companies using this solution expect cargo bikes to become more interesting in the near future, as city legislation gets stricter towards ICE vehicles. If this trend continues, cargo bike transportation will become a competitive alternative to delivery by truck or van.

However, another company (n°8) mentioned the need for better policies to incite the adoption of cleaner vehicles like cargo bikes, for example by investing in road infrastructure. This was also a potential barrier highlighted in literature (Oliveira et al., 2017). Measures that favor transportation by cargo bikes (such as setting up bike lanes) would need to be taken by local authorities to encourage the use of this solution by logistics providers (Schliwa et al., 2015).

Some companies (company 6 in particular) pointed out that the initial investment to acquire a fleet can be consequent: the price depends on the type of bike and on its quality, and can be as high as the price for a small, motorized vehicle. The purchasing cost is also mentioned as a barrier in the literature (Fikar et al., 2018). Moreover, like for EVs, investments in infrastructure for recharging is needed if the bike is electrically powered (Bosona, 2020; Oliveira et al., 2017).

For several interviewees (group B), it was difficult to attract a customer base at first. This customer acceptance concern was highlighted in the literature (Schliwa et al., 2015). The reason usually seems to be that logistics providers performing the LM by cargo bikes are often small companies. Some customers tend to choose bigger logistics companies for delivering their products (Bosona, 2020; Fikar et al., 2018).

Lastly, concerns about the health of riders were mentioned in the literature, as the capacity in weight can be high for some cargo bikes (Bosona, 2020; Oliveira et al., 2017). However, no company using this solution pointed out this concern, but some of them (group B) highlighted the importance of the quality of the bike to increase the comfort of employees.

3.3.6.3 Barriers mitigation: micro-hubs

As mentioned before, the bikes need to be dispatched close enough to the city center to stay cost-efficient. Two companies in particular (n°1 and 6) implemented micro-hubs to complement this solution. These hubs are small depots located in the city center (in a parking space or another space owned by the company), used for transshipping the goods (Fikar et al., 2018).

These two companies rent parking space to set up several micro-hubs. Goods are sorted in a central hub in the outskirts of the city, then transported from the central hub to the micro hubs using vans (ideally electric vans) and put into racks. Afterwards, the goods can be dispatched right away by cargo bikes.

Based on the interviews, the main objectives of these micro-hubs are to reduce the distance to travel by bike between the starting point and the destination, and to reduce the delivery time. This can be verified in the literature: goods are first brought by motorized vehicles to the hub, then cargo bikes perform the last part of the delivery, which often takes place in areas that are congested or restricted for traditional vehicles. This could reduce the delivery time (and thus the cost) (Fikar et al., 2018). Implementing a network of micro-hubs in the city can reduce the number of trips, the total distance traveled and can have a positive impact on the congestion level in the city center (Ballare & Lin, 2020).

Due to the additional transshipment operations, this method adds costs in terms of working time. Investments are also needed for setting up the hub, and possibly renting the location (if parking space is used as the location, for example). For the companies using this method, the benefits still outweigh these additional costs. However, other companies using cargo bikes (companies 7 and 8) didn’t implement this solution as their distribution center, from where the bikes begin the delivery, is close enough to the city center. According to them, adding micro-hubs would likely generate more extra costs than benefits.

We can find several initiatives using micro-hubs in the literature. The Citylab project in Amsterdam (2018), for example, consisted in using several micro-hubs in the city center in combination with cargo bikes. The micro-hub network was composed of existing hubs owned by PostNL. This project resulted in the reduction of the total number of van deliveries (Ballare & Lin, 2020). It also resulted in an increased employee satisfaction: the bike drivers were less impacted by the parking restrictions and traffic congestion, making them less stressed (European Environment Agency, 2020).

3.3.7 Urban Consolidation Center

An urban consolidation center (UCC) is a depot zone located near the city center, where the goods are consolidated in a facility before being delivered to the end destinations (to retailers or to final users) in the city. It is usually done using a lighter and less polluting vehicle (like EVs or cargo bikes). The UCC is also called satellite by some researchers (Perboli et al., 2021).

The main idea is that all the logistics providers that collaborate with the UCC send their goods to the consolidation center, instead of delivering them separately to the end users in the city. From there, a carrier delivers the goods to the customers in the urban area. The UCC can use its own fleet or collaborate with various logistics providers (which is more often the case) to perform the deliveries (Perboli et al., 2021). These UCCs often result from a local authority initiative, with the objective of reducing pollution and congestion in the city center. Improving road safety can be another objective (Akgün et al., 2020). "Binnenstadservice", in the Netherlands, is a successful example of UCC (Quak et al., 2020).

We can make a distinction between UCC and cross-dock. A cross-dock depot is only a transshipment zone (no inventory), where the packages are consolidated and loaded on smaller vehicles. The main objective is to increase the load factor of the vehicles performing the LM, improving its efficiency (Kin et al., 2018).

The location of the UCC itself is an important factor: the distance traveled (thus the cost) will increase if the consolidation center is too far from the end destinations (Akgün et al., 2020).

Most companies interviewed were open to the idea of cooperating with a UCC (companies 1, 5, 6 and 7 in particular). One logistics provider (n°5) is collaborating with UCCs for some deliveries. Other companies are directly in touch with cities in Belgium (notably company 1 and the city of Brussels) to collaborate on a new shared consolidation center.

3.3.7.1 Benefits

Since all the logistics operators collaborating with the UCC send their packages to the consolidation center instead of transporting it to the end destination in the city, the number of vehicles going into the city can be reduced (which also decreases the total distance traveled) (European Environment Agency, 2020). The load factor is also increased (Nocera et al., 2020). Moreover, the vehicles used for the LM are often lighter and generate lower emissions (Perboli et al., 2021). The companies interviewed mentioned several benefits for this solution, including the consolidation aspect and the reduction of traffic in the city center. It appears especially interesting for them with the rising trend of same-day delivery, which will affect the road traffic in the city.

Cost is a decisive factor for choosing whether a logistics provider should collaborate with a UCC or not. Successful UCCs would decrease their costs (therefore attracting more customers) by reducing the traveled distance and delivery time (Akgün et al., 2020). Moreover, by collaborating with a UCC, logistics companies don't necessarily need to make trips in the city center anymore, as they can drop off all their parcels at the UCC. This means they are no longer affected by strict policies in the city center (like car restrictions) and can use vehicles with a larger capacity for their trips to the UCC. The time windows are also less restrictive by using a UCC than by performing the deliveries to the end customers. This can allow logistics providers to decrease the total distance traveled and delivery costs (Quak et al., 2020).

Besides taking care of the LM, UCCs can also offer several value adding services, such as inventory management, unpacking or waste management (Perboli et al., 2021). For instance, the UCC Binnenstad adapted its business model over the years to keep being profitable. Binnenstadservice's UCC originally only took care of the delivery of packages to its customers, and its focus was not on the logistics operators but on the receivers of the parcels. Customers, usually shopkeepers, would get their parcels delivered to the UCC. Then the UCC would deliver the parcel at a time that was convenient to its customers. This model was not cost-effective and was maintained by subsidies. Afterwards, the UCC decided to focus on providing value adding services to logistics providers. The transportation itself was outsourced to local carriers. This way, the UCC was not seen as a competitor by the logistics providers anymore, and their satisfaction level increased (Quak et al., 2020).

3.3.7.2 Barriers

However, the additional transshipment generates an extra set-up and operating cost, which doesn't always make this solution viable in terms of costs (European Environment Agency, 2020).

This type of initiative requires the cooperation of multiple stakeholders, who have different interests: the local authority (initiating and/or supporting the UCC), logistics providers and retailers. Local authorities emphasize on various reasons (quality of life of the citizens, environmental concerns, support of businesses), while logistics providers and retailers prioritize cost efficiency, flexibility and reliability of the deliveries. It is necessary to set common objectives to ensure a sufficient collaboration. According to researchers, these stakeholders should already be involved in the early stages (in the development process) of the UCC (Akgün et al., 2020).

According to some companies that were interviewed (n°1 and 4), a high level of collaboration between all stakeholders is indeed needed to implement this solution efficiently. One company in particular (n°1) was interested in establishing a UCC with other companies in the transport sector and a city in Belgium. However, a lot of details still need to be fixed, such as how to apply to this collaboration, how to establish the responsibilities between each stakeholder... The biggest question is which stakeholder will run the UCC. According to the company, it would make more sense to leave the management of the UCC to logistics companies that have expertise in that sector, as opposed to the city. The city would have to approve such a decision and will remain an important stakeholder in any case, since the location used by the UCC would probably be the city's property.

According to some authors, the biggest barrier of UCCs is that it needs to attract a sufficient number of users, otherwise it would become financially unfeasible. This is the reason why this solution often heavily depends on subsidies, at least for the short and medium term (Akgün et al., 2020). This can be explained by the fact that many logistics providers already have acquired a lot of experience in consolidating freight before delivering to the city center, so the consolidation service offered by UCCs doesn't seem very cost attractive to some of them (Akgün et al., 2020). This explanation was often highlighted by the companies interviewed that were not interested in collaborating with a UCC. Other local policies can be used as a way to support the UCCs and encourage its use, such as an exemption from time restrictions allowing for night-time deliveries (Akgün et al., 2020). Off-peak hour deliveries can bring many benefits, including reducing the delivery time and energy consumption (Hu et al., 2019).

Additional barriers were mentioned by an interviewee (company 6). Like parcel lockers, this solution would not be effective with some types of goods: for example, it might not be adapted for goods that need to be assembled at the destination (like furniture and home appliances). Moreover, deliveries that have strict constraints, such as a small time window, would make the organization of trips difficult for the UCC.

3.3.8 Passenger/freight transport integration

Passenger and freight transport integration is a solution that combines passenger and freight flows. This combination is already common in long-haul rail, water and air transportation, but it is much less applied to short-haul urban transportation (Nocera et al., 2020). Passenger and freight transportation systems often share the same infrastructure, which increases congestion during peak hours (Fatnassi et al., 2015).

The general idea is that passenger transport systems have a low loading factor during off-peak hours, when the passenger flow can decrease by more than 60%. Thus this spare capacity could be exploited to transport freight on top of passengers (Ma et al., 2022).

Several variations can be found in the literature: trams, subway systems or even taxis can be considered to transport freight outside of peak hours (Fatnassi et al., 2015). Fatnassi et al. (2015) researched the coordination of passenger and freight in personal rapid transit (PRT) and freight rapid transit (FRT), which are typically autonomous modes of transportation over a relatively short distance, using small vehicles. For this solution to be successful, there would need to be a synchronization between all the different transportation systems (Fatnassi et al., 2015).

Ma et al. (2022) researched “metro-integrated logistics systems” (MILS): the combination of passengers and freight in the metro systems, specifically by exploiting the idle capacity of the metro during off-peak hours. They studied the strategic interactions between two stakeholders: the metro operators and the logistics providers. They found that both stakeholders can have a financial interest in implementing a MILS (Ma et al., 2022).

Several initiatives have already been put in place, like City Cargo in Amsterdam, that started in 2008. Freight would be loaded on trams, then unloaded at specific stops in the tram’s route (not at passenger stops) to avoid impacting the passenger transportation schedule. From these specific stops, the parcels were transferred to electric vehicles that would perform the last part of the LM (Kelly & Marinov, 2017).

This solution wasn’t a big focus for any of the companies interviewed, but some interviewees (companies 1 and 8) were interested in it and are doing some testing with the STIB in Brussels.

3.3.8.1 Benefits

Bruzzone et al. (2021) evaluated the efficiency of passenger/freight transport using two case studies: in Venice and in Velenje (Slovenia). According to the researchers, this solution has a good potential in FMLM: it can reduce the distance traveled, energy consumption and negative externalities generated by freight transportation. For example, this integration of transportation could mean a better use of land in urban areas (by sharing the same infrastructure efficiently) (Bruzzone et al., 2021).

The integration of freight and passenger flows can increase the cost efficiency by mixing passengers and freight, reducing the spare capacity of vehicles (increasing the load factor) and thus the environmental impact (Cardenas et al., 2017; Nocera et al., 2020). This can also benefit the passengers, since cost reductions would permit transport operators to improve their services, for example, by setting up more frequent trips or establishing new routes (Bruzzone et al., 2021).

3.3.8.2 Barriers

However, integrating freight and passenger flows is a complex task as it requires the goods and passengers to share the same vehicles and infrastructure. Integration is also difficult to implement due to timing-related constraints, such as the strict customer requirements (passengers are sensitive to any delay in the transportation schedule) for the transportation of passengers and strict time windows for the delivery of parcels (Bruzzone et al., 2021). Moreover, there can be a negative impact brought by this integration: passengers and parcels would both share the same vehicle, which might be negatively perceived by the passengers. This can decrease the passenger's satisfaction and might in turn decrease the demand (Ma et al., 2022).

Moreover, to implement such a solution, a strong cooperation between various stakeholders is needed: the city administration, shippers, logistics providers and end customers. All these stakeholders pursue different interests: local authorities focus on the mitigation of negative externalities (such as congestion, pollution, accidents…), while businesses (logistics providers and shippers) focus on decreasing the delivery costs. Customers are more sensitive to the delivery time, the quality and the cost of the delivery service (Bruzzone et al., 2021; Nocera et al., 2020).

According to Bruzzone et al. (2021), the biggest barrier would be the regulation aspect. The government often considers freight and passenger transport as two different sectors, which follow different regulations and are under different authorities. This can pose problems in the implementation of a solution that integrates passenger and freight flows.

According to the literature, another main barrier is the financial aspect. To put such a solution in place, consequent investments (private and public) would be needed to make modifications to the existing infrastructure (Kelly & Marinov, 2017). This barrier was the main concern of some interviewees (like company 8). Such a solution would likely require large investments to adapt the transportation system's infrastructure and allow for a quick loading/unloading of the goods.

Another limitation is that the existing light rail transportation system (such as the metro) might not be able to support the additional weight of the freight, since the system was originally designed for passengers (Kelly & Marinov, 2017).

On top of these barriers, the qualitative interviews highlighted additional areas of concern for the logistics providers (mainly companies 1, 6 and 8).

Transportation systems like the tram, metro… all have fixed routes. This lack of flexibility means the "last part" of the LM, between the stopping point (like a station near the destination) and the end destination, would need to be filled in. For example, goods would be first carried to the metro system, then dropped off at a station underground closer to the destination, and these goods would need to be picked up again and delivered to the customer. This complexity brings additional transshipment operations, which would reduce the cost effectiveness of such a solution.

Moreover, the loading and unloading operations can be done without problems at the beginning and at the end of the line, but it becomes more complicated to handle these operations at stops in the middle of the line. The loading/unloading would have to be done in a limited amount of time to avoid any delay in the operator's transportation schedule.

However, for another company (n°6), the fixed routes are not considered as a problem: to keep the LM delivery as CO_2 neutral as possible, cargo bikes or even walkers (if the distance is short enough) would be considered to fill in the last part of delivery. We can observe that according to this company, CO_2 emissions would be a decisive factor for the adoption of this solution. Thus, the decision to implement such an integration of flows depends heavily on the logistics provider's objective (and on which KPIs have the most weight).

In conclusion, according to several logistics providers, there are too many barriers for its implementation. Due to the reasons cited above, these companies consider that this solution might not be feasible in most cases, considering the balance between the benefits and barriers: the barriers of this solution would outweigh the potential benefits.

3.3.9 Summary table

Several solutions for the FMLM were identified during the literature research and the interviews: crowdshipping, parcel lockers, UCCs, passenger/freight integration, electric vehicles and cargo bikes. Each of these solutions can have an impact on various KPIs.

Below in table V is a clear overview of the KPIs impacted by each solution. The main benefits and barriers are also summarized.

Table V. Overview of the main KPIs improved, benefits and barriers for each FMLM solution (source: own composition)

FMLM solution	Main KPIs improved	Main benefits	Main barriers
Crowdshipping	○ Distance traveled ○ Cost per delivery ○ CO_2 emissions	○ Flexibility ○ Low investments (cheaper workforce and reduced investments in vehicle fleet)	○ Social and ethical issues ○ Trust building problems ○ Minimum number of customers and crowdshippers needed ○ Scalability ○ Modal choice of crowdshippers
Parcel lockers	○ Distance traveled ○ Cost per delivery ○ Time to delivery ○ Energy consumption ○ CO_2 emissions ○ Delivery success rate ○ Customer satisfaction	○ Consolidation ○ Unattended delivery ○ No time window, allowing for off-peak deliveries ○ Reduction of congestion level	○ Minimum volume of goods needed ○ Modal choice of customer ○ Limitation on the type of good ○ Strong collaboration needed
Electric vehicles	○ Cost per delivery ○ CO_2 emissions	○ Cleaner than ICE vehicles ○ Lower operating costs than ICE vehicles ○ Lower TCO than ICE vehicles in the long term ○ Less impacted by restrictions in the city center	○ Sourcing of electricity ○ Significant investments needed (initial purchase, infrastructure) ○ Lower autonomy than ICE vehicles
Cargo bikes	○ Distance traveled ○ Time to delivery ○ Energy consumption ○ CO_2 emissions ○ Employee satisfaction	○ Cleaner than ICE vehicles ○ Less impacted by traffic and restrictions in the city center ○ Reduction of congestion level	○ Sourcing of electricity ○ Significant investments needed (initial purchase, infrastructure) ○ Lower capacity: higher number of trips needed ○ Lower autonomy than ICE vehicles ○ Customer acceptance ○ Impacted by city geography ○ Additional transshipment (if micro-hubs) ○ Limitation on the type of good

Urban Consolidation Center	○ Distance traveled ○ Cost per delivery ○ CO_2 emissions ○ Delivery success rate (time window) ○ Load factor	○ Consolidation ○ Reduction of congestion level ○ Additional services can be offered ○ No need for logistics providers to go to the city center ○ Wide time window, allowing for off-peak deliveries	○ Usually depends on subsidies for short and medium term ○ Additional transshipment ○ Minimum number of users needed ○ Limitation on the type of good ○ Strong collaboration needed
Passenger/freight integration	○ Distance traveled ○ Energy consumption ○ CO_2 emissions ○ Load factor (of transport system)	○ More efficient use of infrastructure ○ Reduction of congestion level (due to integration of flows)	○ Complex integration constraints ○ Passengers' perception ○ Strong collaboration needed ○ Legislation ○ Significant investments needed (infrastructure) ○ Weight capacity of the system ○ Lack of flexibility: fixed routes bringing additional transshipments

We can observe that many KPIs can be impacted by a single solution. As mentioned before, this is partly due to the fact that these indicators are interrelated.

It can also be noted that this table presents the results under a rather optimistic point of view. The impact made by each solution on the different KPIs depends greatly on many different factors. Several examples can be given. For instance, the benefits (such as the reduction of CO_2 emissions) that can be achieved by crowdshipping and parcel lockers are significantly influenced by the modal choice of the crowdshippers and customers. Parcel lockers also need to be filled up to a minimum volume for the benefits of consolidation to appear (Visser et al., 2014). The benefits of a UCCs also depends on the vehicles used for the last mile delivery.

3.4 Discussion

By researching in the literature, a list of KPIs was established, several solutions for the FMLM were identified, and its benefits and barriers were discussed. Each solution can have an influence on various KPIs and thus has the potential to improve the sustainability of the FMLM. These results were confirmed and new elements were added by analyzing the qualitative interviews with logistics providers.

Based on the qualitative interviews, we can observe that many companies (mainly group A) have focused on EVs to make their FMLM more sustainable. Cargo bikes also seem to be often in use (mainly by group B). On the other hand, other concepts such as crowdshipping or passenger/freight integration seemed to be considered by the interviewees, but were not implemented in practice due to the numerous barriers and uncertainties.

All the different solutions that could improve the sustainability of FMLM were treated separately in this work. However, it is usually not the case in practice, as many solutions are complementary and can be combined. This was also emphasized by the qualitative interviews. For example, a company (n°6) considered the implementation of a freight/passenger flows integration (by tram or metro) and cargo bikes. The parcels would be loaded on the tram, then transported to the city center. The parcels would be unloaded at a stop near the end destination and cargo bikes would perform the last part of the LM. The objective would be to keep the LM delivery as CO_2 neutral as possible. However, this project is still at its conceptual stage, so it isn’t used in practice.

Other companies specialized in the transportation by cargo bike (group B) mentioned their interest in using parcel lockers to store the parcels in a single location instead of delivering parcels to each individual customer, and to increase the delivery success rate.

As mentioned in a previous section, some other companies (n°1 and 6) sometimes use EVs for the transportation of parcels to micro-hubs in the city center. From there, the packages are picked up and delivered to the end customers by cargo bikes.

Many examples can be found in the literature as well. For instance, studies have been carried out about the combination of taxis and parcel lockers. On top of transporting passengers, taxis drivers could use their spare capacity to pick up a shipment at a parcel locker, then deliver it to another locker closer to the end destination (Boysen et al., 2021).

Moreover, UCC initiatives usually involve the use of smaller, less polluting vehicles for the deliveries (Akgün et al., 2020). Binnenstadservice, in the Netherlands, is an example of a UCC using light vehicles for the LM (European Environment Agency, 2020). Many other projects promoting the use of UCCs and cleaner vehicles (EVs and cargo bikes) exist, like the LaMiLo project in Brussels, with the objective of reducing road traffic in the city center (Nocera et al., 2020). Furthermore, UCCs can be seen as a solution to the limited battery capacity of EVs and cargo bikes, since the vehicles can start from a location that is close to the city center (Quak et al., 2020).

City Cargo in Amsterdam was another combination of different solutions. Parcels would be transported by tram on the first part of the LM, then would be transshipped to electric vehicles for the rest of the delivery (Kelly & Marinov, 2017).

Ballare and Lin (2020) investigated the efficiency of a combination of parcel lockers and crowdshipping: the crowdshippers would pick up the packages from a locker, then perform the deliveries to the different destinations. According to the authors, this delivery model could greatly reduce the distance traveled, number of trucks, fuel consumption and daily operating costs.

Most interviewed companies focus on the LM delivery especially, as it constitutes a major part of their activities. Some companies (n°1 and 4) also stated that the first mile is optimized enough as they have acquired expertise over the years, as opposed to the last mile which still has to be improved. It also appeared in the qualitative interviews that few solutions are really used in practice for the first mile pickup, apart from EVs and cargo bikes (companies 5, 6, 7 and 8).

However, several solutions can be applied to the FM in the context of reverse logistics. Indeed, this first mile is very similar to the last mile of delivery. The LM consists in delivering packages from a distribution center to the individual customers, while for the FM of reverse logistics, goods are collected from the end users and sent back to a depot. The flow of goods is reversed (Jäämaa & Kaipia, 2022).

Both flows are subjects to similar constraints, like a low collection/delivery volume per destination (Jäämaa & Kaipia, 2022). Some companies (in group B) also mentioned that this first part of reverse logistics is very similar to LM delivery since it takes place in the same environment (the collection points are usually in the city center). Thus the FM is subject to the same restrictions in the city center, like congestion, low-emission zones… which can make the use of bikes and EVs more interesting.

The qualitative interviews (notably company 5 and group B) have highlighted that many companies mixed the pickup and delivery of parcels in the same route. The vehicles would leave a distribution center to perform the deliveries, make additional stops for the collection of parcels, then come back to the distribution center to drop off the returned parcels (or waste). The vehicles used can consist of electric vehicles and cargo bikes. The combination of collections and deliveries can be seen as a type of consolidation, which can bring several benefits. This integration can considerably increase the cost efficiency, and can lead to a reduced total number of vehicles in traffic, thus reducing polluting emissions (Ranathunga et al., 2021).

Many authors have also researched the integration of FM and LM. For example, Ranathunga et al. (2021) have studied the combination of FM pickup and LM delivery by analyzing the literature about the capacitated vehicle routing problem (CVRP) and the different algorithms to solve it. A study by Bergmann et al. (2020) found that FMLM integration could increase the efficiency by up to 30%.

UCCs, which are often used in combination with EVs and cargo bikes, can offer the handling of returned goods or waste as an additional service (Quak et al., 2020).

Parcel lockers can also be used as a collection and delivery point (Bell, 2021). In particular, Ballare and Lin (2020) consider the use of both crowdshippers and parcel lockers for the collection and delivery of parcels. Lockers are used as micro-hubs, where parcels are picked up by crowdshippers and delivered to their destination. On their way, crowdshippers also collect packages and bring them back to a parcel locker. There, the packages can be sorted (by destination) and stored in the locker. Afterwards, the vehicles that drop off the parcels to deliver in the locker can collect the goods to be returned.

4 Conclusions

The objective of this research thesis was to identify several solutions that could be used by logistics providers to improve the sustainability of the first mile and last mile of logistics.

To do so, a research in the literature was performed to first highlight KPIs that can be used to measure the sustainability of FMLM. The results from the documentary research were validated and complemented by qualitative interviews, then a summary of relevant KPIs used in practice was presented in a table.

Those indicators were classified based on the three aspects of sustainability: economic, environmental, and social. Some indicators belong to several categories and can have an impact on several aspects of sustainability. Furthermore, the literature review and results from the interviews revealed that most KPIs are interrelated. If an indicator is impacted by a solution, it will likely have an influence on several other ones.

Different solutions that could improve the sustainability of FMLM were presented: crowdshipping, parcel lockers, EVs, cargo bikes, UCCs and freight/passenger integration. Each solution can bring several benefits, but its implementation can be challenging due to numerous barriers.

Crowdshipping appears to be an interesting solution due to its flexibility and low investments, which can bring down the delivery costs. But it is limited by several obstacles, such as trust building issues between the stakeholders, the need for a minimum number of crowdshippers and customers, and ethical issues due to the working status of crowdshippers. For these reasons, crowdshipping seems to be ignored by the interviewed companies.

Parcel lockers are a good solution for consolidating the deliveries, which can lower the distance traveled, delivery costs and CO_2 emissions. Another significant benefit is that it can increase the delivery success rate and enable off-peak deliveries, as there is no need for the customer to be present during the delivery. However, the positive impacts of this solution can be offset by several factors, such as the modal choice of the customers when picking up their parcels. This solution is also limited by the types of goods that can be delivered to the lockers.

For many companies, electric vehicles are a core focus for improving the sustainability of their logistics. Compared to their ICE counterparts, EVs typically generate less polluting emissions and are less impacted by restrictions in the city center. However, the electrification of the fleet requires heavy investments, due to the high purchasing cost and the need for recharging infrastructure. Moreover, the autonomy is more limited than ICE vehicles.

Cargo bikes can greatly reduce CO_2 emissions and are less impacted by traffic and policies in the city center, such as low-emission zones and parking restrictions. It can also help in reducing congestion as bikes can avoid traffic and take paths that are exclusive to bikes, such as bicycle lanes. Thus the delivery time and distance can be reduced as well. This solution is often used by companies to aim for CO_2 neutral deliveries. However, the load capacity and the autonomy are more limited compared to motorized vehicles. Micro-hubs can be set up to mitigate these problems, but this can generate additional costs due to the transshipment. Nonetheless, micro-hubs are not always necessary: some companies chose to dispatch the bike directly from a distribution center, as it was close enough to the city center to allow for efficient deliveries.

Urban Consolidation centers can be an effective solution to consolidate the deliveries, which can improve the load factor of the vehicles. The total number of vehicles in the city center can be reduced, thus reducing the congestion level. This solution can potentially reduce the total distance traveled and CO_2 emissions. Moreover, as UCCs often use EVs and cargo bikes, which can bring additional benefits. Logistics providers that collaborate with the UCC can also be offered additional services, such as waste management. However, the cost efficiency of these UCCs is not guaranteed and this solution often depends on subsidies for the short and medium term. Successful UCCs require a sufficient number of customers (logistics providers) and a strong collaboration between all the stakeholders involved.

The integration of freight and passenger flows can lower the congestion level, the CO_2 emissions, the energy consumption and improve the load factor by allowing a more efficient use of the transport infrastructure. However, this integration is complex to implement as it is subject to several time constraints. Significant investments are also required to adapt the infrastructure, and a high level of collaboration between stakeholders is needed. Companies often pointed out the lack of flexibility of this solution, as passenger transportation systems (such as the tram or the metro) have fixed routes. The last part of the LM would still need to be filled in by another solution (such as bikes). Another important barrier is the legislation aspect: passenger and freight transportation are considered as separate flows and are run by different authorities and subject to different regulations.

All these concepts were presented independently. However, several solutions are often combined in practice. As mentioned before, UCCs often rely on clean vehicles, such as EVs and bikes, to perform the LM. The integration of passenger and freight flows can also involve the use of EVs or bikes to fill in the last part of the delivery. Another example could be the combined use of parcel lockers and crowdshipper for parcel delivery and collection.

Several solutions can be used for the FM pickup. In practice, EVs and sometimes cargo bikes are used by companies for the FM. However, multiple solutions can also be effective in the FM of reverse logistics, which is very similar to the LM. For example, parcel lockers are often considered for the collection of packages to be returned. Crowdshippers, EVs and cargo bikes can also be used for the collection of parcels. The qualitative interviews showed that many logistics providers integrate the LM deliveries and the FM collection of reverse logistics in their delivery trips.

We can point out several limitations and future paths of research. First, the effectiveness of these solutions often depends on a large number of factors, making the generalization of the results difficult. Moreover, it can be challenging to compare different solutions with the qualitative results only. Quantitative data would be useful to better assess the sustainability of each concept. For that purpose, future research could focus on quantitative analysis to measure the effectiveness of each solution (or combination of solutions) based on the KPIs presented in this work.

Furthermore, this thesis is focused on the potential benefits and barriers of a limited number of FMLM solutions. Further research could be conducted to investigate the benefits and the obstacles to the implementation of solutions that were not mentioned in this work. The use of barges for the first mile and the last mile delivery in cities with a fluvial network can be an example of a potentially sustainable solution. Vehicles using an alternative source of energy (other than electricity, such as biogas) could also be studied.

Finally, this thesis only considered some FMLM solutions that have the potential to improve sustainability. However, routing and scheduling optimization is another way to achieve better sustainability in the transportation sector. Future research could focus on developing heuristics to improve the FMLM through the optimization of planning.

5 Appendices

5.1 Appendix n°1: interview guide

Introduction

The aim of this research is to highlight some interesting concepts in first and last mile logistics, study it under the angle of sustainability and identify the potential benefits and barriers. Another objective is to verify if these concepts used in the last mile can also be applied to the first mile. The questions are related to the context, the KPIs used, and the solutions put in place (some questions are closely related).

Context

- Are you familiar with the concept of sustainability? Do you do any sort of reporting?
- Do you specialize in the first / last mile or are you active in both?
- What is the size and composition of your fleet of vehicles?
- How large is the area in which you perform the collections / deliveries?
- Do you ship directly from a plant or warehouse to the customer or do the goods first stop by a hub / distribution or consolidation center?

Key performance indicators

- What are the most important KPIs you use to measure performance in the sustainability aspect (economic, social or environmental indicators)?
- What measures have you taken to improve the results of these KPIs (for example parcel lockers to reduce delivery failure rate…)?

FM/LM solutions

- Have you considered using crowdsourcing for delivery (or collection)? Why?
- Have you considered using alternatives to traditional attended delivery, such as parcel lockers or pickup points? Why?

- Have you considered using electric vehicles and/or cargo bikes? Why?

- Have you considered collaborating with a third party that manages an urban consolidation center (explain the concept if not known by the interviewee)? Why?

- Have you considered combining freight and passenger flows (for example, using the metro or tram system to transport freight)? Why?

- What other solutions / new processes have you tried to implement to become more sustainable? Did you succeed?

- What was the impact of this solution? What obstacles did you encounter?

- Could your last mile solutions (delivery of parcels) be applied in a first mile context (collection of parcels)?

6 References

Akgün, E. Z., Monios, J., & Fonzone, A. (2020). Supporting urban consolidation centres with urban freight transport policies: A comparative study of Scotland and Sweden. *International Journal of Logistics Research and Applications*, *23*(3), 291–310. https://doi.org/10.1080/13675567.2019.1679743

Ballare, S., & Lin, J. (2020). Investigating the use of microhubs and crowdshipping for last mile delivery. *Transportation Research Procedia*, *46*, 277–284. https://doi.org/10.1016/j.trpro.2020.03.191

Bányai, T. (2018). Real-Time Decision Making in First Mile and Last Mile Logistics: How Smart Scheduling Affects Energy Efficiency of Hyperconnected Supply Chain Solutions. *Energies*, *11*(7), 1833. https://doi.org/10.3390/en11071833

Bell, M. G. H. (2021). City logistics and the urban environment. In *Urban Form and Accessibility* (pp. 359–378). Elsevier. https://doi.org/10.1016/B978-0-12-819822-3.00021-3

Bergmann, F. M., Wagner, S. M., & Winkenbach, M. (2020). Integrating first-mile pickup and last-mile delivery on shared vehicle routes for efficient urban e-commerce distribution. *Transportation Research Part B: Methodological*, *131*, 26–62. https://doi.org/10.1016/j.trb.2019.09.013

Bosona, T. (2020). Urban Freight Last Mile Logistics—Challenges and Opportunities to Improve Sustainability: A Literature Review. *Sustainability*, *12*(21), 8769. https://doi.org/10.3390/su12218769

Boysen, N., Fedtke, S., & Schwerdfeger, S. (2021). Last-mile delivery concepts: A survey from an operational research perspective. *OR Spectrum*, *43*(1), 1–58. https://doi.org/10.1007/s00291-020-00607-8

Bruzzone, F., Cavallaro, F., & Nocera, S. (2021). The integration of passenger and freight transport for first-last mile operations. *Transport Policy*, *100*, 31–48. https://doi.org/10.1016/j.tranpol.2020.10.009

Cardenas, I., Borbon-Galvez, Y., Verlinden, T., Van de Voorde, E., Vanelslander, T., & Dewulf, W. (2017). City logistics, urban goods distribution and last mile delivery and collection. *Competition and Regulation in Network Industries*, *18*(1–2), 22–43. https://doi.org/10.1177/1783591717736505

Comi, A., & Savchenko, L. (2021). Last-mile delivering: Analysis of environment-friendly transport. *Sustainable Cities and Society*, *74*, 103213. https://doi.org/10.1016/j.scs.2021.103213

Dell'Amico, M., & Hadjidimitriou, S. (2012). Innovative Logistics Model and Containers Solution for Efficient Last Mile Delivery. *Procedia - Social and Behavioral Sciences*, *48*, 1505–1514. https://doi.org/10.1016/j.sbspro.2012.06.1126

Deutsche Post DHL Group. (2020). *2019 Sustainability Report*. https://www.dpdhl.com/content/dam/dpdhl/en/media-center/responsibility/dpdhl-sustainability-report-2019.pdf

European Environment Agency. (2020). *The first and last mile: The key to sustainable urban transport : transport and environment report 2019.* Publications Office. https://data.europa.eu/doi/10.2800/200903

Fatnassi, E., Chaouachi, J., & Klibi, W. (2015). Planning and operating a shared goods and passengers on-demand rapid transit system for sustainable city-logistics. *Transportation Research Part B: Methodological*, *81*, 440–460. https://doi.org/10.1016/j.trb.2015.07.016

Fikar, C., Hirsch, P., & Gronalt, M. (2018). A decision support system to investigate dynamic last-mile distribution facilitating cargo-bikes. *International Journal of Logistics Research and Applications*, *21*(3), 300–317. https://doi.org/10.1080/13675567.2017.1395830

Gdowska, K., Viana, A., & Pedroso, J. P. (2018). Stochastic last-mile delivery with crowdshipping. *Transportation Research Procedia*, *30*, 90–100. https://doi.org/10.1016/j.trpro.2018.09.011

Goldman, T., & Gorham, R. (2006). Sustainable urban transport: Four innovative directions. *Technology in Society*, *28*(1–2), 261–273. https://doi.org/10.1016/j.techsoc.2005.10.007

Hu, W., Dong, J., Hwang, B., Ren, R., & Chen, Z. (2019). A Scientometrics Review on City Logistics Literature: Research Trends, Advanced Theory and Practice. *Sustainability*, *11*(10), 2724. https://doi.org/10.3390/su11102724

Jäämaa, L., & Kaipia, R. (2022). The first mile problem in the circular economy supply chains – Collecting recyclable textiles from consumers. *Waste Management*, *141*, 173–182. https://doi.org/10.1016/j.wasman.2022.01.012

Kelly, J., & Marinov, M. (2017). Innovative Interior Designs for Urban Freight Distribution Using Light Rail Systems. *Urban Rail Transit*, *3*(4), 238–254. https://doi.org/10.1007/s40864-017-0073-1

Kin, B., Spoor, J., Verlinde, S., Macharis, C., & Van Woensel, T. (2018). Modelling alternative distribution set-ups for fragmented last mile transport: Towards more efficient and sustainable urban freight transport. *Case Studies on Transport Policy*, *6*(1), 125–132. https://doi.org/10.1016/j.cstp.2017.11.009

Krechetova, V. (2021). *Green and sustainable logistics network: Micro mobility in the first—Last mile*. ESCAP. https://repository.unescap.org/handle/20.500.12870/3850

Lebeau, P., Macharis, C., Mierlo, J. V., & Maes, G. (2013). *Implementing electric vehicles in urban distribution: A discrete event simulation*. *6*, 10.

Lemke, J., Iwan, S., & Korczak, J. (2016). Usability of the Parcel Lockers from the Customer Perspective – The Research in Polish Cities. *Transportation Research Procedia*, *16*, 272–287. https://doi.org/10.1016/j.trpro.2016.11.027

Logistics in Wallonia. (2020). *Who are we ? | Logistics in Wallonia*. https://www.logisticsinwallonia.be/en

Lozano, R. (2015). A Holistic Perspective on Corporate Sustainability Drivers: A holistic perspective on corporate sustainability drivers. *Corporate Social Responsibility and Environmental Management*, *22*(1), 32–44. https://doi.org/10.1002/csr.1325

Ma, M., Zhang, F., Liu, W., & Dixit, V. (2022). A game theoretical analysis of metro-integrated city logistics systems. *Transportation Research Part B: Methodological*, *156*, 14–27. https://doi.org/10.1016/j.trb.2021.12.005

Macioszek, E. (2018). First and Last Mile Delivery – Problems and Issues. In G. Sierpiński (Ed.), *Advanced Solutions of Transport Systems for Growing Mobility* (pp. 147–154). Springer International Publishing.

Na, H. S., Kweon, S. J., & Park, K. (2021). Characterization and Design for Last Mile Logistics: A Review of the State of the Art and Future Directions. *Applied Sciences*, *12*(1), 118. https://doi.org/10.3390/app12010118

Nocera, S., Pungillo, G., & Bruzzone, F. (2020). How to evaluate and plan the freight-passengers first-last mile. *Transport Policy*, S0967070X19306584. https://doi.org/10.1016/j.tranpol.2020.01.007

Oliveira, C. M. de, Albergaria De Mello Bandeira, R., Vasconcelos Goes, G., Schmitz Gonçalves, D. N., & D'Agosto, M. D. A. (2017). Sustainable Vehicles-Based Alternatives in Last Mile Distribution of Urban Freight Transport: A Systematic Literature Review. *Sustainability*, *9*(8), 1324. https://doi.org/10.3390/su9081324

Perboli, G., Brotcorne, L., Bruni, M. E., & Rosano, M. (2021). A new model for Last-Mile Delivery and Satellite Depots management: The impact of the on-demand economy. *Transportation Research Part E: Logistics and Transportation Review*, *145*, 102184. https://doi.org/10.1016/j.tre.2020.102184

Punel, A., & Stathopoulos, A. (2017). Modeling the acceptability of crowdsourced goods deliveries: Role of context and experience effects. *Transportation Research Part E: Logistics and Transportation Review*, *105*, 18–38. https://doi.org/10.1016/j.tre.2017.06.007

Qi, W., Li, L., Liu, S., & Shen, Z.-J. M. (2018). Shared Mobility for Last-Mile Delivery: Design, Operational Prescriptions, and Environmental Impact. *Manufacturing & Service Operations Management*, *20*(4), 737–751. https://doi.org/10.1287/msom.2017.0683

Quak, H., van Duin, R., & Hendriks, B. (2020). Running an urban consolidation centre: Binnenstadservice 10 years back and forth. *Transportation Research Procedia*, *46*, 45–52. https://doi.org/10.1016/j.trpro.2020.03.162

Ranathunga, M. I. D., Wijayanayake, A. N., & Niwunhella, D. H. H. (2021). Solution approaches for combining first-mile pickup and last-mile delivery in an e-commerce logistic network: A systematic literature review. *2021 International Research Conference on Smart Computing and Systems Engineering (SCSE)*, 267–275. https://doi.org/10.1109/SCSE53661.2021.9568349

Ranieri, L., Digiesi, S., Silvestri, B., & Roccotelli, M. (2018). A Review of Last Mile Logistics Innovations in an Externalities Cost Reduction Vision. *Sustainability*, *10*(3), 782. https://doi.org/10.3390/su10030782

Sahay, R., & Wolff, C. (2021). *Pandemic, Parcels and Public Vaccination: Envisioning the Next Normal for the Last-Mile Ecosystem*. World Economic Forum. https://www.weforum.org/reports/pandemic-parcels-and-public-vaccination-envisioning-the-next-normal-for-the-last-mile-ecosystem

Savelsbergh, M. W. P., & Sol, M. (1995). The General Pickup and Delivery Problem. *Transportation Science*, *29*(1), 17–29. https://doi.org/10.1287/trsc.29.1.17

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*, *15*, 50–57. https://doi.org/10.1016/j.rtbm.2015.02.001

Simoni, M. D., Marcucci, E., Gatta, V., & Claudel, C. G. (2020). Potential last-mile impacts of crowdshipping services: A simulation-based evaluation. *Transportation*, *47*(4), 1933–1954. https://doi.org/10.1007/s11116-019-10028-4

Siragusa, C., Tumino, A., Mangiaracina, R., & Perego, A. (2022). Electric vehicles performing last-mile delivery in B2C e-commerce: An economic and environmental assessment. *International Journal of Sustainable Transportation*, *16*(1), 22–33. https://doi.org/10.1080/15568318.2020.1847367

Treebike. (2022). *TreeBike | Vélos Cargos Electriques*. TreeBike. https://www.treebike.eu

Visser, J., Nemoto, T., & Browne, M. (2014). Home Delivery and the Impacts on Urban Freight Transport: A Review. *Procedia - Social and Behavioral Sciences*, *125*, 15–27. https://doi.org/10.1016/j.sbspro.2014.01.1452

Executive summary

Last mile logistics (LML) is a very complex and inefficient part of logistics, thus this subject is often studied in the literature. The subject of first mile logistics (FML) is also gaining interest, as its complexity is increasing due to the growth of e-commerce. The objective of this thesis is to identify first and last mile solutions that could improve the sustainability of these segments of logistics.

First, key performance indicators (KPIs) that can be used to measure the sustainability of the first and last mile were identified and classified based on the three aspects of sustainability: economic, environmental and social. Many of these indicators, such as the distance traveled and the CO_2 emissions, are interrelated and can influence each other.

Then, several solutions were highlighted: crowdshipping, parcel lockers, electric vehicles (EVs), cargo bikes, urban consolidation centers (UCCs) and passenger/freight transport integration. For each solution, the benefits, KPIs impacted and barriers to its implementation were identified. The results were obtained by analyzing the literature, and were validated and supplemented by qualitative interviews with several logistics operators.

In practice, several solutions, such as electric vehicles and cargo bikes, can be used for the first mile pickup, especially in the context of reverse logistics. We can also observe that these solutions are often combined. For instance, UCCs and passenger/freight integration can be used together with EVs and cargo bikes to improve the efficiency of deliveries.

Finally, in the conclusion, the key results are summarized, the limitations of this thesis are presented and areas for future research are suggested.

Keywords: logistics, sustainability, first mile pickup, last mile delivery, KPIs, qualitative interviews, crowdshipping, parcel lockers, electric vehicles, cargo bikes, urban consolidation centers, passenger/freight integration

Word count = 16.417