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Alternative and innovative models of last-mile delivery: a systematic literature review

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Abstract

Last-mile delivery has always been regarded as the least efficient part of the supply chain for companies, with the cost of transport to the end customer having a high impact on the price of the finished product. Until a decade ago, the problem perceived by companies was purely economic, a mere question of price; if a company was unable to achieve a high enough sales volume to reach critical mass, it was forced to turn to a logistics operator. The latter can manage the entire chain, using modes of transport designed to minimize total costs. However, the context has completely changed in the last decade. The boom in e-commerce, climate change, and the push toward urbanization has drastically highlighted the inefficiencies that were considered secondary until a few years ago of last-mile delivery. The trend of companies has therefore changed, with the aim not only to minimize transport costs but also to reduce environmental emissions and traffic congestion, aspects that are also decisively affected by restrictions imposed by laws and decrees of national governments. Customers themselves have changed their demands: increasingly, retailers must be able to guarantee deliveries within the day. In this scenario of high managerial complexity and a very high degree of uncertainty, innovation and digitization come to the rescue of companies. With the development of artificial intelligence, drones, and robots, although not yet approved, can alleviate traffic and air pollution emissions in cities, making the delivery service faster and more flexible. Unattended delivery solutions such as lockers or reception boxes, on the other hand, reduce the logistical 'drama' of missed deliveries, while the development of proximity infrastructures such as hubs shared by several logistics operators are able, through the consolidation of deliveries, to make better use of the capacity of the available transport fleet. This thesis aims to investigate the main intervention solutions currently found in the literature, classify them into macro-areas, and go on to analyze the environmental, social, economic, and logistical impact through a framework generated by an impact assessment analysis that compares the solutions emerged and the 'base case' of attended home delivery.

Keywords: last-mile delivery; systematic literature review; B2C; innovative city logistics; impact assessment

Abstract in lingua italiana

Il last-mile delivery è sempre stato considerato come la parte della catena di approvvigionamento per le aziende meno efficiente, con un'elevata incidenza del costo di trasporto al cliente finale sul prezzo del prodotto finito. Fino ad un decennio fa, il problema percepito dalle aziende era puramente di natura economica, una mera questione di prezzo; se un'azienda non era in grado di raggiungere un volume di vendita abbastanza elevato da raggiungere la massa critica, era costretta a rivolgersi ad un operatore logistico. Quest'ultimo è in grado di gestire tutta la catena, utilizzando modalità di trasporto volte a minimizzare i costi totali. Il contesto però è completamente cambiato nell'ultimo decennio. Il boom dell'e-commerce, il cambiamento climatico e la spinta verso l'urbanizzazione hanno drasticamente portato in evidenza le inefficienze considerate secondarie fino a pochi anni fa del last-mile delivery. Il trend delle aziende è dunque mutato, non solo come obiettivo vi è la minimizzazione dei costi di trasporto ma anche la riduzione delle emissioni ambientali e delle congestioni del traffico, aspetti decisamente interessati anche da restrizioni poste da leggi e decreti dei governi nazionali. I clienti stessi hanno mutato le loro richieste: sempre più spesso i rivenditori devono essere in grado di garantire consegne entro l'arco della giornata. In questo scenario dall'alta complessità manageriale e caratterizzato da un grado di incertezza elevatissimo, vengono in soccorso delle aziende l'innovazione e la digitalizzazione. Con lo sviluppo dell'intelligenza artificiale, droni e robot, sebbene non ancora omologati, potranno attenuare il traffico e le emissioni di inquinamento atmosferico nelle città, rendendo il servizio di consegna maggiormente veloce e flessibile. Soluzioni di unattended delivery come i lockers o le reception boxes riducono invece il "dramma" logistico delle missed delivery, mentre lo sviluppo di infrastrutture di prossimità come gli hub condivisi da più operatori logistici sono in grado, attraverso il consolidamento delle consegne, di sfruttare in maniera migliore la capacità della flotta di mezzi di trasporto disponibili. La tesi si propone di indagare quali siano le soluzioni di intervento principali attualmente presenti nella letteratura, di classificarle in macro-aree in base alle caratteristiche comuni e di andare ad analizzare l'impatto ambientale, sociale, economico e logistico attraverso un framework generato da un impact assessment analysis che mette a confronto le soluzioni emerse e il "caso base" dell'attended home delivery.

Parole chiave: consegna dell'ultimo miglio; revisione sistematica della letteratura; B2C; logistica urbana innovativa; analisi dell'impatto

Contents

Introduction

The *last mile* (LMD) in supply chain management and transportation planning, is the last leg of a journey that includes the movement of people and goods from a transportation hub to a final destination - the recipient's preferred destination point - *[16]*.

The goal of last-mile delivery logistics is to deliver packages as quickly, accurately, and economically as possible. Last-mile is a critical phase for any retail company because it hides a wide variety of pitfalls and huge problems *[60]*:

- Poor route planning;
- Lack of transparency;
- High delivery costs;
- Unpredictable external factors;
- Failed deliveries and Return management;
- Rising demand for same-day deliveries.

. The main reason it represents a real challenge for companies is the high impact it has on the total amount of transportation costs, often costing more than half of the overall shipping costs *[61]*. The result of this situation is that for those companies able to optimize all the activities required in this critical phase - starting from the picking in the regional warehouse to the arrival of the package in the hands of the final customer - they will be able to build a considerable competitive advantage that turns out to be a key differential. While on the contrary, those companies failing in the optimization of their processes, the inefficiencies lead to very high costs that dramatically reduce their profits.

Considering the boom in recent years of e-commerce, which is set to grow further in the coming years *[124]; [91]*, there has been a dramatic increase in the frequency and volume of parcel deliveries. In addition, considering that one of the world's population trends is the ever-increasing urbanization (population shift from rural to urban areas) *[24]*, communication routes in particular of the major cities of each country are clogged every day by the presence of vehicles and vans of logistics operators for last-mile delivery activities. Urban traffic congestion has certainly complicated the work of couriers. In addition, the last mile has been heavily regulated and companies must comply with precise regulations, i.e. laws concerning transportation emissions and packaging waste. This impacts deliveries by establishing set loading and unloading times, and traffic limits that affect both vehicles and certain areas of cities. A further issue related to e-commerce that cannot be overlooked is the "seasonality" of demand that affects delivery activities - i.e. before Christmas or during Black Friday, orders and consequently transports intensify. Setting up an efficient and effective last-mile logistics system is essential for maintaining a company's competitiveness. This is not an easy task for managers, who have to satisfy increasingly attentive and demanding consumers without driving up company costs *[111]*. Costs are high for companies operating in the e-commerce, since in few occasions products can be consolidated or grouped with the technique of the groupage before being shipped. The key element to business success is the provision of a great customer experience: errors, delays, and complications in delivery to the customer will ruin what has been achieved throughout the supply chain *[126]*. This is a highly customer-centric market, where the customer wants to customize delivery methods and decide when, where, and how to receive their item. Numerous studies have investigated what are the most important choice criteria that consumers evaluate before proceeding with an online purchase, among the most impactful, were :

- *shipping time*, and for this reason companies have focused on the speed of delivery, coming to be able to offer in some cases even the "same-day delivery";
- *punctuality*, i.e. the indication and respect of a precise time for the arrival of the courier;
- *price of the service*, although customers are willing to spend a higher price to have the product on the same day of the order, they are still sensitive to the price, always making the trade-off between the price and the type of service chosen; *[95][13]*.

The freight transport sector represents the foundation of today's globalized society. If the transport sector is in general a very inefficient sector, this is even more evident in cities because of the consequences that it produces, exacerbating phenomena such as air and noise pollution, the number of accidents and congestion. Today, commercial (freight) vehicles account for between 20% and 40% of CO2 emissions from urban transport and produce 30% to 50% of the main air pollutants (PM and NOx). (Smart Freight Centre, 2017).

The impacts of last-mile delivery in terms of costs, environmental and social sustainability are topics that have seen great interest from scholars and practitioners, especially in the last ten years. Its rapid growth is mainly due to the change in customer behavior, which has led to the boom in online shopping, and urbanization that together with the previous cause has led to major problems in terms of road conditions and traffic congestion, and increasing awareness of the importance of environmental sustainability issues *[3]*. All these problems, combined with technological innovation have stimulated the generation of new alternatives as possible solutions for the optimization of costs and environmental and social impacts related to last-mile delivery.

As an industry generating such a wide variety of negative externalities and many inefficiencies, all stakeholders, to a greater or lesser extent, have many interests in making improvements. For a deeper understanding of the industry, it is fundamental to know who the most important stakeholders are and what their goals are. Stakeholders involved in last mile logistics can be found both inside the market - shippers and freight carriers -, and outside the freight market - residents and administrators - *[144]*. While the internal players are interested and associated with commercial logistics, residents and administrators are rather interested in the economic development of city, safety, security, and environment *[98]* Regarding stakeholder goals: Shippers pursue the objective of increasing their profits and improving the reliability of sending and receiving their commodities, while freight carriers also try to increase their profits and meet the requests of shippers in terms of keeping time windows of picking up commodities at senders and delivering them to receivers *[5]*. Residents seek objectives of improving the environment, security, safety and generally speaking the quality of life in communities. and Administrators intend to promote economically development of the whole city and improve the environment *[40]*.

Considering the large number of scientific articles and papers about last mile logistics, the aim of this thesis is to propose a framework for the classification of the various solutions, considering mainly those already present but also looking at those still in the planning phase or in a beta test that have not yet reached an efficient application.

This thesis is organized as follows: **Chapter 1** describes the systematic literature review methodologies and objective; **Chapter 2** describes the literature review landscape, including themes, an evolutionary timeline, and theories; **Chapter 3** develops a framework based on the classification axes identified through the systematic literature review; **Chapter 4** contains a discussion on managerial implications and directions for future research. Finally, the main results of this study and their implications are summarized in the conclusions.

1 | Methodologies and Objectives

The purpose of this thesis is to seek out papers and studies of high quality and reliability, integrate them with each other and analyze them critically. To this end and to properly conduct a systematic review of the literature, authoritative guidelines have been taken as examples, starting with that of [145], one of the first re-adaptations of classic systematic literature review (SLR) to the managerial field and the version of [83], more current and used as a model in SLR applied to the field of last-mile logistics. The result of this preliminary phase of guidelines analysis has led to the definition of the following key stages:

1. **Definition of Research Scope**: in this phase, the research questions are identified and defined, and a justification is given for the review in terms of relevance and timing, highlighting the contribution of the SLR;

2. **Planning of the Study**: determine the characteristics required by the primary study, crafting inclusion and/or exclusion criteria, developing in this way criteria for determining whether the publication can provide information regarding the topic of the study;

3. **Identification of Works**: In this stage, search procedures are first determined - i.e., databases, search strings, words, and concepts that must be present in the title, abstract, or keywords reported by the author is identified. The result of this structured and rigorous research is a set of papers, ranging from journal integrate literature reviews, and conference proceedings;

4. **Selection of Pertinent Literature**: Considering the set of papers obtained from the previous phase, the inclusion and exclusion criteria chosen during the planning phase are applied; in this way, a preliminary screening is carried out to highlight which articles are potentially relevant to the topic under examination;

5. **Screening and Eligibility**: In this final stage a detailed relevance test that goes beyond what is stated in titles and abstracts is conducted. The work then concludes with a synthesis of the studies by integrating or cumulating several results across

the primary studies

1.1. Definition of Research Scope

The literature review aims to address the following research questions:

- **RQ1**: *What are the main solutions investigated in the literature to the problem of last-mile delivery?* - To achieve the intended goal, the research question that drives the entire SLR is a survey of solutions currently present and described in the literature.
- **RQ2**: *What are the areas of impact and improvement of the different solutions that emerged with the SLR?* - The innovative component of this thesis is the proposal of a framework, whose axes are generated by the SLR, for classification based on common features among solutions in the literature.

From previous partial research, obtained using search strings in which words such as "Last Mile Delivery", "Home Delivery", and "City Logistics" were combined with the use of Boolean operators such as AND/OR, it was noted that current knowledge on the subject is very fragmented, and there are a few articles that attempt to propose a grouping of today's home delivery solutions. For this reason this thesis wants to bring a significant contribution to the analysis of the current last-mile delivery situation through the proposal of a classification framework of the different solutions in the literature.
As a unit of analysis, the decision was to use only the black literature, as it is already of a conspicuous order of magnitude, thus excluding conference proceedings and other literature reviews. Moreover, about the time horizon, it was decided to use articles that are as current as possible, excluding those before 2010 and giving more prominence to those of recent years. The reason why the unit of analysis excludes publications before the year 2010 is that the 2010s was the decade that presented the strongest growth of the e-commerce market year by year *[147]* and brought to light the critical aspects of an industry with great consequences for the everyday life of every person. The most impactful changes that have emerged during these last few years have been the exponential growth of online marketplaces, the use of mobile devices to make online purchases, and the explosive growth of online and digital marketing and advertising *([46]*.

1.2. Planning of the Study

In the planning phase as noted in the previous description, the crafting of inclusion and exclusion criteria for SLR occurs.
The main inclusion/exclusion criteria applied as search filters for literature skim were:

- **Language**: *Only English* - English represents the dominant language in logistics and supply chain management research.
- **Document Type**: *Article* - As justified before, only black literature was taken into account, primarily to ensure the highest possible quality of this final product.
- **Source Type**: *Peer-Reviewed Journal* - In this case, it is purely an organizational choice, the focus of the SLR is intended to be a literature review of articles from journals, so there was an exclusion of books. For the evaluation of the journals from which the articles are taken in terms of reliability and quality, it was used scimagojr.com site, which provides data regarding journal ranking on the different topics they cover.
- **Main Topics**: *Exclusion of topics not related to the managerial perspective* - It must be ensured that only papers with a clear focus on last mile or urban delivery are included in the SLR since the review regards the topic of LMD from a business, logistics, and managerial perspective. Therefore, articles focusing on humanitarian logistics, public transportation, crisis management, and tourism should be excluded.

1.3. Works Identification

First of all, it is important to clarify that Scopus was used as a bibliographic and citation database, as it is equipped with tools for the evaluation of scientific research through the use of bibliometric indicators.
The search string used for the literature review was as follows:
TITLE-ABS-KEY (("urban freight" OR " last mile") AND "delivery" W/15 ("sustainab" OR "innovat*" OR "transp*" OR "green" OR "multimodal") AND NOT ("public" OR "humanitarian" OR "Covid*" OR "passenger*")).*
To filter the search as much as possible to obtain publications useful to the pursuit of the thesis objective, the decision was made to apply an additional inclusion criterion, deepening the search string with a filter on the topics addressed by the journal articles.
The following macro-topics on the Scopus database were deemed appropriate and consequently included:

- Engineering
- Computer Science
- Business, Management, and Accounting
- Decision Science
- Mathematics
- Social Science
- Environmental Science
- Economics, Econometrics, and Finance.

The complete search string on the database can be found in Appendix 1 By reviewing the title, the abstract, and the reference list of each paper, a total of 198 publications were considered relevant to the review topic.

1.4. Selection of Pertinent Literature

With the application of the inclusion and exclusion criteria described in section 2.2, 154 newspaper articles were excluded, because even though among the keywords, in the title or in the abstract they presented combinations of words belonging to the search string, they did not have a focus considered in conformity with the one searched. For this first exclusion, it was sufficient to read the abstract and the introduction to understand it.

1.5. Screening and Eligibility

For the remaining 95 scientific publications, an in-depth reading of the article was performed, leading to a further exclusion of 13 papers, arriving at the final number of articles considered relevant to the systematic literature review. What are the gaps in the literature are also analyzed, giving suggestions for possible future research to fill these shortfalls.

2 | Review of the Literature

2.1. Main features of the articles

As is often the case in systematic literature reviews, articles were clustered not only by topic as we will see later, but also classified on the basis of some basic characteristics such as the year of publication, the journal, and the country of affiliation of the first author.
Regarding the analysis of *the year of publication*, the first articles deemed relevant are dated 2010. This is consistent with the focus of the literature review as it is only since the 2010s that there has been an increased interest in the topic of innovation in last-mile delivery, while all excluded papers dated before that date, and in particular concentrated between 2001 and 2012 had, as their primary objective, to optimize traditional last-mile delivery models *[1] [122] [136]*.
The great majority of the articles considered in this review were published in recent years, from 2018 to 2022, consistent with SLR's goal of wanting to give a clear description of the current situation and clustering the solutions presents for solving the serious problem plaguing last mile logistics. In addition, this high concentration of publications in recent years is consistent with the growing awareness of the environmental impacts of traditional means of last-mile delivery, the explosion of e-commerce sales - primarily due to changing consumer behavior -, and the greater general interest of public stakeholders such as governments who are perpetrating policies for environmental sustainability and the quiet life of citizens often stuck in traffic during peak times that coincide with the period of home deliveries.
Considering the *sources of the selected papers*, the journal with the highest number of publications is Sustainability (Switzerland) with 12 articles, followed by a group of journals well known for their reliability on logistics issues such as Transportation Research Procedia (7) European Journal of Operational Research (6), Transportation Research Part D Transport and Environment (6), Transportation Research Part E : Logistics and Transportation Review (5), and finally Research in Transportation Business Management, Sustainable Cities and Society and Transport Policy (each with 3 publications per journal).

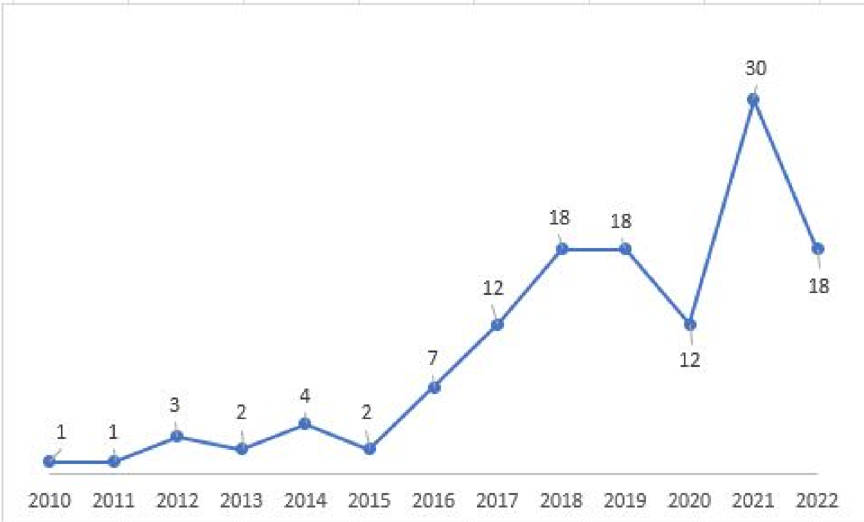

Figure 2.1: Yearly Papers Distribution

To conclude this initial analysis of article characteristics, the *nation of affiliation of the first author* was evaluated. The nations with the most publications were found to be USA and Italy with more than 20 papers each and Germany (13), more detached there are UK and China (8), followed by the Netherlands and Sweden (6), Belgium, and Poland (5).

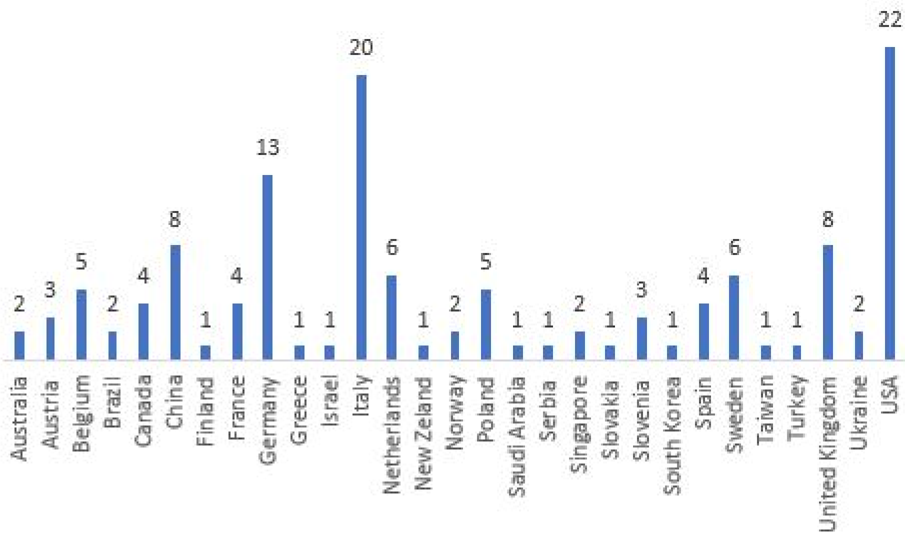

Figure 2.2: Affiliation Nations of the first author

Abbreviations will often be used throughout the thesis; this table contains their full meaning

LMD	Last Mile Delivery
SLR	Systematic Literature Review
RQ	Research Questions
GHG	Greenhouse Gases
EV	Electric Vehicle
ICEV	Internal-Combustion Engine Vehicle
LCA	Life-Cycle Assessment
TCO	Total Cost of Ownership
E-VRP	Electric Vehicles Routing Problem
E-ARP	Electric Arc Routing Problem
E-TOP	Electric Team Orienteering Problem
UAV	Unmanned Aerial Vehicle
TSP	Traveling Salesman Problem
VRPD	Vehicle Routing Problem with Drones
LCV	Light Commercial Vehicle
CD	Crowd Delivery
FFBS	Free Floating Bike-Sharing
RTZ	Restricted Time Zones

Table 2.1: Abbreviations Table

2.2. Review based on contents

The literature covers a wide variety of topics, as can be seen by applying search filters based on the main theme of the publication (i.e. managerial perspective, business perspective, social and environmental sustainability perspective, etc.), which gives a good idea of how complex the research area is. To present the literature in a more structured manner, the different topics were grouped into macro-categories, based on the characteristics that the solutions and strategies encountered in the research phase have in common and the objectives they pursue. The macro-categories identified as groupings to cluster the different solutions currently present in the field of last mile logistics are:

1. *Alternative transport solutions*: This category includes all those innovations potentially disruptive to the vehicle market: new engine technologies (i.e. hybrid and electric vehicles), autonomous guided vehicles and new delivery means (i.e. drones, droids, robots,and cargo e-bikes).

2. *Alternative Delivery Destination*: This cluster of solutions brings together all those strategies that can improve the efficiency of last-mile delivery. In particular, they are based on the use of a depot station where items can be stored until customers can pick them up, thus eliminating the risk of delivery failure.

3. *Warehousing and Sorting Facilities*: is a form of the sharing economy; it can be considered a business model that has revolutionized also the world of last mile logistics, as companies have the opportunity to outsource the delivery of goods to "common" people who, underpayment or free of charge, take care of delivering the goods to the final recipients. Usually these ordinary people offer themselves for this service as the route to reach the recipient of the good is similar to the route they have to take to reach their home or place of work.

4. *Public Policies*: Local and national administrators aim to provide the best possible environmental and social living conditions for their citizens. How they can do this is through the imposition of policies whose primary effect is to reduce environmental emissions, alleviate city traffic, reduce congestion and the number of accidents, the infrastructure wear and tear and improve public health.

2.2.1. Alternative Transport Solutions

This section discusses innovative vehicles that companies have implemented or are in the process of implementing in their fleet of vehicles to make last-mile delivery increasingly efficient. Considering the explosion of e-commerce and the increasing urbanization of both developed and developing nations, last-mile delivery can be contemplated as one of the main causes of increased urban traffic and urban pollution, particularly in large urban centers *[14]*. The issue is highly topical, as climate change has placed a great deal of focus on pollution and the type of vehicles that travel the increasingly clogged streets of increasingly polluted cities every day. In this context, the European Commission formulated the European Green Deal, which set a target to reduce the emission of transport-related greenhouse gases (GHG), by 90 percent by 2050 compared to the 90's scenario. Taking strong action on the transport sector is of paramount importance since about a quarter of all GHG emissions in Europe are attributed to this sector. And of all the types of transport, road transport has to be considered the largest emitter - primarily because it is by far the most widely used, not because it is the most polluting per se -. For increasingly sustainable last-mile logistics, there are several innovations from the perspective of the vehicles used, to ensure increasingly clean and green deliveries.

ALTERNATIVE TRANSPORT SOLUTIONS	Advantages	Barriers
Drones	• Avoid congestions • Faster delivery times • Lower delivery costs • Lower energy consumption and GHG emissions	• Must follow severe protocols regarding customers' privacy rights • Can only carry out one order at a time • UAV must abide by strict rules and laws
Droids	• Can haul multiple small packages • Can enter RTZ • Higher battery life and lower development costs than UAVs	• Low speed and transport capacity • Safety and security issues
E-vehicles	• Minimize logistic's impact to the environment • Decrease noise emissions • Lower maintenance costs and full costs	• High purchase costs • Current lack of vehicle charging stations • High charging time • Vehicle autonomy not yet satisfactory
Crowd shipping	• Exploit unused transport capacity • Reduction of delivery costs • Fewer vehicles on the roads	• Participation of all stakeholders is required • Data and information sharing risks
Public transport	• More efficient and environmentally friendly • Utilisation of unused capacity on public transport • Congestion reduction	• Must have sufficient capacity to allow the integration of people and goods • Excellent technology for fast loading/unloading activities • Consistency with laws
(e) Cargo-bikes	• Access to city centers • Reduction on environmental emissions • Low purchase costs	• Low transport capacity • Not suitable to cover long distance

Figure 2.3: Alternative Transport Solutions

First among them is undoubtedly the introduction of ***electric-powered vehicles (EVs)***, which for last-mile delivery certainly represent an innovation whose potential has yet to be fully developed. The first relevant publication on this topic for the literature review is dated 2018 *[108]*, in these four years a considerable number of articles have emerged with multiple purposes: from comparisons in terms of cost and environmental emissions with internal combustion vehicles, through routing optimization algorithms, and case studies with analysis of technology implementation tests.

This innovation certainly has attractive benefits: from an environmental point of view, it contributes to lower CO2 emissions and leads to energy savings. With the considerable decrease in the emission of harmful substances to the environment, companies have the opportunity to their reduce carbon footprint and minimize the impact of logistics on the environment *[20]*. Furthermore, from the social point of view, they bring a benefit in terms of noise emission *[36]*. For companies operating in the logistics sector, the adoption of electric-powered vehicles, allows them to enter areas of the city such as restricted traffic areas, bringing a great deal of cost savings in case, for example, where for internal-combustion engine vehicles access to such areas is possible only underpayment of an entry fee. In addition to this, another advantage is represented by the fact that these vehicles during their entire life cycle go against lower expenses, particularly for the minimization of fuel costs *[157]*, both because electricity has a lower cost than fuel and because these vehicles consume much less. Furthermore, the use of electric vehicles saves considerable time and costs for fleet maintenance. On the other hand, there are still some barriers to overcome before the adoption of this type of vehicle becomes the main solution for last-mile delivery. Among the most impactful ones should certainly be mentioned the high purchase cost compared to the internal-combustion engine vehicles (ICEVs), the lack of an adequate amount of infrastructure dedicated to vehicle charging, a battery autonomy that still cannot fully satisfy every buyer, and finally a charging time that is still too high in many cases.
To address this problem and incentivizing the purchase of electric vehicles, could be a great improvement the use of national and local policies that can make EVs attractive to third-party logistics providers, such as tax incentives and limitations to city centers for internal combustion vehicles. Three types of incentives are considered [108]:

- *Direct incentives on the purchase price*: This makes the price to the end buyer more affordable and stimulates the sale of this type of vehicle.
- *Zone fee*: Limited access zones in urban centers, also called low-emissions zones, where access to internal combustion and heavy-duty vehicles is restricted.

- *Vehicle taxes reduction for EVs*: Reduction of annual road fees for electrically driven vehicles.

Among the most widely used impact assessment methodologies in the literature for analyzing EVs are: the life-cycle assessment (LCA) for the environmental impact *[31]*, while the economic assessment is based on the total cost of ownership (TCO) model, which allows for comparison between the different types of vehicles over the ownership period *[135]*.
The introduction of electric vehicles for last-mile delivery is seen by researchers and experts in the logistics industry as one of the viable solutions to the implicit problems that plague this topic. Especially having a fleet of electric vehicles, allows companies to reduce costs and pollutant emissions *[71]*, thus pursuing a blended sustainability gain, both from an economic and environmental perspective.
Through the use of a systematic literature search, a wide variety of articles related to the use of electric vehicles for last-mile delivery emerged. Although it should be noted that the social and environmental aspects have received increasing attention in recent years *[114]*, the economic feasibility perspective is the aspect most widely covered, usually analyzed through simulation of costs incurred by transport and logistics operators in delivering. Assessment of external and internal costs through the TCO methodology will allow for a comprehensive and responsible approach to the planning and organization of urban transportation. The challenge facing urban planners is thus to find solutions that can reduce the impacts of urban goods mobility without penalizing city life.
In conclusion for the current situation, considering both the pros and cons of the technology, we can summarize that EVs are undoubtedly a feasible option for short-distance trips in urban areas, involving low daily driving range.

The term "electric vehicles" also refers to a subcategory of vehicles represented by **e-bikes**, a decidedly revolutionary means of transportation for parcels delivery especially for city centers where there could be restrictions on motorized vehicle access and for this reason the use of two- or three-wheeled vehicles is the fastest and most sustainable way to reach customers for home deliveries *[21]*. To understand the extent of the advantages and benefits that the adoption of this means of transport allows for logistics companies an LCA analysis can be used to quantify the reduction in environmental emissions resulting from replacing traditional means of delivering goods in urban scenarios (i.e. ICEV vans, e-vans, light trucks) with a fleet of e-bikes. The result of this analysis reveals that cargo bikes are the solution with the most benefits and least costly in absolute terms, while if

we base the analysis of the cost/km traveled ratio turns out to be the most expensive *[94]*. Therefore, it can be said at a general level that cargo bikes are an interesting solution from both an economic and ecological point of view but only for deliveries characterized by a relatively low distance to be covered between the warehouse/depot and the final customer, in cities with a high population density and for a low number of stops *[50]*.
For the efficient adoption of electric vehicles, there is also the importance of an effective management of charging times and range, which being limited, makes optimization of delivery routes critical. Thus, the introduction of electric vehicles has surely raised new operational challenges due to the inclusion of limitations such as the scarcity of recharging stations, a higher uncertainty on the remaining driving capacity and long recharging times ([52]).
The researchers' interest, has seen the emergence of numerous route-optimization algorithms of different types and with different focuses. A possible classification based on three main axes representing a different kind of algorithm is the following: Electric Vehicle Routing Problems (E-VRPs), Electric Arc Routing Problems (E-ARPs) and Electric Team Orienteering Problems (E-TOPs) do *[38]*. The number of scientific publications on E-VRPs *[112]* is much higher than the ones corresponding to E-ARPs *[162]* and E-TOPs *[159]* (see Appendix 2), which also means that there are many open research lines in the latter problems. E-VRPs algorithms are in turn differentiated on their focus, which can be battery charging time, customers' demands, carbon emissions, and the integration of hybrid fleets.

Other innovative vehicles that may prove to be a market-changing innovation are **drones or unmanned aerial vehicles (UAVs)**. A drone is an unpiloted aircraft. It could be controlled by computers, operated remotely by a person. or by a combination of both.
Drones that were initially only associated with the military and aviation sectors over the past decade have moved closer to being used in the commercial sphere for deliveries. Recent years have seen a growing interest in this technology for logistical uses, which has also led to large investments in the development of an economically sustainable model *[80]*. The main peculiarity of drones is that they move in the air, allowing them to avoid congestion, traffic, and complex navigation paths on the road *[65]*.
From the perspective of logistics operators, the adoption of the use of UAVs certainly promises faster delivery times that potentially reduce shipping costs for customers and can result in increased sales for retailers *[142]*. Speed of delivery turns out to be a key factor in satisfying all those customers willing to request drone delivery if their parcel can be in their hands within a few hours of online purchase. It is therefore of paramount

importance for the logistics company that manages deliveries to understand the propensity of a sample of its customers to request this type of delivery to have their goods in a truly time. The use of drones to deliver parcels may have the potential to decrease delivery costs, have no driver or trucks costs, eliminate congestion costs, and have fewer missed deliveries due to the very short delay between item dispatch and delivery, and is now the object of intense research activities *[143]*. An important peculiarity about UAVs is that they are relatively inexpensive and widely available. They fly at low altitudes and can be launched and landed without a runway. From the customer preference point of view, drone delivery combined with mobile phone applications to ensure traceability and scheduling could provide conditions to satisfy the highest demand profitability *[7]*.
From an environmental point of view, however, the use of a drone instead of diesel-burning delivery trucks lend a hand in stopping climate change by reducing energy consumption and the release of greenhouse gases (GHG) into the atmosphere. In this way, it becomes easier for companies to comply with government-imposed environmental limits by replacing classic on-road vehicle exhausts (usually internal combustion vehicles) with electric-powered drones *[139]*.
The acceptance of this technology by customers has been the subject of analysis for several years, but no publications have emerged on the subject, suggesting potential future research on this issue. However, from the typical online questionnaires used to collect data, it was possible to obtain the reasons why e-buyers do not trust drones as a delivery option, and among the reasons most frequently found among the various responses are: security, privacy, and technology concerns, the cost, the risk of theft and of receiving damaged packages *[29]*.

Some issues related to the management of UAVs are still open: there is a need to develop UAV traffic management technology, a technology that can operate in a GPS-denied environment, ensures safety during the flight in case of weather changes and improve the reliability of automation (Gentry C.,2019).
Security and privacy concerns must also be addressed. As for the former, there are in place laws for the remote identification technology that will tell them who is flying and allow them to identify drones that are unauthorized, flying unlawfully or displaying malicious intent. For the second open issue, privacy, we can state that there is still no regulation ensuring privacy in the context of drone operations. Currently, drones require compliance with state and local laws that protect privacy rights, but almost exclusively general laws, while laws directly regulating drones and privacy are almost completely lacking *[86]*. The most relevant topics that have emerged from the literature review concerning the use of UAVs are highly topical and investigate resolutions to some of the aforementioned

problems, algorithms for optimizing the delivery route, surveys to investigate customers' acceptance of this modern technology, and case studies of the application of drone delivery. The most important case study for the application of drone deliveries concerns the city of Milan, and the potential of this publication is that it complements the literature on the topic by adding a Stated Preference analysis to assess users' propensity to use drones, a financial feasibility analysis to assess costs and revenues for a logistics operator offering this type of delivery service, and the application of this methodology to a case study in the city of Milan (Italy). It is also understood that for drone delivery to be efficient, there is a need to also reorganize its delivery network, requiring a change in depot structures. The location and number of depots required must consider the needs of drone flight in terms of flight range, allowing every point in the urban area to be reached. Furthermore, the depots must have a structure characterized by considerable height development with the presence of doors to allow drones to take off and land *[12]*.
After a few attempts over the past decade with some study phases and field tests - the most famous examples concerning the use of drones to make deliveries are Amazon Prime Air and UPS Flight Forward, two subsidiaries of Amazon and UPS for their drone operations - a handful of companies are approaching package delivery in some countries through the use of drones. The flight of these drones is expected to cover not too long distances and in a fairly brief time.
A few years have passed between the birth of these subsidiaries and the present day, and the main reason for the delay in the official launch of drone deliveries is the lack of regulations authorizing delivery using UAVs. The other major barrier facing drones is technology. In fact, before drone delivery becomes routine, there is a need to optimize the development of existing detect-and-avoid technology, which is necessary as there is no human pilot on board. The improvement of this technology should allow drones to fly beyond the visual limit of a remote pilot, and above all, it must be made more affordable, accessible, and available.
Another potential last-mile delivery mode results from the parallel use of drones and trucks, as they possess complementary characteristics *[103]*. The use of drones for delivery is quick and inexpensive in terms of cost per kilometer, but their size imposes major limitations in terms of the size and weight of the packages they are able to transport, and in addition, they have limitations in terms of battery life, so they are unable to make many deliveries without recharging. On the other hand, classic fuel-based trucks offer a higher travel range and can transport several types of parcels, but they are expensive and slow to operate. Using the two different means of transport together can mitigate the effects of both and create a synergy with better benefits than using the individual means alone; specifically, a truck leaves the depot with a drone; the drone is launched from the

truck to serve one customer; when the drone is in flight, the truck continues its route to unvisited customers; the drone rejoins the truck at the next customer location, which differs from its launch location. For a correct assessment of the impact, it is correct in the management phase to try to minimize both operational costs and time completely by using the Traveling Salesman Problem (TSP-D) *[152]* (See Appendix 3). The effectiveness of this type of algorithm if validated through the use of numerical examples can be an important support tool for decision-takers as it provides managerial insights into the applicability of this solution *[130]*.

One of the first companies to bet on cooperation for deliveries between trucks and drones was Mercedes-Benz, which was already in 2016 with the acquisition of the start-up Matternet, a company whose core business is autonomous drones, entered the goods delivery market. The German car manufacturer subsequently unveiled its concept for an autonomously guided van for drone delivery. UPS, too, the following year showed its concept for a hybrid van with a nest drone built into the roof, whose drones have the potential to carry up to 5kg of parcel weight in the initial study alone, with the possibility of increasing this capacity in the future. The Mercedes van is of the same design as the Sprinter - the classic Mercedes van -, is fully electric, and is equipped internally with a fully automated space: there is a mechanical shelving system that can load packages and knows their final destination in advance. When the driver is approaching one of the destinations, he receives a notification. The van's shelving system pushes the package to a drone on the roof of the van, at which point the drone takes off to reach the delivery destination.

Imagining a scenario in which UAV-based delivery services take over and become almost commonplace, bearing in mind that they still have many limitations in terms of battery life, logistics companies need to equip themselves with a large fleet of vehicles for commercial-scale operations. For this reason, it is also correct to make simulations of the possible low-altitude traffic flow of drones *[133]*. The publication reported as an example investigates self-organized UAV traffic flow in low altitude 3D airspace and formulates equilibrium conditions for the user. Two test scenarios are investigated: one with a conventional ground-based distribution structure and another with an innovative airborne fulfillment center concept. The operational costs and energy consumption of both configurations are quantitatively evaluated, and the results obtained provide important insights that may prove useful for both logistics operators and policymakers to achieve efficiency and sustainability in last-mile delivery operations.

One of the problems brought to light by the systematic literature search is the difficulty in comparing the key variables (timing and operational costs) of drones and surface vehicles. When managers are called upon to evaluate different vehicle alternatives for last-mile delivery, transportation decisions are made by comparing the speed and cost of different workable solutions. But to compare drones with surface vehicles, not only transit time but the overall total delivery time must be examined, the reason why the development of efficient models capable of analyzing the dynamic interaction of different impacting variables and assessing the total delivery time is of paramount importance. In literature, only one article tries to deal with this issue *[141]*, developing a model proven by simulations to define the ideal context for the use of drones by comparing them with other last-mile delivery solutions. Results are clear and lead to the conclusion that the use of UAVs is less efficient for long distances, except in the case of rural areas, where the conformation of roads makes drones a viable alternative to classical surface vehicles.

For drones, as for any other innovative means of last-mile delivery, there are different types of routing models (VRPD - Vehicle Routing Problems with Drones) in the literature. For this systematic review of the literature, those considered useful for the classification of solutions are given, considering not only costs but also energy consumption as variables to be optimized, thus assessing not only their economy but also their environmental impact. Different types of VRPD have emerged: from those analyzing the study associated with the use of a warehouse *[123][26]*, combined with the use of a surface vehicle such as a truck *[68]* or with a public transport vehicle such as a moving charging station *[109]*. Among the most relevant articles is certainly the one by *[123]* in which a reactive routing method is proposed to solve the problem of UAV fleet mission planning in a dynamically changing environment, a type of problem often found in practice but rarely investigated in nature, despite being one of the major problems plaguing this last mile delivery mode. The authors considered plans for UAV fleet missions in the event of weather changes beyond the previously forecasted situations. The need to be able to react in these situations necessitates the design of condition-reaction rules that allow the drone to complete the mission safely and continue it despite the changed weather situation. The main advantage of the proposed model is the open structure that allows it to take into account several variables and restrictions as related to the cost of a mission, the heterogeneity of UAVs, etc. However, it is worth emphasizing that the model proposed presupposes a thorough knowledge of all environmental parameters in which a mission is carried out (i.e. flight speed, flight time, and maintenance of service time are uncertain parameters).

Delving deeper into the topic, the publication by *[26]* proposes a linear green mixed-integration routing model for UAVs to exploit the sustainability aspects of using UAVs for last-mile parcel deliveries. An algorithm is also developed to efficiently solve the complex model and an experiment is conducted to illustrate and validate the analytical model and algorithm solution. In this way, the environmental sustainability aspects of adopting UAVs for last-mile delivery are explicitly considered. Experimental results show that in

the case of using UAVs, fixed costs are reduced due to the reduction in total delivery time and the number of vehicles required because drones and vehicles can deliver packages jointly. Variable costs are also reduced, mainly due to the reduction in fuel expenses, and consequently, carbon emissions are also substantially reduced. The conclusion the authors come to as a result of these analyses is that drones represent a new trend for the delivery industry as they minimize delivery time and energy used as well as CO2 emissions and that the best choice from a managerial point of view is to shift smaller-package delivery from trucks to drones.
Another VRPD that has been highly successful present a research that explores the combination of drones and trucks with the idea of allowing drones to take off from delivery trucks, make their reciprocal deliveries to customers and return to their home base on the nearby truck for battery exchange or recharging and package retrieval. The goal of the algorithm is to optimize their delivery route, minimizing the total arrival time of both the trucks and the drones at the depot after all deliveries have been made. A case study is then conducted in the article to quantitatively analyze the results of the algorithm. The result of this numerical experiment is that due to the introduction of drones, the completion of deliveries is much faster than in the base case of using only the truck.
[68]'s on the other hand, is particularly interesting in that two drone tasks are considered in the algorithm: drop and pickup. After a drone has completed a delivery, it can return to the depot to deliver the next parcel or fly directly to another customer for pickup. A constraint programming approach is proposed and assessed with problem instances of m-truck, m-drone, m-depot, and hundred-customer distributed across an 8-mile square region.
One of the proposed solutions to the problem of limited battery life is that of *[109]*, which integrates drone flight operations with the public transport network to be considered as a mobile charging station. The main objective of using public transport is to reduce delivery time and energy consumption by operating drones that can take public transport to recharge their battery and travel on public transport close to customers' homes or alternative delivery points. The paper proposes a mixed-integration linear programming model for scheduling a fleet of drones employed to deliver a series of orders per trip. The model was tested, implemented, and analyzed using a real scenario with real input data (i.e. distributed locations of warehouses, customers, and public bus stations) from the city of Bremen, Germany. Also, using public transport vehicles, which enables drones to charge their battery or approach customers, can reduce the number of drones required for satisfying the demands in a service area. The results show that there are high potentials to save energy for drone-enabled last-mile delivery by using the public transportation network.

The third type of innovative vehicle that emerged during this systematic literature review is **droids**.
The term droid identifies those small autonomous vehicles, slightly larger than a regular parcel, capable of delivering parcels to the doorstep. They have a fairly low speed, typically the prototypes tested so far have a speed between 5 and 10 km/h and use sidewalks instead of roads to reach customers. Compared to UAVs, droids receive regulatory approval much more easily because they do not travel on roads. They are equipped with an electronic locking system that ensures the safety of the cargo from ruinous falls on the way, they can transmit their location in real-time to both the supervisor who can maneuver them remotely in the event of obstacles or accidents, and also the customers so they can track the location of their packages and they are equipped with cameras that shoot live video which is designed to deter thieves.
Among the main benefits of adopting droids for last-mile delivery are *[25] [90]*:

1. Droids can haul multiple small packages to multiple locations. This is an element in their favor in comparison to drones, which instead have a limit on the weight capacity they can carry and are used for the delivery of a single package before returning to base. The other peculiarity due to this possibility of being loaded with more goods is to allow customers to use them for returning packages to the retailer;
2. The battery life is longer than that of UAVs, which makes it possible to reach more distant destinations or to travel longer distances;
3. Lower development and construction costs compared to UAVs;
4. Using GPS location navigation, assistance from a supervisor is not required or is only limited in exceptional cases;
5. Can safely walk on sidewalks and paths;
6. Possibility of access to restricted traffic zones.

Among the major disadvantages are the lower speed and transport capacity (in terms of weight and volume) compared to classic street and road vehicles, the danger of accidents with people, animals, and moving objects, which makes them unsuitable for large, densely populated urban centers, and they encounter great difficulties in foul weather, especially snow *[137]*.
The droids are used in parallel with a truck capable of transporting them in the vicinity of a core of customers along with the packages to be delivered, so through simultaneous

delivery, companies can achieve higher efficiency and satisfy increasingly demanding customers in terms of the speed of delivery of their orders.
As for UAVs, similar types of articles can be found in the literature for droids: algorithms for optimizing routing *[160]*, comparisons from the point of view of economics and environmental and social impacts with other solutions for last-mile delivery *[57]*, and studies on the implementation of droids to identify scenarios in which they provide greater efficiency *[134] [15]*.
The pillars used as a source of comparison between droids and other urban logistics solutions are *[49], [125]*:

- From an *operational point of view*, the quality of service, is evaluated by calculating the time required for the shipment to reach the final recipient;
- From the *economic point of view*, economic productivity is assessed, thus capital costs, annual operational costs, and return of investment are calculated;
- From the *environmental point of view*, reductions in air pollutant emissions (i.e. CO, NOx, PM10 emissions), reduction of GHG emissions, and energy efficiency are evaluated;
- From the *social impact*, the comparison regards noise minimization and the improvements in safety and security.

Results indicate that the implementation of autonomous ground vehicles can have a positive impact on the environment, improving the quality of services by shortening the very times. Nevertheless, due to the compact size of those solutions, they should be coupled with an assisting technology for larger parcels and for those not willing or not capable of using the droids *[87]*.
The identification of the scenario in which droids coupled with a truck result in an efficiency improvement for the logistics operator compared to the basic situation of the van making a customer-by-customer delivery has focused the attention of many researchers. The results of some research *[134]* often indicate that despite their low speed of movement, droids can yield considerable time efficiency gains when they can make several consecutive deliveries and in the presence of traffic congestion. The maximum distance that can be covered by robots is a key factor to take into account when evaluating overall efficiency.
A way to further improve the delivery service via droids compared to the prevailing solution in the literature (autonomous robots and a truck with both a mobile depot function and a package delivery function in parallel with droids) is made possible by recent developments in smart-lock technologies (e.g. Amazon Key), which have made unattended home delivery with autonomous ground vehicles a tangible possibility. [15].

For the evaluation of routing algorithms in the literature concerning the combination of van and droids, the article by *[160]* is of particular interest, as it not only presents their new two-echelon van-based robot routing problem with hybrid pickup and delivery, including a new van-robot capacity trade-off problem but also presents a classification that highlights similarities and differences between all van-based robot routing problems, some of which also emerged using the basic search string of this thesis.
The most famous example related to the joint use of droids and a surface vehicle is the partnership Mercedes-Benz formed with Estonian start-up Startship Technologies in 2016, a company that develops self-driving delivery vehicles (Daimler 2017). Mercedes with its 'Robotic Delivery Systems' project created its 'mother ship', a Sprinter designed to hold a range of packages and up to eight delivery robots. The idea is quite simple: the driver of the Sprinter drives to its target area; upon reaching the location, the eight appropriately loaded droids are dropped off and carry out the last few hundred meters of delivery simultaneously. The robots' storage is locked and can only be opened by customers with a code. For security reasons, they move at pedestrians' speed as they travel along sidewalks. The mother ship and the droids interact intelligently with each other in both software and hardware. The Sprinter always knows where all his delivery robots are at any time. Starship's droids are equipped with numerous cameras and navigate using GPS, and can constantly monitor their surroundings to ensure the safety of autonomous locomotion.

The fourth solution concerning means of transport is a collaborative business model, **crowd-shipping**, which achieves remarkably performance in terms of efficiency and effectiveness. The first comprehensive definition of crowd delivery (CD) is given by *[6]*, who define CD as a new logistics concept that uses the crowd, intended as ordinary people, as a workforce to deliver goods. However, there is no formal definition of this concept; in fact, a further definition that has emerged from the literature states that CD is "the outsourcing of logistics services to a mass of actors (not necessarily commercial), where the coordination is supported by a technical platform, hosted and managed by a logistics service provider" *[51]*.
Crowd-shipping is a beautiful example of a sharing economy, in which the resource's transport capacity is shared thanks to the digital platforms on which some online commerce players rely *[140]*. The concept refers to a transfer of goods that takes place by a private individual on behalf of a third party, another private individual, or even a company. Whoever agrees to receive a shipment using crowd-shipping exploits the service of a crowd-shipper *[129]*, i.e. a private individual who, with his or her own me for example on the usual home-work journey, decides to also take on the function of a courier in return for

a small remuneration. By doing so, crowd-shipping drastically reduces the overall number of vehicle trips, increasing the load factor for all those private vehicles that normally travel with an empty trunk. A truly sustainable and environmentally friendly idea that can be implemented on an urban, national, and even international scale.

Crowd-shipping is expected to generate substantial opportunities for sustainable urban freight through the utilization of unexploited resources of individuals. The transfer of logistic work to individuals is observed as a major disruption to the arrangement of the existing business logistics models. The investigation of these disruptive impacts and the feasibility of this business model is therefore of paramount importance. In this sense, an analysis of the literature makes every nuance and characteristic of this concept clearer.

The first scientific article addressing the new business model is the one written by *[22]* which classifies 4 different CD models in a matrix. The matrix originates from the intersection of the two Cartesian axes representing the level of centralization of logistics management (decentralized vs. centralized) and the type of relationship between logistics and collaboration (logistics seen as support for collaboration vs. purpose of collaboration).

Two years later, the same authors broadened their analysis by taking into account the more complex concept of crowd logistics, extending the nature of services that can be offered in four main typologies: crowd storage - crowd-sourced goods storage service - and then the classic goods transport services, which are, however, divide based on the distance covered, crowd local delivery (within a limited radius), crowd freight shipping (within domestic or at most continental borders) and crowd freight forwarding (intercontinental).*[23]*.

Another classification of the diverse types of crowd-sourcing deliveries can be made based on the composition of the fleet of vehicles used. A first model with completely free-degree deliveries people collects and deliver parcels for acquaintances, typically making small deviations from their common or original itinerary. The second model involves the use of a platform that coordinates people who accomplish occasional deliveries, usually bringing parcels to members of their community. Operationally speaking, the crowd-shipping package delivery process with the use of a platform consists of five steps *[44]*:

1. *Publication*: The client posts a delivery request on the crowd-shipping platform, which details the shipping and package characteristics and requirements;

2. *Bidding*: The posted delivery request becomes visible on the platform system and all registered couriers within a specified geographic range can begin communicating with the customer and bidding. The bidding is related to pick-up arrangements such as flexibility or timing and does not include shipment pricing which is determined by the platform using a size and distance-based formula;

3. *Accepting*: The client can then decide to "accept" or "decline" the couriers offer, representing the accepting phase. If no courier is selected, the request is canceled by the system;

4. *Picking-up*: The accepted delivery order enters into its picking up phase where the timing and location specifics are negotiated;

5. *Delivering*: The last step is the physical delivery of the parcel, where the customer can track the shipment.

The third model is a hybrid solution involving the combined use of traditional and crowd-sourcing modes for deliveries. How this model can be applied can be manifold, the most commonly used at the moment on a practical level being e-commerce players who supplement their fleet of vehicles with a group of occasional riders, who deliver parcels in small quantities without deviating too much from their original route, or through the use of public transport vehicles, such as a taxi, bus or metro. The fourth and most developed model involves the composition of a fleet of ad-hoc riders, whose operations are centrally coordinated by a logistics operator or the logistics business unit of the e-commerce company, which optimizes them to offer a more efficient (greater saturation of the means of transport) and effective (able to satisfy a higher volume of customers with fast deliveries) service.
Crowd-shipping offers benefits for all stakeholders involved in the process: for companies, there is a reduction in delivery costs *[132]* and the possibility to extend their delivery horizons by serving larger areas. For customers, the benefit is in terms of speed, convenience, flexibility, and customization of the service *[25]*. For drivers, the benefit is to be able to earn extra income by making small detours from their traditional daily route between home and workplace. Finally, it is also fair to assess the impact on society, which can benefit from reduced emissions and minimized traffic congestion as there is less need for vehicles to deliver goods. The participation of all stakeholders is a concept of paramount importance for the success of urban logistics collaboration projects and initiatives. The factor that undoubtedly influences these decisions most positively concerns the expected benefits, both economic as well as environmental and social sustainability, while the main obstacle identified competitive intelligence risks. From the companies' point of view, the greatest fear is to lose their competitive advantage when sharing certain information and data with other stakeholders of the same project who may be their business rivals. *[93]*.
Crowd-sourcing delivery can be carried out through the use of different types of means. Among the most commonly used are cars, bicycles, or a combination of both. The KPIs most often used in research aimed at finding the optimal fleet composition is the total number of deliveries made within a day and the on-time delivery rates. A particularly

relevant case study that takes the city of Copenhagen as an example is the scientific article by *[41]*, which investigates whether there are significant differences in the logistical efficiency of different vehicle fleets by carrying out a simulation that attempts to give as true a representation as possible of the traffic conditions at different times of the day in a city with a well-developed network of cycling infrastructure. The result of this study shows that the introduction of bicycle-based crowd-sourced couriers leads to an improvement in delivery performance in the case of a single-parcel urban delivery scenario. The main reasons are lower delivery costs as there are no fuel or parking expenses and reduced maintenance costs. This allows the business to offer customers a much more affordable price. Secondly, the use of the bicycle unlike the car does not require a driver's license, which gives the possibility of engaging a larger courier base. Finally, there is a positive impact on the environment that is made possible by the reduction of carbon-dioxide emissions in line with the latest environmental sustainability policies that the increased awareness of the danger caused by climate change is driving.

Regarding the use of bicycles in crowd-sourcing, another possible way to encourage the use of more sustainable transport alternatives is to add free-floating bike-sharing (FFBS) as a delivery option. Specifically, some users of the FFBS service make themselves available to deliver small packages during their route (or by making a small diversion). This activity cannot be considered as a second job or as an obligation imposed on anyone who takes a rented bike, but simply as a possible alternative for those who make themselves available to deliver goods in exchange for a small reward and as an incentive for those people who care about the environment to make their small contribution to the cause, allowing a reduction in traffic and the resulting emissions *[11]*.

About the use of cars in crowd-sourcing, it was noted that this solution outperforms the use of bicycles in particular when the number of deliveries the driver agrees to complete is greater than one (many-to-one assignment). For this reason, there are articles in the literature investigating the use of car trip sharing systems, to leverage the available private car trips to incidentally deliver parcels during their original trips. An example is *[152]* that developed Car4Pac, an intelligent last mile last-mile delivery system adds that to the challenges of how to accurately estimate parcel delivery trip costs and how to maximize overall performance by assigning tasks to available and suitable car trips.

Crowd-sourcing delivery cannot replace the traditional goods delivery system, but it is possible that the solutions described so far can be integrated into a hybrid delivery network. To facilitate this integration *[64]* have developed a framework based on the theory of socio-technical transition, called "Five-Basic Principles". This framework is supposed to help increase the chances of success for Crowd Delivery innovations and facilitate the integration of an initial niche solution, helping to make it scalable (i.e. more far-reaching) with the classical goods delivery network, enabling it to reach a level of co-functionality that is the core concept of a sharing economy with the objective not only to reduce logistics costs but also to reduce GHG emissions and traffic congestion *[96]*.

One of the main risks of crowd-shipping is that the retailer can hardly guarantee completion of its promised delivery services when subcontracting individuals *[119]*. One way to avoid this problem is the user reputation system, which is often a component found in sharing platforms to prompt crowd-shipping individuals to adequate services. However, this may not be enough and the systematic survey in the literature revealed that the lack of trustworthiness is seen as one of the biggest obstacles to successful crowd-shipping applications. Therefore, a trend from a field test of one of the largest German retailers that were also tried out by the US retail chain Walmart is that the retailer offers its employees in its distribution centers to make their deliveries after work to online customers living in their neighborhood or on their way home, earning them an extra on top of their normal salary. *[17]*.

The necessary asset to optimize crowd-sourcing delivery is the service platform in which the drivers available to deliver the goods and the customers, with their requests for the delivery of their orders from the point of view of their timing, are present. The platform has the task of automatically creating matches between parcel delivery tasks and ad-hoc drivers. For the optimization of platform services, there are several articles in the literature; among those that emerged during the systematic research, there is a crowd-shipping framework capable of assigning LMD work to people on their way to work. The framework is centered on two modules of crowd profiling and task assignment optimization that simultaneously work on maximizing the jobs acceptance and the platform profitability *[62]*; the analysis of the potential of a decentralized decision-support system for bidder-requester performed through the simulation of a model for the understanding of the effects of fixed and variable costs in the operations of a less-than-truckloads platform capable of suggesting and proposing new tours based on location data, travel time and time-window constraints using a matching algorithm to reduce the number of trucks in use, their operational costs, distance and emissions *[110]*; the analysis of a platform operating in conjunction with a fleet of dedicated vehicles to make those delivering that cannot be done by ad-hoc drivers. Having to match tasks, drivers, and dedicated vehicles in real-time raised a new variant of dynamic pick-up and delivery problems. *[6]*.

Finally, the analysis of how Crowd-shipping delivery is facing challenges in the particular context of a rapidly emerging economy such as Saudi Arabia, with the description of benefits in the fields of the 3 sustainability pillars to the different stakeholders (economic, social, and environmental), the identification of the main internal success factors for the B2C and C2C business model (order assignment, compensation and the payment model) and the highlighting of the main challenges that currently hinder the success of these crowd-shipping implementations: legislation, availability of supply/drivers, trust and culture. *[2]*.

A further opportunity that has recently been investigated by practitioners and researchers is the use of public transport for goods delivery in urban scenarios *[43]*.
This solution promises to be an important opportunity to improve the current situation by contributing to the achievement of the ambitious climate targets set by nations and policymakers in agreements related to the reduction of environmental emissions (such as those of the European Commission in 2020).
The combination of the flow of goods and people has already proven to be successful when applied over long-haul distances *[19]*. This success according to the researchers can also be transferred, when certain conditions are met, to last-mile delivery through the realization of synergies leading to a more efficient and environmentally friendly delivery system. Such synergies can be achieved on various levels such as *track sharing*, where goods traveling on separate vehicles only share the infrastructure with public transport vehicles. An example already put into practice of this as yet the poorly integrated level of combined goods and passenger transport is light railways, where goods are transported in wagons without any passengers present and where the only logistical difficulty to be faced is having to ensure that the goods vehicles do not interfere with the normal service of passenger vehicles. Examples of this type of sharing infrastructure discussed in the literature can also be found in European cities like Paris, Dresden, Zurich, and Amsterdam *[104]*.
The intermediate level of integration is the *sharing of transport vehicles*. In this case, goods and passengers are transported in separate wagons in the case of light railways or trailers in the case of other public transport vehicles such as buses *[90]*. In this case, goods and passengers share the same travel route, the same timetables, and travel the same distances. It is of paramount importance to have the right technology in place to be able to load and unload goods quickly enough so that the natural public transport service is not compromised.
Finally, the highest level of integration occurs when goods and people *share the same unit load*(e.g. the same wagon). The logistical difficulty, in this case, relates to the dangerousness of managing peak periods for the delivery of goods at peak commuter transport times, with the aim of not disrupting the smooth flow of both parties involved, with an eye also on the issue of safety for people and not damaging the transported goods *[81]*.
For researchers aiming at transport optimization, this solution of integrating freight on

public transport in urban areas, which can be seen as a system of buses and trains operating at regular times and with fixed routes, can lead to several benefits ranging from improved environmental pollution, increased traffic efficiency with the consequent reduction of congestion, better utilization of unused capacity on public transport (especially at off-peak times), to more efficient logistics networks *[30]*.

Because interest in this solution is growing steadily, it is important to understand what the biggest barriers are to a successful and successful implementation. The necessary condition is that the public transport network has sufficient capacity to guarantee the integration of goods and passenger flows. Secondly, to keep the impact on passengers as low as possible, goods must be able to be loaded and unloaded in a short time with the necessary technology and the right coordination between the transport carrier and the ground handlers for loading/unloading operations.

Following this first pair of technical barriers, what appear to be the main obstacles without any doubt are of a legislative nature - in many countries the simultaneous transport of people and goods is not allowed by law - *[19]*, of economic and financial nature (i.e.large investments are necessary to start the project such as the purchase of new equipment and wagons), and the involvement of stakeholders - a topic that has not yet been investigated in the literature *[54]* -.

In conclusion, the strengths of this solution are similar to those of crowd-shipping although it is necessary to point out their main difference in that crowd-shipping does not necessarily employ the public transport system as a means of optimizing last-mile delivery, nor does it necessarily have to operate according to fixed time schedules and follow fixed routes. For this reason, it can be said that the two solutions are adjacent research areas.

Among the case studies that emerged during the systematic literature search, of particular interest and ambition is a study carried out in the city of Madrid that utilizes the metro network to provide the delivery service by exploiting the existing under-saturation of carriages at off-peak times with the addition of parcel lockers in the various metro stations to allow customers to take possession of their parcels *[151]*. The result of this study has led to the quantification of the benefits in terms not only of economics, a major limitation of the other articles dealing with this issue but also of the environmental and social advantages compared to the classic situation of dedicated delivery using vans directly to the customer's home.

2.2.2. Alternative Delivery Destination

This section presents in detail the alternative solutions for the delivery of goods from the point of view of the final node, the place where the customer takes possession of his order. The established knowledge is that services related to 'E-logistics' can be identified in three basic types: Attended Home Delivery, Reception Boxes, and Unattended Collection and Delivery Points. Since the focus of the thesis is on alternatives to attended home delivery, alternatives excluding the former are investigated and analyzed. About the two remaining solutions, the main difference lies in the fact that reception boxes are installed directly in homes while unattended collection and delivery points are automated parcel collection points located within public and private facilities, where guaranteed access depends on the type of facility itself.

ALTERNATIVE DELIVERY DESTINATION	Advantages	Barriers
Parcel lockers	• No failed deliveries • Consolidation of deliveries • Reduction of GHG emissions	• Customers have to reach lockers to grab their packages • Benefits can be eroded by poor locker location management
Click and collect	• Lower shipping costs • Very flexible for customers • No failed deliveries	• Customers have to reach shops to grab their packages
Receptions boxes	• No failed deliveries	• Privacy and security potential issues
Trunk delivery	• No failed deliveries	• Privacy and security potential issues • Car manufacturer and freight corriers partnerships

Figure 2.4: Alternative Delivery Destination

Currently, the most successful solution is undoubtedly the use of **parcel lockers**. They are a 24/7 unattended facility that can intelligently record, store and retrieve goods *[74]*. The key element that characterizes automated Parcel Lockers concerning home delivery is the possibility of successful delivery without the physical presence of the consumer. This aspect brings both advantages and disadvantages points to the solution. Among the strengths of this solution, the first one is economic: considering that the impact of the delivery cost for the logistic service provider is extremely high, the use of parcel lockers, which allows consolidation of deliveries, enables a cost reduction by grouping geographical close destinations into a single delivery point *[127]*. Another aspect that can be an interesting advantage is the environment. Post-implementation studies have shown a considerable decrease in carbon emissions due to the reduction in kilometers traveled by the traditional delivery van: according to *[74]*, parcel lockers would, all things being equal, be able to eliminate 2/3 of the CO2 emissions compared to normal home delivery and reduce the total kilometers traveled by approximately 53%.

The downside of this relative approach is that the customers have to drive or walk to grab their packages. The activity of picking up the package can take place en route when customers are on their way anyway or by making an extra trip. The potential economic and environmental benefits of using parcel lockers can only be realized with their correct location. Poorly managed location policies could weaken or even completely negate the environmental and economic benefits of parcel lockers *[131]*. A group of aspects to be considered is then that of consumer behavior about the use of parcel lockers *[148]*. The most important one is certainly the means of transport the consumer uses to reach the facility, which is mainly related to the distance the consumer has to cover to add the locker and the type of city. Generally, the means that one decides to use is the private one with great difficulty in discouraging the use of such means. However, it must be emphasized that the mode chosen by the consumer depends very much on the type of city, for example, if it is characterized by high population density and a good public transport network, the propensity to use a car will be lower. Whereas in the case of car-dominant cities such as those in Australia, this will be preponderant [85]. Given the enormous impact on the benefits of smart lockers, it is recommended that both transport operators and policymakers recognize the importance of creating these benefits and reducing costs for users by incentivizing and planning an optimal locker distribution network. For *[161]*, the key concept to be taken into account is that of customer perceived value, which is influenced by the degree of convenience. private security and reliability of the smart locker network. Regarding reliability, logistics operators must ensure that smart lockers offer accurate and error-free service. As for convenience, the lockers must be designated and located in such a way as to provide time and location efficiency for users, they must provide a good level of flexibility (which is why the service is currently 24/7) and provide courier return service. Finally, on the issue of security and privacy, smart lockers have adopted multi-factor authentication and data encryption to protect users' private information and data.

Concerning the optimal planning of the locker network, which together with the utilization rate constitutes the key to the success of this alternative solution *[120]*, numerous articles have emerged from the literature search that investigates and propose algorithms to optimize the usability and efficiency of parcel lockers from an economic and environmental perspective. The aforementioned article by *[85]* states that an agreement between facility location and accessibility for customers is crucial for network design. Still, on the topic of accessibility, *[97]*proposes an active-learning Pareto evolutionary algorithm for parcel locker network design using customer accessibility as a variable to be optimized. Other variables addressed by algorithms for their optimization are total profit maximization *[153]*, and the overall demand of customers attracted by the system *[146]*. Another solution is the one proposed by *[100]* which formalizes a vehicle routing problem with a mixed delivery approach, combining traditional attended home delivery and parcel lockers innovatively. According to this model, customers can either be served at home during their preferred time windows or they can be asked to pick up their goods at a locker. For each customer served using a locker, the logistics operator pays a compensation price to reduce the decrease in the perceived service level. According to this model, it is the logistics operator who decides which solution will complete the delivery and in a simulation, an increase in service quality of up to 40 percent was observed while the customers' perceived service quality did not vary.

Of lesser impact than lockers and already extensively investigated in the past, **click and collect** should be counted among the alternative solutions. Offering click and collect, also called buy online and collect in the shop, allows sellers to facilitate logistics and reach more consumers, whose buying habits have changed radically in recent years.
The definition of the solution is a hybrid purchase method between online and offline, which allows users to select and purchase items online and pick them up in a shop or at a centralized collection point *[63]*. The possibility of buying online and picking up in a shop is nothing new; in fact, it is something that large retail chains have been offering for several years. What is new is that small and medium-sized companies have now also started to offer it. With click-and-collect, the user can browse the online catalog anywhere, anytime. Once the product has been added to the shopping cart, the user can choose to personally pick up his purchase in the shop. The customer can choose the nearest shop to his home on a map according to the options offered by the seller. Depending on the type of product, the user can choose the time slot in which to pick it up considering that the shop usually keeps the ordered product for a few days *[107]*.
Click and collect was created to simplify the purchasing and payment processes. In this respect it offers several advantages, for buyers and sellers: for customers, the most important ones are saving on shipping costs, waiting time for delivery at home, the possibility to choose when and where to pick up their order, and the product can be available immediately or within the same day, and they can return the order immediately to the point of sale *[76]*. For sellers and logistic operators, on the other hand, the advantages are different: shipping and packaging costs are reduced, which also translates into a more eco-friendly e-Commerce that leads to greater customer satisfaction that is mindful of their environ-

mental impact, and the customer has more freedom to choose the shipping method they prefer, and offering more choice helps to convert more customers, there are no possible problems with the courier (primarily delivery delays and damage during transport). To conclude, the key features that an effective and efficient click-and-collect service cannot fail to have at present are analyzed. These characteristics are to offer an omnichannel service, i.e. to ensure that there is homogeneity in all online and offline sales channels as this improves the shopping experience of its customers; to enhance its customer care service, to ensure the presence of online 'salespeople' ready to answer visitors' questions via chat or telephone. Offering a tracking service for customers, giving them a tracking code so that they can always check the status of their order *[118]*. Finally, a key element must be real-time stock management to avoid orders for products that are no longer available.

One topic analyzed in the past, as can be seen from the grey literature used in this thesis, is the use of **reception boxes**. These are containers owned by private citizens, similar to mailboxes but large enough to hold packages. These structures are installed in customers' homes, usually in the garden, and are only accessible to couriers or logistics operators with the use of an access code or electronic key *[84]*. In this way, unless there is an error with the access code, the delivery will always be successful, eliminating the factor of missed deliveries in the absence of the customer at home, and the customer can consequently pick it up once back at home *[122]*. The boxes can be of various sizes and can also be refrigerated *[105]* and have the function of protecting the products inside before collection by the customer from potential dangers of theft, weather conditions, and other damage caused by other situations outside (e.g. damage caused by pets).

Finally, a further possible solution is the use of the **trunk of customers' private cars** as a mobile receiving node for deliveries *[9]*. With this delivery method, the courier is given free access to a vehicle's trunk for a limited time through an application code and then securely closes it once the delivery operation is complete. In this case, it is essential to have a car equipped with GPS to facilitate its location by the courier and to have a secure application to guarantee total security for the customer, and of lesser importance, to receive notification of the completion of the operation *[48]*. The temporary key for access to the car's trunk is generated for a limited time usually on the application, which is why strategic partnerships between car manufacturers and logistics companies are important *[78]*. Quite current examples are those between Volkswagen and DHL in Berlin and between Volvo and Amazon in the US.

Warehousing and Sorting Facilities

This section analyses the current state of the art concerning those infrastructures that can bring benefits concerning the issue of urban deliveries, acting as facilities at the city gates, where main order consolidation operations are conducted. The common characteristic of these facilities is their proximity to the city center, usually the very first suburbs. The

WAREHOUSING and SORTING FACILITIES	Advantages	Barriers
UCC	• Consolidation of deliveries • Great logistical and environmental benefits	• High capital cost • Necessity to involve all stakeholders • To be profitable there is the need to achieve a high amount of goods managed
SHD	• Consolidation of deliveries • Since they are located close to city centers, the delivery can be performed by environmentally friendly means	• Need good location management

Figure 2.5: Warehousing and Sorting Facilities

first type of facility, well known but not yet optimally developed, is the **Urban (freight) Consolidation Centres (UCCs)**. UCCs are the most common example of the concept of a shared economic resource that can create new opportunities to address the well-known problems in the urban transport sector. The initial idea behind most urban consolidation centers for the delivery of goods in the last years of the last century was to divide the delivery flow between outside and inside cities. UCCs can replace that multiplicity of last-mile deliveries, many of which are characterized by single delivery units or non-saturated vehicles, by providing a common receiving point for goods *[28]*. Located on the outskirts of the most densely populated cities, the last mile becomes more sustainable as the small delivery vehicle is shared by loads of several logistics companies, ensuring a higher utilization rate of the available load. This different conformation of the delivery network can theoretically represent the right compromise between the needs of companies and their customers and the local and global sustainability goals of the last mile. While UCCs have existed for several years anyway, their success rate has been incredibly low compared to the many attempts made *[149]*. The main problems encountered were high costs and lower demand than expected, or as another cause, poor location, often too far away from the city center. However, given the growing trend of increasing demand for e-commerce, advancing technology and increasing public interest in traffic and air pollution issues, the role of UCCs can be instrumental in addressing all these challenges. There are highly populated cities with particularly high pollution rates whose local and national governments are imposing laws to improve the living conditions of their citizens, such as Sao Paulo (Brazil) *[35]* which is attempting to limit the number of trucks entering the city every day, or like London or Singapore which have imposed congestion charges. Considering that most urban delivery trucks entering cities are underutilized, with products gathered in a single place, they can be consolidated into fewer deliveries. The logical reasoning behind this is very simple: through the use of UCCs, delivery vehicles are loaded with goods to saturate their maximum capacity, reducing the number of vehicles entering our cities and consequently decreasing urban pollution and the number of vehicles on the streets, thereby reducing the daily traffic on congested city streets, especially during rush hours *[77]*. This effect is further amplified when the vehicles used for deliveries to shops are eco-friendly. UCCs can perform different tasks. When goods from several carriers are unloaded and stay at the facility only long enough to be sorted and loaded onto local distribution vehicles (cross-docking activity), the UCC acts as a transit point. In this case, the goods do not undergo any handling, but are simply transshipped from a larger vehicle to a vehicle more suitable for the last mile, usually with a total weight of 3.5 t on the ground. From this, it follows that the operation of such a scheme involves the preparation of deliveries to the final customer upstream of the UCC. In the UCC, consolidation operations may also be complemented by storage and warehousing operations, as well as value-added services or product customization for the benefit of retailers *[75]*. The main barriers to the development of UCCs are economic mainly in that the capital cost can be high. This has been noted by previous cases of efficient and effective consolidation centers *[113]*. Most European UCCs were established in the past on their initiative and through public funding, ceasing their activities as these resources run out. Extensive literature has focused on the analysis of the causes of these failures, mainly due to the failure to involve a sufficient number of customers for the business to reach the break-even point within an acceptable timeframe. Often, the basic mistake was to implement the initiative based on intuition rather than on ex-ante economic-financial evaluations supported by precise quantitative analyses. Today, it is realized that for a UCC to be successful, a business model must be devised that is capable of ensuring the economic-financial sustainability of the initiative *[3]*. The experiences of publicly run urban consolidation centers have so far been unsuccessful from an economic point of view. Many UCCs have been closed due to low volumes of goods handled, continuous demands for funding from public authorities, and due to customer disappointment *[39]*. Since 2000, most of the attempts and implementations have been conducted by commercial companies that recognised the benefits of being able to control their logistics operations.

In the literature, the reference article for the description of key success factors for UCCs is that of *[116]*. It results in a classification into institutional elements such as leadership, operational arrangements, financial support, stakeholder obligations and interactions with the logistics network, and operational elements that include the nature of the industry, geographical coverage, location, and fleet management. For *[92]*, the logistical and environmental advantages that urban consolidation centers bring to companies and society are compounded by a further cost advantage in that stock holding costs are reduced since instead of warehouses in the city center, whose rent cost is very high, the UCCs are located in the suburbs where costs are lower.
As cooperation between all stakeholders involved in consolidation projects is a key factor, scientific publications have emerged to define which elements are considered attractive to those who decide to take part in this type of project. According to *[69]* who examined the willingness of carriers to participate in UCC operations and showed that if the UCC is nonprofit seeking, yet remaining self-sustained, higher willingness is favorable towards achieving greater good for all: achieving higher environmental sustainability, helping carriers to save more while making sure that the operation of UCC does not incur losses. According to *[115]*, urban freight consolidation centers represent the right compromise between the needs of companies and customers located in city centers and local and global sustainability goals.
For an analysis of the performance of urban consolidation centers, there is a lack of models for evaluation in the literature; the most authoritative model currently available uses the FAPA model (Five Attribute Performance Assessment) which includes the following attributes: cost, time, quality, productivity and environment for an ex-post evaluation of the effectiveness and efficiency of this solution *[115]*.

The other major alternative is located in more centralized areas than classic urban consolidation centers and is called **shared micro depot (SMD)**. This is a logistic facility, shared by at least two logistic companies, in which these companies have a space to oversee parcels, carry out loading/unloading activities, an area for storing and one for sorting, and can even become an area to offer customer pick-up service *[127]*. Typical locations where these facilities can be efficiently located are near offices or residential areas and mobile nodes such as bus stops or railway stations. Numerous articles are investigating the optimal position of MDs, exploiting as much as possible mathematical and quantitative models to support decision-makers in this strategic choice considering multiple sustainability constraints *[128], [79]*. It emerges that the location of these facilities is crucial for both business partners and residents, influencing their level of acceptance of the solution.

The result of using SMDs is to provide a place where parcels can be consolidated, which is why they are also referred to as micro-consolidation centers *[?]* and allow logistics operators to use less environmentally damaging vehicles such as bicycles and electric vehicles *[117]* due to the shorter distance they must be able to cover *[138]*. In the specific urban context of some cities, finding space for these types of activities at an affordable cost can sometimes be complicated, which is why in some cities SMDs may be an optimal choice for sharing costs and risks between partner companies in a context of trust and total transparency to optimize the logistics network for urban package transport. Case studies testifying to this emerged in research are those of Brussels *[150]* London *[18]* and Manhattan *[32]*.

Public Policies

As far as the application of effective policies for the last mile delivery context is concerned, a collaboration between the public and private sectors is of paramount importance; the public administration when deciding to introduce any kind of policy must consequently always take the interests of both sectors into account when carrying out simulations of the adoption of such solutions. To listen to the interests of all, questionnaires are often used to allow all actors to speak their minds regarding a possible implementation, or another solution may be the use of collaborative tables on issues *[121]*.

The reason behind stakeholder involvement is psychological: people's behavior toward an initiative changes substantially if they feel involved in the design and implementation process *[70]*. In a general sense, the role of administrations at various levels, international, national, and local, is to promote sustainable urban freight transport by meeting the needs of retailers, citizens, and transport providers. The instrument through which administrations can intervene is restrictive, infrastructural, and regulatory measures. Among the regulatory policies for sustainable urban mobility that have been most successful in study/research and of which we also have practical examples with measurable results is the delivery of goods outside peak hours. This policy is officially called **Night Delivery or Off-Hour Delivery** (from now on it will be referred to as OHD), it consists of the temporal shift of the delivery period of goods from the peak hours of daily traffic to off-peak hours to reduce traffic congestion and air pollution *[73]*. The first large-scale voluntary OHD pilot project is carried out in New York *[72]*. The study succeeds in demonstrating that the initiative produces benefits for the system as a whole. Analysis of the data collected shows that, with all other conditions equal, a vehicle burns less fuel off-peak than at times of peak maximum traffic concentration. Congestion not only increases the overall time spent in traffic, forcing drivers to adopt a driving style with numerous stops and starts resulting in increased emissions produced. In addition, OHDs are faster and delivery times less variable than expected, which allows transport companies to increase the number of deliveries per driver and improve the efficiency of the service offered *[102]*. Consequently, by delivering off-peak you can reduce the number of vehicles in circulation and the overall number of kilometers traveled. The reduced overlapping of passenger and freight flows following the introduction of OHD, ensures faster and more reliable journeys. In the case of New York, voluntary membership proved indispensable to ensure the stability of the change, which survived even after the end of the pilot project. The low implementation costs facilitated the transferability of the initiative as demonstrated by subsequent implementations in other US cities such as Los Angeles, Chicago, and Washington and the rest of the world such as Brussels, Dublin, Bogota, Sao

Paulo, and Stockholm. In particular, the evaluation of the Stockholm OHD project is used as one of the main examples because the city, unlike New York, is not subject to traffic congestion at all hours of the day, but only during the morning rush hour and some late afternoon hours. In this case, the incentives for stakeholders to adopt OHD and the long-term feasibility of such schemes are strongly dependent on the benefits of transport efficiency and is an interesting example for the evaluation of the differences between an OHD and a daily urban transport with varying characteristics of traffic congestion compared to the other cities mentioned above.

The four most important dimensions of analysis for the evaluation of efficiency benefits are driving efficiency, delivery reliability, energy efficiency, and finally service efficiency. In the particular case of the Stockholm project, the transport efficiency benefits were in line with previous studies on metropolises more prone to traffic congestion. The impacts on driving efficiency and fuel efficiency are lower and moderate compared to those found in e.g. New York *[53]*.

The experiences gained to reveal the wide variety of forms that the initiative of shifting delivery times can take. The alternative delivery modes present in the projects analyzed in the above-mentioned cities can be classified into three main categories *[59]*:

1. *assisted deliveries*: they involve the presence of an operator who receives the goods upon arrival. The main advantage of this initiative is the security of operations: given how the goods are delivered, the risk of disputes between the parties in the event of damage to the goods is minimized. Moreover, as it usually takes place early in the morning or late in the evening, the goods are also less prone to theft. The disadvantage of assisted deliveries is overtime for staff who may also not like unusual working hours.

2. *Non-assisted deliveries*: these take place in the absence of the trader and usually at night. The advantage is that the business does not have to pay an employee ready to receive the goods at any time. However, this mode of delivery requires the use of appropriate equipment, both for transport companies subject to noise constraints and for traders who must equip themselves with surveillance cameras or take other measures to reduce the likelihood of theft. However, it is essential that there is or is created a relationship of trust between the parties for this mode of delivery to be successful.

3. *Deliveries via a city distribution center (CDU) supplied at night*: in this case, the main advantage is environmental, as last-mile transport usually takes place in the worst traffic conditions. An important criticality of this delivery mode is related to the extra costs due to the load interruption that occurs in CDUs.

Other measures often used in urban contexts are policies related to **restrictive measures**. Access restriction measures include actions aimed at preventing or limiting access to the city or certain areas of the city (typically city centers) for commercial vehicles transporting goods based on dimensional criteria (total weight on the ground length) or power supply.

1. *restricted traffic zones*: It consists of an urban area delimited by special signs, in which rules on access, circulation, and use of spaces are applied that are more limited than in the general town center. The RTZ, therefore, summarizes the vehicle access restriction measures by size and category (analyzed in detail in the following paragraphs), either permanent or based on time windows. The establishment of an RTZ allows the effective and rapid achievement of a multiplicity of objectives, while at the same time being flexible in its implementation: the possibility of remodeling the boundaries and articulating the operating criteria makes it possible to expand it, reduce its impact, or revoke it in the light of the results that have emerged since its introduction (on an experimental or full-scale basis).
   However, there are also some critical factors concerning the implementation of traffic-restricted zones, such as the possible generation of traffic in the vicinity of the crossings, the impact of the restrictions on the logistic operators' margins of freedom in the delivery planning process, and the related economic consequences for them, for the recipients of the goods and thus for the final consumer, and the morphology of the territory and its urban specificities *[21], [88]*.

2. *Time windows*: The provision of time windows in which to allow, with restrictions, activities otherwise prohibited is aimed at influencing the logistical organization of the distribution phases so that deliveries take place at times of reduced or soft congestion *[101]*. Non-immediate effects are the reduction of air and noise pollution and the creation of safer conditions for the mobility of cyclists and pedestrians at times when these interests need greater protection.

3. *Prohibition and restrictions by vehicle size*: The aim of introducing bans or restrictions on the circulation of vehicles is to reduce the presence in the city of vehicles that, due to their size and loaded mass, may hinder or disturb the circulation of other users, represent a safety hazard in areas with a high pedestrian or cycle-pedestrian vocation, have difficulty maneuvering on roads characterized by particular pedestrian or particularly narrow carriageways. The criteria on which to base the limits may be based on full load mass, height, length, and width of vehicles, to be defined concerning the size of the infrastructure present *[55]*.

4. *Prohibitions and restrictions by type of vehicle power supply*: The measure aims to

improve air quality in urban settings by reducing the presence of polluting vehicles and providing incentives for operators to renew their fleets *[92]*. If an RTZ has been set up in the city for a fee or with time slots, the restriction measure can be reinforced with measures that penalize polluting vehicles or facilitate environmentally friendly ones.

Infrastructural measures comprise a set of interventions aimed at increasing the endowment of physical facilities (such as warehouses, for example), available to the urban goods distribution activities or optimizing their use: these interventions may concern the realization of new structures or the redefinition of the modalities of use of existing structures, usually destined for entities operating in different processes than urban freight distribution. These measures aim to increase the level of efficiency and the potential of urban freight distribution, by affecting the organizational methods of deliveries and pushing for an increase in productivity, also by saturation of vehicles *[58]*. The main infrastructural measures, in addition to the already mentioned urban consolidation centers in section 2.2.3, and temporary storage system (i.e. Parcel Lockers) include measures concerning:

1. *Time of use of loading/unloading bays*: The presence of spaces where ordinary loading and unloading operations can be carried out is an important component in the organization of activities as it influences their efficiency and speed. Bays that are adequate in number, size, and availability favor loading and unloading operations, reducing their time, consequently contributing to improving vehicle rotation [89], increasing their productivity, and ultimately reducing traffic and the pollution it generates. The correct use and numerical sizing of parking spaces also reduce traffic obstructions caused by commercial vehicles parked in double lines, an obvious symptom of the lack of parking spaces, their irregular occupation, or inadequate spatial distance from destination points. For the organization of spaces arranged by the administration to be respected by users, illegal occupation of pitches must be prevented and sanctioned: in addition to intensifying on-site checks, the following can be considered the installation of technological systems for detecting infringements or booking remote reservation of parking spaces, also using bollards.

2. *Preferential lanes*: Optimizing the use of existing infrastructure to improve the mobility of goods and delivery activities in the city can be achieved by rethinking the regulation of reserved lanes, allowing commercial vehicles to use them as well. Permission to use express lanes can be linked to the presence of conditions, such as the use of environmentally friendly vehicles. in this way, it can also be seen as a measure of 'rewarding' virtuous choices.

To conclude, the last type of policies concerns **regulatory measures**, which include initiatives implemented by local authorities to regulate various aspects of the circulation of commercial vehicles within the framework of urban logistics programs textit[45]. These measures are aimed at changing user preferences regarding the use of infrastructure and urban transport modes, to reduce congestion in urban centers through the more rational use of infrastructure. Regulatory measures are usually intricately linked to other types of initiatives, such as the establishment of RTZs and the development of a UCC, and include specific actions such as:

1. *Road Pricing and Congestion Charges*: Selective tolling (**road pricing**), which can be defined as charging for the use of infrastructure (according to the rule that the user pays), is typical of the motorway system but can be extended to other situations, such as express roads, bridges tunnels, and city streets. The **congestion charge** is a variant of the selective toll generally applied in urban contexts, where it allows to put a constraint on the use of urban roads, with the possibility to modulate the charge on traffic peaks or vehicle category also according to fuel and reduce the use of private vehicles by pushing the optimization of commercial ones, with direct effects on congestion levels and emission levels *[4]*.
2. *Multifunctional roads*: The measure consists of regulating mobility on certain roads so that in the course of the day are allocated to different categories of users or modes of use *[99]*. Certain city streets could thus be reserved, at certain times of the day, for private traffic, for commercial vehicles only for loading and unloading goods, have two-way traffic or become one-way streets, be reserved for residents' car parking, etc. parking for residents' cars, etc.

3 | Framework Presentation

Since the ultimate aim of this thesis is to provide a model for the classification of the different solutions currently in the field and those being evaluated, this chapter presents a framework resulting from an analysis of the impact each of them can bring to the last-mile delivery scenario. The different solutions are clustered following the same pattern used for the systematic literature review, thus there will be four macro-categories named:

1. Alternative transport solutions;
2. Alternative delivery destinations;
3. Warehousing and sorting facilities;
4. Public Policies;

The analysis developed is an **impact assessment** of the different solutions, taking as a base case (also named as-is situation) the traditional home delivery of goods using a van owned by a logistics company. The evaluation is mainly qualitative, so it will assess how the adoption of one solution rather than another can bring benefits, disadvantages, and risks by comparing it with the as-is situation.

Impact assessment gives a perspective on the effects of interventions, highlighting a broad spectrum of issues, risks, and benefits related to the different impact areas so that it can help policymakers and companies' decision-makers understand which solution may be best suited to their context, where context is defined as a set of characteristics that include the volume of orders, the conformation of the city (size, presence of restricted traffic zones, etc.), the fleet of vehicles currently used, the profile of their customers (what type of delivery they prefer, what is their expectation of delivery times) and the service level the company wants to achieve.

The objective is to provide a dashboard of indicators differentiated by impact area according to the Grant Agreement, which can provide the possibility to assess the potential of different interventions in the complex context of last-mile delivery based on these indices.

The impact areas that were analyzed and to which at least qualitatively in the first instance it was possible to give weight to the scope of change are (ULaaDS Grant Agreement):

1. Environment
2. Traffic conditions
3. Logistics efficiency
4. Economics
5. Technology and/or Infrastructure Maturity Level
6. User experience and acceptance

3.1. Description of the impact areas and KPIs for the evaluation

1. **Environment**: This impact area refers to the preservation of natural resources and the limits within which activities should take place without depleting non-renewable resources. It is well known that urban freight transport greatly contributes to climate change through the emission of greenhouse gases, air pollution through the emission of health-damaging gases, and noise pollution. These three factors enormously characterize the attractiveness of the urban environment and the basic aim of the analyzed implementations is to have a positive impact on society, whereby society means the different groups of people interacting with each other that are part of a community. The first set of indicators assesses **air quality**, which is inversely proportional to the level of pollutant concentration in the air. Air pollution is caused by the diffusion into the atmosphere of gases and fine dust generated by the production and use of fossil fuels, which are used as fuel for the majority of vehicles in our cities today. In more densely populated cities, such as metropolises, the problem of air pollution is regarded as an emergency and one of the prerogatives of governments is to limit it with laws and measures aimed at reducing harmful emissions. Consequently, there is a causal relationship between traffic and air pollution. Road transport is one of the main sources of air pollutant emissions in urban areas (road pollution) *[8]* and sustainable mobility would limit traffic pollution and air emissions from road transport. The main air pollutant gases derived from urban freight transport are nitrogen dioxide (NO2) generated by the combustion of fossil fuels, Particle Matter (mainly PM10) resulting from tire and brake wear, and then

carbon monoxide (CO) and sulfur dioxide (SO_2).
Also dependent on the use of fossil fuels are **greenhouse gas (GHG) emissions**. Increased GHG emissions are responsible for global warming and climate change. The massive use of fossil fuels has led to a huge amount of CO_2 emissions, one of the main greenhouse gases. Another factor disturbing the balance of the natural greenhouse effect is deforestation: the disappearance of forests and plants has greatly reduced the ability of trees to absorb CO_2. Also contributing to the greenhouse effect are methane (CH_4) and nitrous oxide (N_2O), mainly from agriculture, food, and the energy sector, including transport. In this case, a single indicator was chosen to assess CO_2 emissions concerning the IPCC (Intergovernmental Panel on Climate Change) methodology and are expressed in terms of tonnes of CO_2 equivalent by applying the Global Warming Potential (GWP) coefficients of each compound.
Finally, the impact of another type of pollution is also assessed, sometimes underestimated, but which the World Health Organisation (WHO) considers the second most harmful environmental stressor in Europe, behind air pollution, namely **noise pollution**. Its effects stem mainly from the reactions that this stress causes in the human body and that can also occur during sleep. Noise is caused in the context of last-mile transport by both engine noise and loading/unloading activities and can be annoying for nearby residents. The time of the day is a particularly important factor in actually understanding the extent to which noise can be perceived as a nuisance (that is why there is a clear distinction between the actual noise level and the perceived noise level). Currently, the measures that can bring about a greater noise reduction are the use of electrically driven vehicles to replace classic internal combustion engines and the imposition of a speed restriction on densely populated roads.

Indicator	KPI
Air Quality	PM_{10}, NO_2, CO and NH_3 annual emissions
GHG emissions	CO_2 equivalent annual emissions
Noise Level	Daily average noise level

Table 3.1: Environment Indicators *[117]*

2. **Traffic conditions**: In recent years, online sales have become an essential part of the retail trade. Consequently, the volume of traffic caused by delivery services has increased rapidly. The biggest impact on cities is the final route in the supply chain, the last-mile delivery. A severe problem due to the increase in online shopping is the consequent increase in traffic due to the presence of vehicles engaged in urban freight transportation activities, which reduce the efficiency of traffic flow and contribute to stressful congestion, increasing the danger of collisions, illegal parking for unloading goods, all of which affect the quality of life of citizens. Traffic problems also affect the flow of pedestrians and bicycles, not only vehicles as congestion affects roads, but also shared spaces, bike paths, pavements, and squares used for illegal parking for loading and unloading, for example. Congestion due to parking on pavements or partially on streets can jam traffic, especially during rush hours or on particularly busy streets.

   Road safety is directly proportional to the number of vehicles on the road. The logical reasoning is more vehicles on city streets for urban delivery of goods, more traffic, and more danger of road injuries, fatalities, and damages.

   The other issue to be investigated for resolution concerns the **use of urban public land**, occupied by last-mile delivery vehicles for maneuvering, loading and unloading activities, and parking. In addition, urban freight transport solutions also utilize the land for reloading and storage activities, think of parcel lockers. This use of public land has to be effectively regulated by governors and policy-makers as they in turn generate a lot of local traffic in adjacent areas for customer pick-up.

Indicator	KPI
Delays due to Congestion	Average daily delays of the fleet in traffic
Congestion	Vehicles obstructing the movement of other vehicles
Traffic Safety	Yearly number of road accidents
Use of existing Public Space	Time of use for LMD activities of public land areas

Table 3.2: Traffic and Mobility Indicators *[66]*

3. **Logistics efficiency**: Recalling one of the phrases in the introduction, last-mile delivery for companies performing this service was defined as the key problem in terms of lack of efficiency for most supply chains. Efficiency is defined as the ratio between the resources used as input and the service offered/what is produced as output. The fundamental concept is therefore resource utilization, where in the case of last-mile delivery the key resources are vehicles, terminals, logistics operators, and goods receipt. The important indicators for understanding the issue are the vehicle utilization factor (vehicle saturation) and the average number of deliveries per tour per vehicle.
The other aspect that has to be considered in these cases is the service level that the company intends to offer its customers. Consequently, it is of fundamental importance to evaluate elements such as the speed and delivery time that one company promises to its customers and the need for the customer to be present at the time of delivery (and in this case to evaluate the average number of failed delivery attempts) or not by offering services that can solve the 'not-at-home' problem.

Indicator	KPI
Vehicle Utilisation Factor	Average vehicle saturation
Customer Presence	Customers have to be present?
Unsuccessful Deliveries	Average number of missed deliveries per tour
Fleet Efficiency	Average number of deliveries made by one vehicle per tour
Speed of Delivery	Average time for successful delivery
Punctuality	Average weekly deliveries made in the right time slot
Quality	Average weekly deliveries made with no damages/defects
Quantity	Average weekly deliveries made without loss/theft

Table 3.3: Logistics Efficiency Indicators *[55]*

4. **Economic**: Urban freight transport solutions require some **capital investment** and can change the nature of **operational costs** from the as-is situation. Fundamentally, the implementation entails a positive impact from an economic perspective for being feasible and viable. This is certainly the most critical area of impact for companies, as investing in projects that are potentially unprofitable or last a long time before becoming profitable is extremely dangerous and can undermine their economic-financial stability. Economic impact indices focus their attention on the **efficiency benefits** derived from a measure by assessing the costs associated with the initial investment, the preparation, and implementation phases, and finally its operation. Before launching the project to implement an alternative solution, each company makes its estimate of the operational costs required for the project. Among

these costs, in addition to classic employee salaries and training, maintenance, and vehicle depreciation, it is also interesting to investigate the **energy costs** from non-renewable sources, the main example being vehicle fuel. The area of interest of this indicator also integrates perfectly with the environmental interest of the implementation, and in the case of an effective reduction of the energy consumed, an important blending gain can be achieved. Finally, intending to assess the market potential of a solution, which leads to a change in the company's business model, companies need to understand whether there is enough demand for the new service and whether there is a willingness on the part of customers to use it in the context of their product deliveries.

Indicator	KPI]
Investment Costs	Payback time for the investment
Operating Costs	Annual cumulative operating costs
Income Generated	Total income generated
Energy Consumption	Yearly costs for energy consumed (non-renewable sources)

Table 3.4: Economic Indicators *[82])*

5. **Maturity Level**: Often underestimated but with an impact that can be crucial for the success of an implementation or for understanding the right moment for its large-scale launch is to understand the maturity level of each implementation, from different points of view, which are wide and varied but together constitute an important starting point for analysis. The objective of this impact area is therefore to represent a snapshot of the current state of solutions, trying to understand which ones, potentially overcoming obstacles and progressing further in development, are capable of outperforming other types of solutions that may already be at the peak of their maturity level but whose actual impact is limited.
The maturity of a solution must be investigated on a case-by-case basis from an infrastructure, technology, and policy perspective. In the case of **technology**, the tool used is the Technology Readiness Level (TRL), a methodology for assessing the maturity level of a technology, originally developed by NASA in 1974 and subsequently modified. The TRL measures the maturity level of a technology through the progression of the research, development, and deployment phases (see Appendix 4). The TRL scale goes from 1 to 9 and allows project personnel to understand how much development a certain technology still needs before it can be used on a large scale. This tool provides a consistent and uniform way of assessing the degree of maturity of different technologies.
From the point of view of **policy maturity**, the involvement of stakeholders in the

implementation of urban freight transport solutions has to be evaluated primarily. It is fair to say that this concept is directly linked to the degree of stakeholders' awareness of these measures, managerial skills, previous knowledge, experience, and willingness to adopt them. Lack of know-how and for some solutions, an inefficient bureaucracy may constitute a managerial risk that not all companies can cope with.

Indicator	KPI
Technology Maturity Level	Technology Readiness Level
Level of Bureaucracy	Level of bureaucracy in implementation phase
Know-how Level	Stakeholders' level of experience
Awareness Level	Stakeholders' willingness to implement sustainable solutions

Table 3.5: Maturity Level Indicators *[37]*

6. **User experience and acceptance**: The last mile delivery scenario, can be considered customer-centric. The degree of customer satisfaction is one of the key drivers for evaluating the efficiency of urban delivery companies. For this reason, the evaluation of changing customer and user satisfaction when moving from the base case to new urban logistics solutions becomes of paramount importance. The final judgment on the implementation of the measures is the degree of satisfaction with the overall quality of the service from the customer's point of view, which constitutes the so-called acceptance level. The survey covers not only current users but also potential users, the latter being relevant as they allow for greater insight into the potential of the solution for upscaling and its replicability. Companies need to try to intercept the degree of awareness of sustainable deliveries among their customers, to know whether they are willing to pay more for a delivery made with sustainable means of transport or alternative green solutions.

Indicator	KPI [Unit of Measure]
Customer Satisfaction	Customer satisfaction index for the service
Final Users Acceptance	% of customers willing to pay for substitute delivery methods
Market Penetration	Sum of current and estimated potential users

Table 3.6: User Experience Indicators *[67]*

Combining the KPIs of the different macro-categories investigated results in the following dashboard of indicators, which is used for subsequent classification of the different last-mile delivery solutions that emerged during the SLR. The previously defined macro-categories can be considered as classification axes able to demonstrate which solutions are the most suitable for the different urban contexts.

Indicator	KPI
Air Quality	PM10, NO2, CO and NH3 annual emissions
GHG emissions	CO2 equivalent annual emissions
Noise Level	Daily average noise level
Delays due to Congestion	Average daily delays of the fleet in traffic
Congestion	Vehicles obstructing the movement of other vehicles
Traffic Safety	Yearly number of road accidents, injuries, and fatalities
Use of existing Public Space	Time of use for LMD activities of public land areas
Vehicle Utilisation Factor	Average vehicle saturation
Customer Presence	Customers have to be present?
Unsuccessful Deliveries	Average number of missed deliveries per tour
Fleet Efficiency	Average number of deliveries made by one vehicle per tour
Speed of Delivery	Average time for successful delivery
Punctuality	Average weekly deliveries made in the right time slot
Quality	Average weekly deliveries made with no damages/defects
Quantity	Average weekly deliveries made without loss/theft
Investment Costs	Payback time for the investment
Operating Costs	Annual cumulative operating costs
Income Generated	Total income generated
Energy Consumption	Yearly costs for energy consumed (non-renewable sources)
Technology Maturity Level	Technology Readiness Level
Level of Bureaucracy	Level of bureaucracy in the implementation phases
Know-how Level	Stakeholders' level of experience
Awareness Level	Stakeholders' willingness to implement sustainable solutions
Customer Satisfaction	Customer satisfaction index for the service
Final Users Acceptance	% of customers willing to pay for substitute delivery methods
Market Penetration	Sum of current and estimated potential users

Table 3.7: KPIs Dashboard

3.2. Impact assessment analysis

In conclusion, the framework for the overall impact analysis of alternative last-mile delivery solutions will present the following layout:

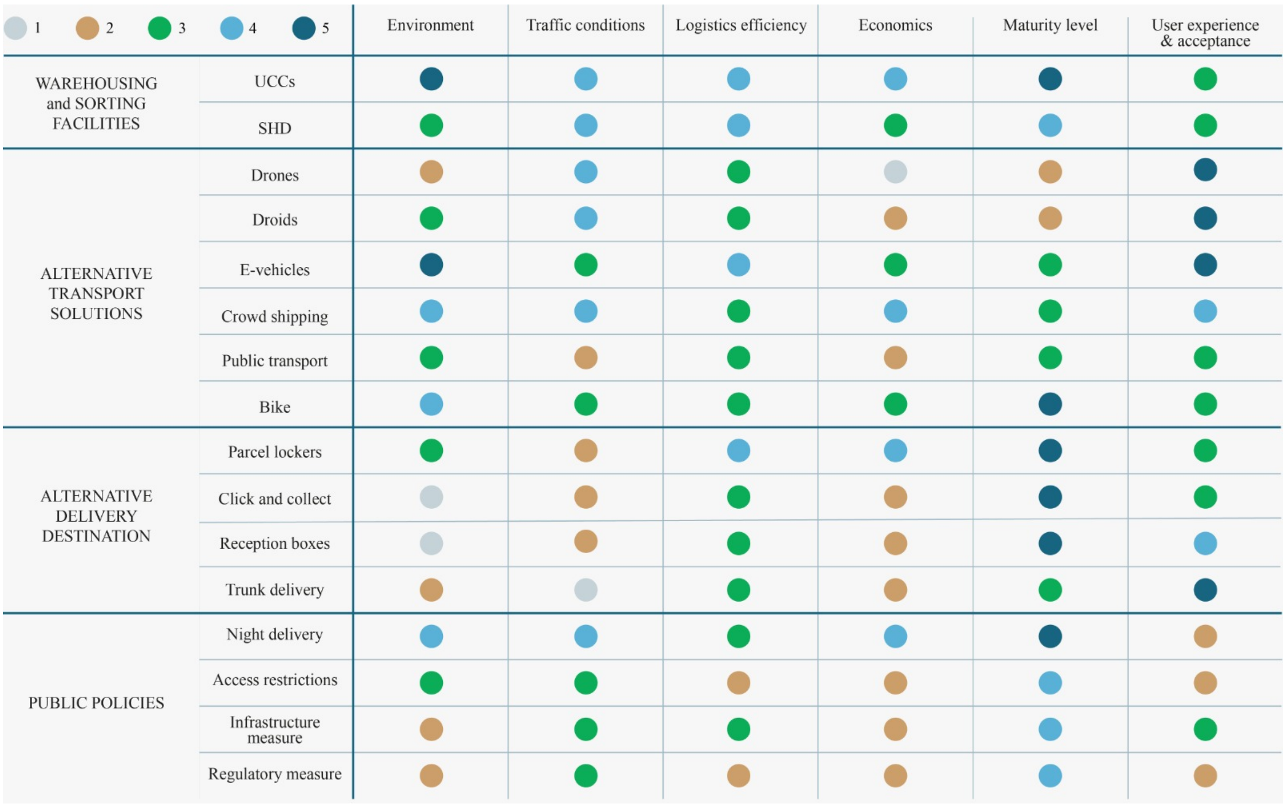

Figure 3.1: Framework

The impacts of the macro-categories are evaluated according to a weighted average, for speed of understanding a scale of 1-5 with different colors of the results is adopted, where, increasingly, we go from a slight improvement over the base case (1) to the greatest impact (5). In this way, it is possible to understand the possible impact following the implementation of each solution from an environmental social, and logistical, the maturity level of the technology/solution through the assessment of the development point of the technology, the main legal and technological barriers, the economic investment required to be able to guarantee a sufficient level of service through the use of a new solution and finally the level of consumer acceptance by comparing each intervention to the home delivery of goods.

Going deeper into the weighted average, more weight is given to each impact area to those KPIs with greater relevance and a higher improvement differential than in the case of attended delivery at home:

- **Environment**: 40% Air quality, 40% GHG emissions, 20% Noise level;
- **Traffic conditions**: 30% Delays due to congestion, 30% Congestions, 30% Traffic safety and security, 10% Use of existing public space;
- **Logistics efficiency**: 20% Vehicle utilisation factor, 10% Customer presence, 20% Unsuccessful deliveries, 10% Fleet efficiency, 10% Speed of delivery, 10% Punctuality, 10% Quality, 10% Quantity;
- **Economic**: 25% Investment costs, 25% Operating costs, 25% Income generated, 25% Energy consumption;
- **Maturity Level**: 40% Technology maturity level, 20% Level of bureaucracy, 20% Know-how level, 20% Stakeholders' awareness level;
- **User experience and acceptance**: 40% Customer satisfaction, 40% Final users' acceptance, 20% Market penetration.

The classification framework aims to provide different guidelines for the various stakeholders:

- **Shippers**: as they seek to increase their profits with an eye on the perceived reliability of customers towards them, shippers will prioritize the areas of economic impact and customer acceptance, assessing which solution can guarantee the highest economic return while at the same time satisfying customer demands;
- **Freight Carriers**: with the desire to improve the bottom line, freight carriers certainly have an eye on the efficiency of their logistics to minimize costs while satisfying customers and shippers in terms of speed of delivery, time windows, and order compliance. Therefore, the solutions they are going to invest in will mainly be those that guarantee a high return on investment, can improve logistical efficiency and customer acceptance, and focus on those solutions that are ready-made (a high technology readiness level) and not too blocked by bureaucracy or lack of know-how.
- **Residents**: they may be seen as marginal stakeholders, concerned only with environmental, traffic conditions and safety and security issues, but it should not be forgotten that they also represent current or potential customers, hence the last node in the logistics chain of last-mile delivery so that their degree of satisfaction with the delivery service should also be added to these fundamental indicators;
- **Administrators**: their main objective is always to ensure a high quality of life for their citizens. They will therefore place great emphasis on those solutions that may be behind in development but can guarantee the greatest improvement in terms of

the environment, traffic conditions, and safety. The tool in their hands is that of policies, through which they can provide incentives for the use of solutions such as bonuses for the purchase of electrically driven vehicles or permission for such vehicles to access RTZs;

4 | Conclusions and future developments

This SLR demonstrates what can be done by entrepreneurs, customers, and governors to make the sensitive topic of last-mile delivery more environmentally sustainable without negative economic feedback, and also gives an indication of what are the most current issues in the literature and their current state of development. The framework presented, aims to give a different vision, as it divides the last mile delivery network, consisting of different entities - companies, stakeholders, and delivery facilities - into four distinct macro-categories: sorting facilities, alternative transport solutions, alternative delivery destinations, and public policies. The solutions that emerged during the research phase were classified according to qualitative aspects into six impact areas, proposing a dashboard of indicators that captures the most critical issues related to urban freight delivery. The impact of these solutions is only considered in isolation, but future research aimed at assessing the benefits of combinations of them, some already in practice and others only at the design stage, may be of interest.

The combination that seems to be the best in terms of cost, timing, and environmental impact at a theoretical level, as it has not yet been proven in the literature by case studies, involves the use of overnight delivery for an electric vehicle or cargo bike, whose delivery operation starts at a shared micro depot or urban consolidation center *[42]* and ends at parcel lockers, and in parallel during daytime hours to customers' homes (where they can find reception boxes *[106]*) or to shops offering click-and-collect service *[10]*. The peculiarity of this solution is that the synergies between the benefits of these four implementations can cover the shortcomings and uncertainty points of each other.

Looking at the publications that emerged, one can see how the profile of each city can influence the successful implementation of one solution over another. The two issues that most influence the path to improving the sustainability of urban freight delivery are recent technological advances, the most illustrious being autonomous vehicles, artificial intelligence (AI), internet of things (IoT), information technology services (ITS), and robots, and collaboration between the various stakeholders involved in city logistics projects.

Those recent technologies that have emerged for the vast majority over the last decade, the unit of analysis of this SLR, are capable of making last-mile delivery operations more efficient and effective, consuming less energy being more environmentally friendly, and able to optimize the logistics network in terms of economics and environmental emissions. As far as a collaboration between the different stakeholders is concerned, this becomes a necessary condition for successful implementations in this particular context, so much so that the public-private partnership (PPP) was developed, a concept that includes the sharing of data, as complete transparency as possible for key information, which is essential to meet the needs and requirements of all parties involved in the implementation of urban logistic solutions.

4.1. Managerial Implications

It is now clear that the key variable for customers is the speed of delivery. This factor inevitably causes pressure on the supply chain of companies that have to be able to offer same-day delivery services also due to making sub-optimal use of available resources. Such deliveries are very problematic from an environmental point of view and worsen the company's carbon footprint.

Without any decisive action, emissions from vehicles engaged in the urban delivery of goods will only get worse. Through cooperation between all actors involved, it will be possible to create a scenario that is much more sustainable, quicker to meet the tastes of businesses, and less costly for the goods delivery sector.

On a practical level, companies, and in particular those who make decisions on a tactical and strategic level within them, have the objective of pursuing targets to help achieve sustainable urban delivery of goods. To do so, they must, for example, encourage the choice of green delivery modes, providing as an incentive a discount on the cost of delivery if customers make themselves available to pick up their packages at a locker or physical shop in the vicinity of their homes instead of choosing home delivery. Incentives, however, are not only those in the relationship between the company and its customers but also those that national and local governments are willing to provide for companies to start adopting a fleet of electric vehicles to replace fuel-powered ones, in this case for example with incentives that can be tax breaks or making recharging these vehicles cheaper by investing in recharging infrastructure.

Another thing that companies need to do is to completely rethink the use of their assets, always keeping sustainability as a priority. Companies whose core business is the delivery of goods in urban areas must think about sharing nodes and arcs of their delivery networks, including for example some fulfillment centers, pick-up and drop-off locations, or some

lockers. Governments themselves can facilitate this network sharing by investing in the construction of delivery consolidation centers on the outskirts of large cities with a high enough delivery volume to justify the investment with a return in environmental and economic benefits.
As a final point, one cannot fail to mention the incredible step forward that urban delivery companies can make through better use of technology to study and analyze forecast data that can let companies know who and where will buy such an item, providing the ability to know in advance which SKU to stock and in which fulfillment and storage center *[137] [155]*. Developing the necessary insights requires analyzing a mix of data from the companies themselves and third parties, listening to what the company wants and desires at a specific time of year, and monitoring local trends and events, with cross-ecosystem data sharing *[27]*.

4.2. Future Research

The literature review revealed a lack of publications dealing with topics of relative importance to fully understand the different possible implementations. For this reason, at the end of this thesis, directions for future research are indicated to complete the study of the topics dealt with. The main shortcomings relate to the study of UAVs and droids, probably because these technologies are still not fully developed and certainly not yet definitively efficient. Going into detail, for *UAVs*, many limitations emerged as a common element in all the publications:

1. There is no comparison in terms of effectiveness and efficiency between drone-only delivery solutions and the use of intermediate solutions such as drones + vans;
2. There is a need for studies concerning the state of charge for performance evaluation considering weather and temperature conditions;
3. An analysis of issues related to regulations, especially for certain densely populated city areas may force the use of different means.

As regards *droids*, research is more advanced than for UAVs, and what emerges is mainly a literature gap concerning the investigation of the impact of this technology for understanding whether the use of droids for deliveries would be sustainable during their entire life cycle, for example using an LCA assessment.
Another alternative technological solution for transport, *electric vehicles*, is not yet fully developed and has shortcomings in the literature:

1. In articles proposing electric vehicle routing trying to optimize some variables (cost,

time, and consumption), simplifying assumptions are recurrently made such as a linear charge and discharge time and linear energy consumption (i.e. *[158]*). Future work focusing on the proposal of E-VRP with the possibility of incorporating these realistic characteristics will certainly be more valuable than current publications;

2. Relevant articles integrating energy price uncertainty into a model are absent in the SLR;

3. Finally, a possible direction for future research should be aimed at the integration of energy generated from renewable sources for a further step in the development of green logistics systems.

For *crowdshipping*, the innovative element is the platform that can connect companies that need to make a delivery and ordinary people who take charge of the transport. Here, future work can explore the impact of different payment methods, pricing strategies, and varied incentives that can provide key support for this model.
In conclusion, it stands out that on *parcel lockers*, the vast majority of articles, and consequently the focus of researchers, is on routing algorithms for finding the most efficient location of them. Future work should focus more on different problems:

1. From the point of view of operational decisions, only one article dealt with scheduling and assignment to locker stations with a look towards capacity management *[17]*;

2. From the perspective of tactical and strategic level decisions, more research will be needed concerning partnerships and collaborative projects involving parcel locker network actors.

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A | Appendix A

The final search string used in this systematic literature review was:
TITLE-ABS-KEY (("urban freight" OR " last mile") AND "delivery" W/15 ("sustainab*" OR "innovat*" OR "transp*" OR "green" OR "multimodal") AND NOT ("public" OR "humanitarian" OR "Covid*" OR "passenger*") AND (LIMIT TO (SRCTYPE,"j")) AND (LIMIT TO (DOCTYPE,"ar")) AND (LIMIT TO(LANGUAGE,"English")) AND (LIMIT TO (SUBJAREA, "ENGI")) OR (LIMIT TO(SUBJAREA, "SOCI")) OR (LIMIT TO (SUBJAREA, "COMP")) OR (LIMIT TO (SUBJAREA,"BUSI")) OR (LIMIT TO (SUBJAREA, "DECI")) OR (LIMIT TO(SUBJAREA,"ENVI")) OR (LIMIT TO (SUBJAREA,"ECON")) OR (LIMIT TO(SUBJAREA,"MATH))).

B | Appendix B

The **Electric Vehicle Routing Problem (E-VRP)** is a typical operational problem in distribution networks and consists of establishing the routes of a set of electric vehicles to serve a set of customers. (Given a set of vehicles with certain characteristics that must visit a set of customers (also with certain characteristics) distributed within a transport network from one (or more) central depots). The E-VRP deals with the management of vehicles ideally from all points of view. This class of problems encompasses a variety of cases, which makes these problems difficult to solve at the optimum. The most general case involves vehicle route planning in the presence of:

- Multiple vehicles;
- Multiple deliveries;

Each vehicle

- can serve more customers;
- has unlimited transport capacity;

Each client has a demand for a certain product; The objective of the algorithm may be:

- the minimization of the cost associated with the vehicle route (distance, time, etc.);
- the profit maximization;

The result of the algorithm provides:

- the allocation of a certain set of customers to each vehicle;
- the elaboration of a route for each vehicle.

The **Electric Arc Routing problem (E-ARP)** can be defined as a special case of the more general E-VRP, in which the arrangement of customers is assumed to be uniformly distributed along transport network connections (such as a road).
E-ARP consists of designing a set of routes to meet the demands of all requesting customers, to minimize total costs. Costs can be defined in terms of operating costs, distance

traveled, or time. Each route is covered by a single electric vehicle that departs and returns to the same depot.

Finally, as far as the **Electric Team Orienteering Problem (E-TOP)** is concerned, the big difference between the two previous algorithms is that in E-TOPs, meeting the demands of all customers is not mandatory. This situation is quite common when there are constraints on fleet size and the maximum distance each vehicle can cover. In classic E-TOPs, each customer offers a reward to the company for being served and the goal of the algorithm is to maximize the gain from the rewards gathered by the fleet of electric vehicles when they visit a group of customers. Typically, the vehicles start at a departure node, serve a group of customers and arrive at a destination node and the limiting variable is the limited driving range due to the battery of the electric vehicle.

C | Appendix C

The **traveling salesman problem (TSP)** is a classic operational research problem posed as follows: A traveling salesman has to visit a certain number of cities. He wants to leave home and return home after visiting each city only once, traveling the minimum distance. Solving this problem has wide applications in logistics, such as finding the path that minimizes the total picking route in the warehouse, finding the paths that minimize the total distance to serve customers, and more generally how to optimize an integrated production and distribution system.

D | Appendix D

Technology Readiness Level (TRL for short) indicates a metric for assessing the degree of technological maturity of a product or process. It is based on a scale of values from 1 to 9, where 1 is the lowest (basic research) and 9 is the highest (first production).

1	Basic principles observed
2	Technology concept formulated
3	Experimental proof of concept
4	Technology validated in Lab
5	Technology validated in relevant environment
6	Technology demonstrated in relevant environment
7	System prototype demonstration in operational environment
8	System complete and qualified
9	Actual system proven in operational environment

Table D.1: Technology Readiness Levels

The nine levels of the technological readiness classification framework can be divided into three macro-clusters:

1. Level 1-2-3 represents the*research phase*
2. Level 4-5-6 represents the *development phase*
3. Level 7-8-9 represents the *deployment phase*

The main purpose of using technology readiness levels is to help management make decisions regarding technology development and to provide a common understanding of the state of technology. It should be seen as one of several tools needed to manage the progress of research and development within an organization.

List of Figures

List of Tables