Supply Chain Forum: An International Journal

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tscf20

Innovative solutions in last mile delivery: concepts, practices, challenges, and future directions

Wassen AM Mohammad, Yousef Nazih Diab, Adel Elomri & Chefi Triki

To cite this article: Wassen AM Mohammad, Yousef Nazih Diab, Adel Elomri & Chefi Triki (2023): Innovative solutions in last mile delivery: concepts, practices, challenges, and future directions, Supply Chain Forum: An International Journal, DOI: 10.1080/16258312.2023.2173488

To link to this article: https://doi.org/10.1080/16258312.2023.2173488

Published online: 07 Feb 2023.

SUPPLY CHAIN FORUM: AN INTERNATIONAL JOURNAL
https://doi.org/10.1080/16258312.2023.2173488

Innovative solutions in last mile delivery: concepts, practices, challenges, and future directions

Wassen AM Mohammad[a], Yousef Nazih Diab[a], Adel Elomri[a] and Chefi Triki[b]

[a]Division of Engineering Management and Decision Sciences, College of Science and Engineering, Hamad Bin Khalifa University, Ar-Rayyan, Qatar; [b]Department of Analytics, Operations and System, Kent Business School University of Kent, Canterbury, UK

ABSTRACT

In the last decade, e-commerce has been growing consistently. Fostered by the covid pandemic, online retail has grown exponentially, particularly in industries including food, clothing, groceries, and many others. This growth in online retailing activities has raised critical logistic challenges, especially in the last leg of the distribution, commonly referred to as the Last Mile. For instance, traditional truck-based home delivery has reached its limit within metropolitan areas and can no longer be an effective delivery method. Driven by technological progress, several other logistic solutions have been deployed as innovative alternatives to deliver parcels. This includes delivery by drones, smart parcel stations, robots, and crowdsourcing, among others. In this setting, this paper aims to provide a comprehensive review and analysis of the latest trends in last-mile delivery solutions from both industry and academic perspectives (see Figure 1 for overview). We use a content analysis literature review to analyse over 80 relevant publications, derive the necessary features of the latest innovation in the last mile delivery, and point out their different maturity levels and the related theoretical and operational challenges.

ARTICLE HISTORY
Received 15 February 2022
Revised 21 January 2023
Accepted 23 January 2023

KEYWORDS
Last mile; parcel delivery; smart logistics; trends and innovations; operations research; e-commerce; smart cities

Introduction

From steam engines to the present cyber-physical systems, the world is evolving rapidly into what is referred to as the Fourth Industrial Revolution or Industry 4.0. These current technologies facilitate advancements in urban areas through modelling and prediction, where logistics plays an integral role. However, logistics is currently facing major issues in the urban environment. Delivery vehicles used by many suppliers are a major cause of air pollution. According to (Dablanc, Diziain, and Levifve 2011), trucks used by delivery companies in Paris cause between 15% and 20% of overall vehicular congestion and nearly 60% of total emissions. Additionally, researchers have highlighted that these companies operate inefficiently, and thus accumulate suboptimal mileage (Jiang and Mahmassani 2014). The authors of (Fan et al. 2009) have claimed that temporal dimensions are not effectively incorporated in route planning. The inaccessibility of vehicles to parking slots in congested urban areas is another reason for their inefficiency (Boussier et al. 2011). In the mobile world of Industry 4.0, customers require that suppliers make deliveries in a short time, which requires efficient and flexible logistics.

All logistical operations associated with delivering goods and parcels to customers' households are known as last mile delivery, which has been described in literature as the most expensive, inefficient, and polluting part of the supply chain (Olsson, Hellström, and Pålsson 2019). There are five main challenges faced in last mile delivery according to (Boysen, Fedtke, and Schwerdfeger 2021), which are presented in Figure 2.

Increasing volume of shipments

Driven by the two mega-trends – urbanisation and e-commerce – demand has been rising for last mile delivery services. Urbanisation led to massive population increases in urban areas. Some studies have estimated that by 2050, around 6.3 billion people, i.e. approximately 70% of the global population, will be living in big cities (Bretzke 2013). In 2018, e-commerce itself grew by 23.3% worldwide (Coppola 2021). The growing number of online orders has consequently increased the number of parcel deliveries. For example, research in Germany (Brandt 2019) has shown that by 2023, 4.4 billion parcels will be delivered annually compared to the 1.69 billion shipments in the year 2000. Another study (Stevens 2019) showed that in the USA, Amazon will deliver approximately 6.5 billion parcels in 2022, compared to the 3.5 billion delivered in 2019.

Sustainability

More delivery vehicles are needed to meet the volume increase of shipments, which will have negative impacts

CONTACT Adel Elomri aelomri@hbku.edu.qa Division of Engineering Management and Decision Sciences, College of Science and Engineering, Hamad Bin Khalifa University, Ar-Rayyan, Qatar

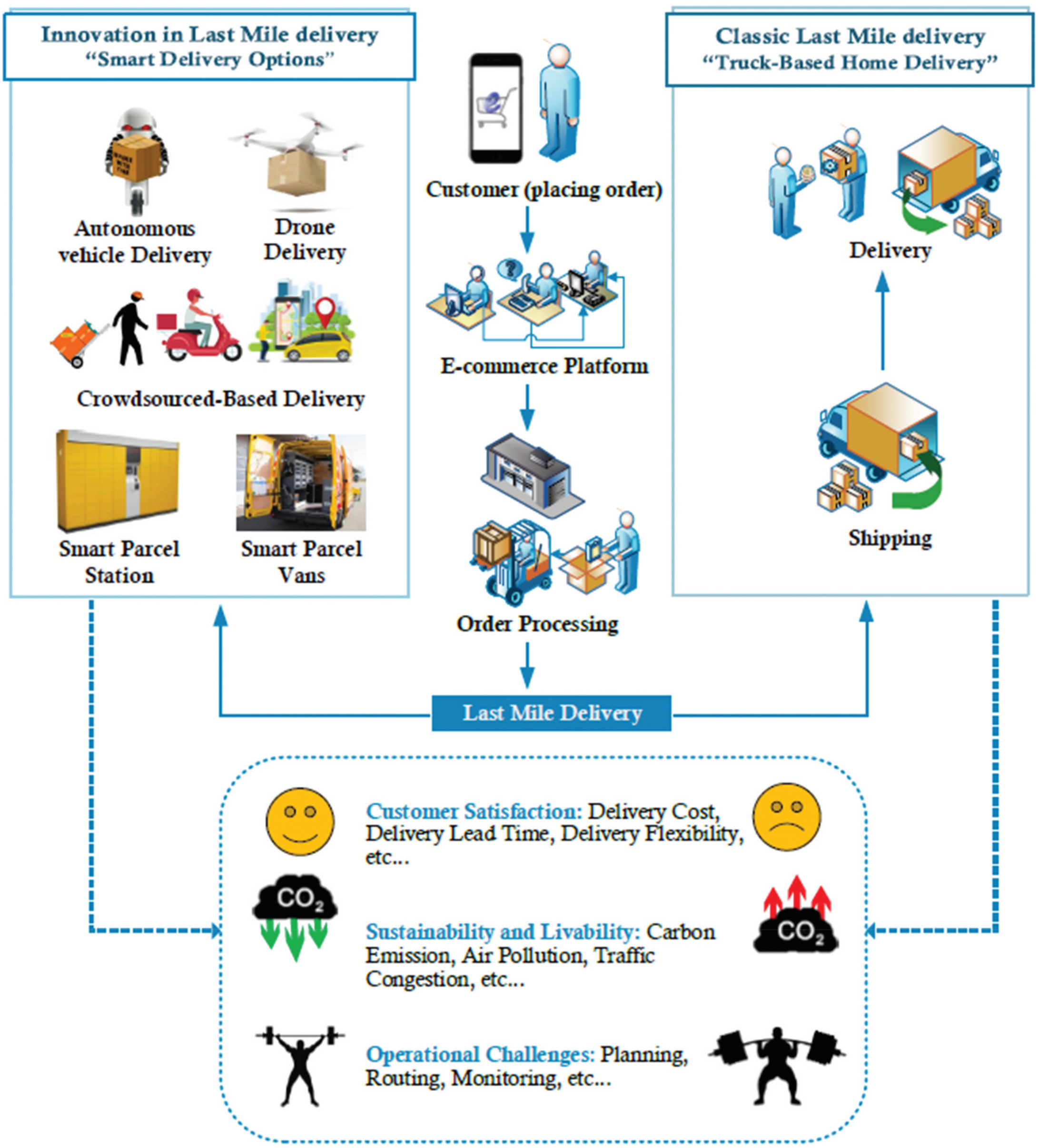

Figure 1. Overview and Graphical Abstract.

on the environment, health, infrastructure, and will increase congestion. This rapid expansion results in urban transport congestion, which in turn affect the wellbeing of citizens living in urban areas (Arroub et al. 2016). Higher customer awareness and new governmental legislations have pressured delivery services to provide an environmentally friendly and sustainable service (Hu et al. 2019). For example, an increase of 60 self-collection lockers can result in avoiding 193 tons of carbon emissions annually (Stevens 2021).

Costs

Traditional delivery trucks are costly. A case study from Finland has shown that traditional delivery by vans costs from 2€ to 6€, based on the density of the area (Punakivi et al. 2001). In addition, the cost of delivery increases with traffic congestion and lack of parking on busy streets. Delivery drivers face uncertainties regarding allowed parking areas, exact customer addresses and customer availability (Ulmer and Streng 2019). According to (Song et al. 2009), research reported between 12% and 60% first-time failed deliveries due to customers not being home for long periods. This is a consequence of lifestyle and cultural changes, such as the increase in employment rates of women and single-person households. Alternative solutions for deliveries, such as unattended deliveries and self-collection by customers, are of great benefit and help in reducing delivery costs.

Time pressure

The growth of e-commerce has directly led to a massive increase in the volume of delivered parcels. Many online businesses and retailers have also intensified efforts to provide customers with next-day or same-day deliveries (Yaman, Karasan, and

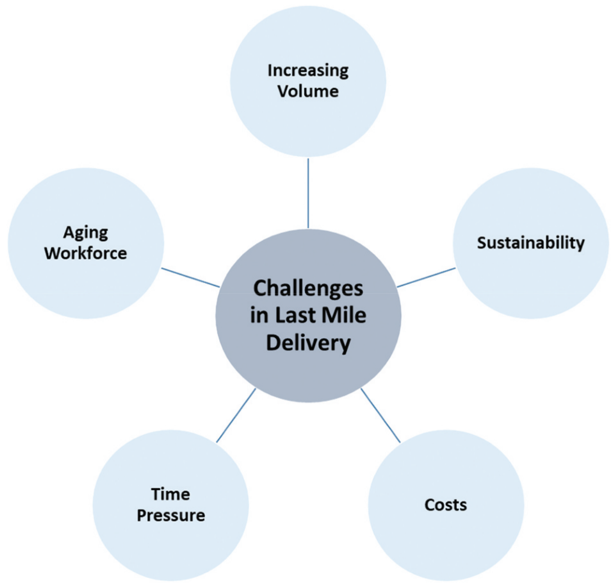

Figure 2. The five main challenges faced in Last Mile Delivery problems (Boysen, Fedtke, and Schwerdfeger 2021).

Kara 2012; Dablanc et al. 2017). To this end, last mile delivery activities need to operate under very tight deadlines. The volume of online orders for deliveries also varies throughout the week, the peak being Monday (Poggi et al. 2014); as well as over the year due to seasonal sales (Boysen, de Koster, and Weidinger 2019). Therefore, last mile deliveries deal with workloads that are stochastic and significantly vary over different periods. Modern approaches to such deliveries thus need to be both flexible and scalable.

Ageing workforce

The ageing workforce in urban areas has created a shortage of personnel in the field of parcel delivery, which is a physically demanding field (Peterson 2018).

The recent boom in e-commerce has greatly promoted the advancement of technologies related to logistics (Yu et al. 2017). A high-quality, responsive, and professional delivery process boosts customer and retailer satisfaction (Li et al. 2006), especially in the final stage of the parcel delivery process, where the only human interaction takes place for the customer. Human interaction is reduced or eliminated with self-service alternatives such as parcel lockers or delivery through autonomous vehicles (drones or robot-assisted deliveries) (Narayanan, Chaniotakis, and Antoniou 2020).

This research seeks answers to the following questions: What are the recent innovative trends in the field of last mile delivery, and how do they function? What are some gaps in the relevant literature, and what are the areas that need to be further investigated in future work from an operations research perspective? A similar review by (Mangiaracina et al. 2019) looked at how innovative solutions in last-mile delivery affected efficiency in B2C e-commerce. Following a systematic review, they identified major innovative solutions and how they might reduce last-mile delivery costs. This review on the other hand, aims to extend the knowledge on innovative solutions from an industry as well as from an operations research perspective.

The remainder of this paper is organised as follows: In Section II, we provide the methodology used to conduct this review. Section III discusses the prevalent delivery solutions from the perspective of the industry. Section IV presents the operations research perspective on these solutions and discusses the different models employed. Finally, directions of future work in the area and the conclusions of this study are provided in Section V.

Research methodology

Material collection

To answer the above questions, a systematic literature review was conducted to analyse the state of the art in related research. The guidelines presented in (Durach and Wieland 2017) for conducting a literature review in supply chain management were followed. The research method consisted of the following five steps:

(1) Formulating the research questions and identifying the keywords
(2) Determining a clear criteria for inclusion and exclusion
(3) Researching the literature using databases
(4) Selecting the most relevant papers
(5) Discussing the results and their descriptive analyses

Research questions and keywords

The first step in this review was to formulate the research questions. Our main interest was studying the recent trends in last mile delivery and the state of the art from an operations research perspective. We also investigated the trends in terms of their level of maturity and deployment in the industry, as well as identified related work in literature. For this purpose, a number of keywords were used to collect the references. The set of keywords used were 'last mile delivery innovative solutions', 'e-commerce delivery', 'smart logistics', 'parcel delivery', 'unmanned aerial vehicles', 'delivery robots', 'drones', 'robot-assisted delivery', 'autonomous vehicles', and 'smart parcel lockers'.

Criteria for inclusion and exclusion

The criteria were as follows:

Inclusion criteria:

(1) Papers published between 2015–2021
(2) Publications in journals, conferences, and books
(3) Papers focusing on innovative trends in last mile delivery from an operations research perspective

Exclusion criteria:

(1) Papers in languages other than English
(2) Papers focusing on last mile delivery and relevant trends from a perspective or field other than operations research

Literature and databases used to select papers

We approached the material collection from two perspectives: scientific and industrial. The scientific perspective was divided into two phases. The first phase involved selecting the scientific databases and searching for articles using the above keywords and inclusion/exclusion criteria. The databases used included *Scopus* and *ScienceDirect*, which are considered the largest databases of peer-reviewed scientific literature. Articles on last mile delivery were then selected based on their abstracts. The second phase involved the use of the reference-based technique while going through the relevant articles preselected in phase 1. This was done to avoid excluding any relevant articles, following the same keywords/abstract technique. We gleaned the industrial perspective by referring to websites of companies, such as DHL and Amazon, which offer innovative last mile delivery services to gain insights from their operations. Finally, after reading through the articles and checking their relevance, 61 papers were selected for review. Among them, 38 were journal papers (62.2%), 18 conference papers (29.5%), and five review papers (8.1%). Review papers focused on either using drones or robots as innovative delivery solutions, and discussed their specific applications. We analyzed several solutions for delivery and discussed the traditional ones for comparison. We also described several optimization models from the literature related to the most relevant solutions. Finally, we proposed an application for an emerging innovative solution: the moving smart parcel station.

Discussion of results and descriptive analysis

Analysis by year and journal type

A descriptive analysis of the selected papers is provided according, but not limited to, some of the features below:

- Numbers of published papers per year and journal type
- Most cited papers and co-citations
- Methodology used

Figure 3 shows the distribution of the selected papers over the years. The selected period to analyse the most recent studies was 2015 onward. The distribution of published papers shows an increasing interest in the area among researchers in recent years, with more than 70% of the selected papers published during the last three years. It is interesting to see that most of the articles were published in 2021, and this trend is expected to continue in the near future. The growth in number of publications in recent years can be attributed to the increase of interest in last mile delivery, and in better managing e-commerce delivery with less human interaction, especially following the COVID-19 pandemic. This shows that knowledge in this area has been evolving.

Concerning the venue of publications, the majority of papers appeared in *Transportation Research Procedia* with seven publications. *Networks Journal* and *Transportation Research, Part E: Logistics and Transportation Review* had four publications each, *Computers and Industrial Engineering, Sustainability (Switzerland)*, and *Transportation Research Part C: Emerging Technologies* had three publications each. Finally, *Computers and Operations Research, European Journal of Operational Research, Transportation Science,*

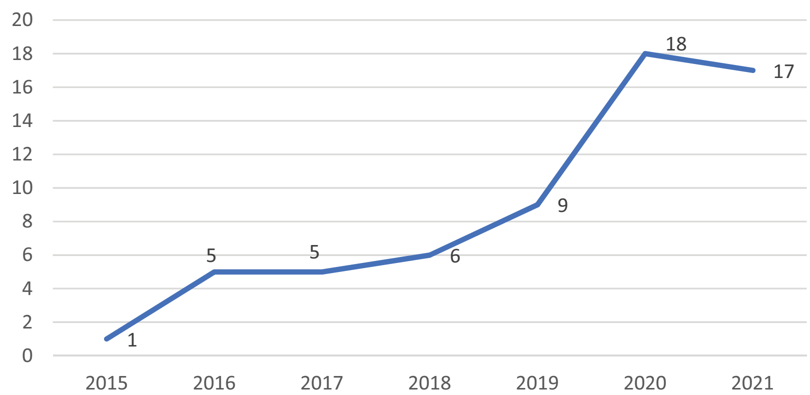

Figure 3. Distribution of papers by year.

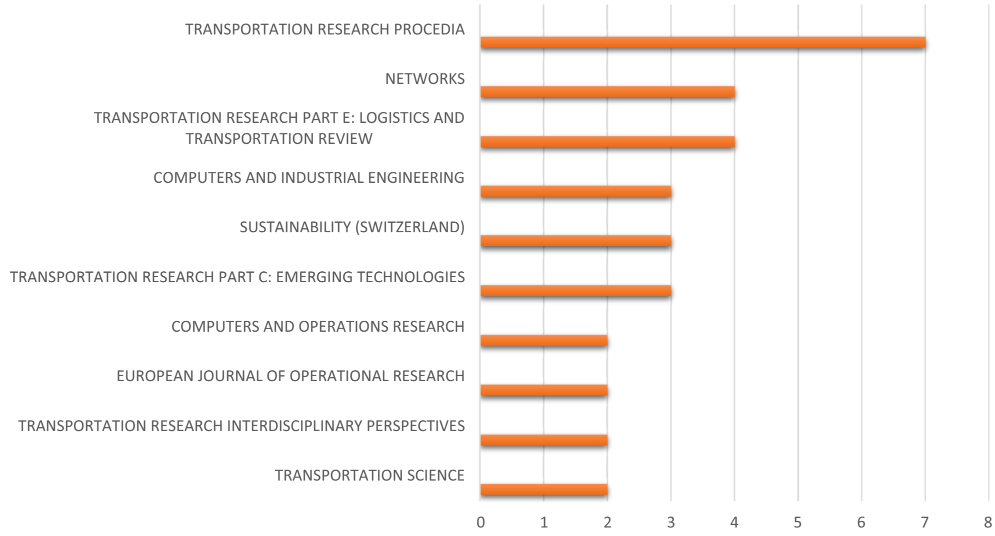

Figure 4. The topmost publishing journals in this area.

and *Transportation Research: Interdisciplinary Perspectives* had two publications each. Figure 4 shows the distribution of these 29 articles; each of the other nine papers were published in different journals.

The relevance of the above-mentioned journals is logical. For instance, operations research on the topic of innovative solutions in last mile delivery looks into different aspects of logistics, location, transportation and routing systems and discusses how these solutions operate in specific networks. Implementing sustainable solutions is one of the major drivers in last mile delivery – this fact validates the relevance of the *Sustainability* journal in the context of this study.

Most cited papers and co-citation analysis

In citation analysis, the number of citations a paper has can be interpreted as the impact or influence it has in a particular area of research. By using citation analysis, the most impactful papers can be determined and examined. We focus on 25 of the most influential publications considered in this study, illustrated in Figure 5. The article by Murray and Chu in (Murray and Chu 2015) had the highest number of citations at 386, followed by a study by Dorling et al. (Dorling et al. 2017) with 341 citations. These papers examined the flying-sidekick travelling salesman problem and the vehicle routing problem, respectively. Both studies examined the optimisation of drone-assisted parcel delivery. They were followed by four articles that had

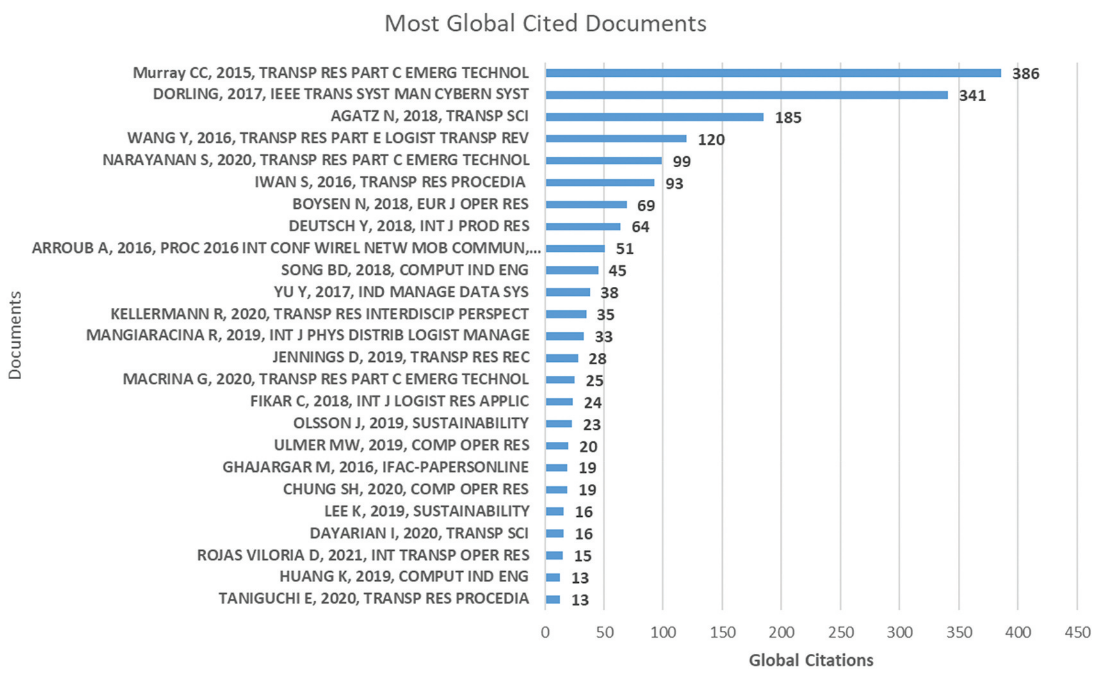

Figure 5. The topmost cited scientific papers in Logistics Management.

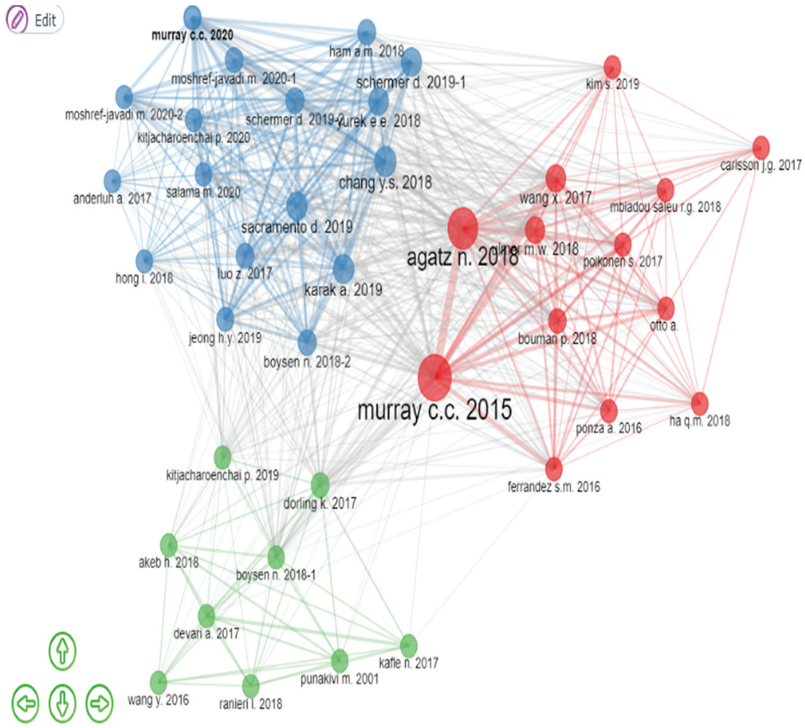

Figure 6. Biblioshiny co-citation network.

been cited 185, 120, 99, and 93 times respectively. The number of citations for the other 19 papers ranged between 69 and 13.

Another interesting feature is co-citation. Co-citation analysis is used to map articles that are often referenced together, and investigate similar topics (Hjørland 2013). In a co-citation network, two nodes (publications) are linked together when both are present in the reference table of any other publication. Additionally, the larger the node is, the more often the relevant publication is cited. Co-citation analysis can help identify the most influential publications as well as recognise the different thematic clusters. Indeed, the clusters here were categorised based on the co-cited publications. Three clusters were identified and shown in red, green, and blue, as shown in Figure 6. The co-citation network graph was constructed using Biblioshiny, in which the links represent the co-citation process.

Keyword co-occurrence

Biblioshiny was also used for analysing the keywords co-occurrence in the 61 publications. This is used to analyse the content presented in a publication. The words are usually extracted from the keywords provided by the authors in their articles. If they are absent, they can be pulled from the title or the abstract. Like the co-citations, keyword occurrence analysis assumes that words that often appear together are thematically related. Each node in the network represents a keyword, and its size reflects how many times that keyword has occurred. The links between keywords represent their co-occurrence. The thicker the link is, the more often the relevant keywords co-occur. The different colours of the nodes indicate different thematic clusters. The nodes and links between clusters are used to explain the fields of a study and how they are related. As shown in Figure 7, six clusters were mapped by Biblioshiny. Cluster 1 (red) tackled the themes of drones and the travelling salesman problem. Cluster 2 (blue) was related to vehicle routing. Cluster 3 (green) covered the logistics sector. Cluster 4 (purple) focused on last-mile delivery. Cluster 5 (brown) was related to parcel delivery. Finally, Cluster 6 (orange) focused on transportation and innovation.

Classification by methodology

Figure 8 illustrates the delivery methods used in the chosen papers. It can be seen that drones were the technology considered most often. Drones are already used by large delivery companies, and their prominence here reflects the maturity of research on drones, in both scientific literature and in the industry.

Other technologies, such as robots, electric vehicles, and parcel lockers, were also frequently represented. Few papers tackled a combination of technologies, such as trucks and drones operating jointly, or several solutions at once. The rest presented the general scope of smart cities and smart logistics in relevant areas.

Means of transportation in urban logistics

Urban logistics can be defined in several ways. It commonly refers to the effective and efficient process of

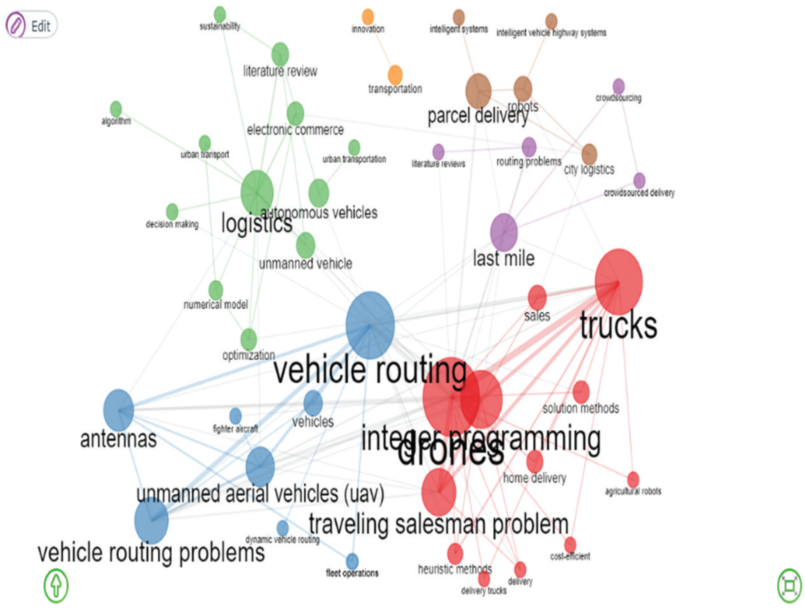

Figure 7. Biblioshiny keyword co-occurrence network.

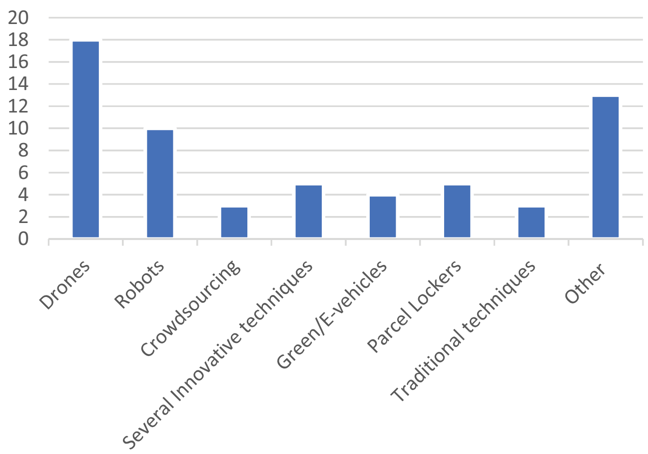

Figure 8. Distribution of papers by method discussed.

transporting goods within urban areas, while considering its impact on traffic congestion, the environment, and safety. In supply chain management, last mile delivery is the final step of transporting goods to their final destination. Most urban logistics deliveries involve traditional means, such as trucks and light vehicles. However, innovative strategies for last mile delivery can be employed through information and communication technologies (ICTs), environmentally friendly vehicles, and robotics with augmented reality (AR). These technologies have inspired research on urban logistics in the context of food delivery, parcel lockers, and electric vehicles that can help in solving several transportation and delivery problems in emerging urban areas.

Some studies have discussed the use of electric vehicles in logistics and evaluated their impact on the environment. The author of (Jovanović, Pamučar, and Pejčić-Tarle 2014) discussed the use of green vehicles in transportation networks. Using neuro-fuzzy logic, they formulated the problem as a nonlinear optimisation problem, and applied and tested it on a transportation network in Belgrade, Serbia. The study in (Lee, Chae, and Kim 2019) proposed a mixed truck–bike model to reduce the total operation costs of a transportation system that previously used only trucks. They assessed the impact of replacing some trucks with bikes, and found that it reduced not only the cost of fuel but also the total carbon emissions by up to 10%; however, the cost of labour increased. More insights into the traditional and modern concepts of delivery used in the industry are discussed below.

Innovative solutions for parcel delivery: industry perspectives

Current delivery concepts

This section discusses delivery concepts that are currently being used in daily operations in the industry.

The traditional concept of home delivery for online ordered parcels is still the most common delivery method, especially for densely populated countries (Molin, Kosicki, and van Duin 2022). We start the section with the traditional method of home deliveries by human-driven delivery vans to describe the standard followed by more recently applied innovative methods. To tackle the traffic challenges, some companies started using cargo bikes and decentralised micro-depots in congested city centres for delivery. In addition, several courier services have been applying concepts of self-service parcel collection to minimise human interaction and the use of personnel in last mile delivery operations. These concepts are discussed below.

Human-driven delivery vans

Globally, the most common method of parcel delivery is home delivery (International Post Corporation 2020). Humans driving delivery vans from central warehouses or depots to customers is the most common delivery process around the world. The delivery routes of the vans are determined according to where the shipments are to be delivered. Along this route, the delivery driver parks the van and goes door to door to hand the parcel to the customers. This process is referred to as attended home delivery. In the courier service industry, parcels arrive to a central warehouse in an urban area after being transported by a truck from one depot to another. Subsequently, the trucks are unloaded at the depot. The parcels are then placed on a conveyor attached to a sorting system to sort them according to their destination, using the barcodes, before they are sent to the collection area.

Once the parcels arrive at the collection area, the delivery person responsible places them in the truck. The parcels are generally organised in the truck according to the route, so that they can be easily unloaded at their destination, e.g., the parcel intended for the first destination along the route is loaded last. A common challenge for delivery drivers is finding a suitable space to park the truck, near the customer's location. This may incur the risk of parking violations or a long walk for the delivery person. Another problem is not finding the customer at home, whereby the delivery fails. In this case, the driver is obliged to return the shipment to the depot to be again delivered in the near future, or to schedule a suitable pickup time with the customer (Nguyễn et al. 2019).

Drivers can sometimes drop parcels off at the customer's doorstep or a concealed location around the property (McKinnon and Tallam 2003). This process is referred to as unattended home delivery. Even though unattended home deliveries can be convenient in specific conditions (such as contactless food delivery in times of the pandemic), this is considered risky, and is not allowed unless the customer consents to it.

Cargo bikes

Alternative solutions for the delivery process have been established for the heart of large cities featuring traffic jams and vehicular congestion. One of these solutions is the cargo bike. The mode of operation of cargo bikes can be manual or electrical, and they are already being used in several European countries. Both manual and electrical modes of operation give bikes an environmental advantage over traditional vans operating with a combustion engine and would contribute to a sustainable last mile logistics (Boysen, Fedtke, and Schwerdfeger 2021). Their use has been studied in Antwerp, Belgium and Vienna, Austria in (Arnold et al. 2018) and (Anderluh, Hemmelmayr, and Nolz 2017), respectively. Recently Amazon has announced that it will be launching a fleet of cargo bikes to replace thousands of van deliveries in London (Butler 2022). Cargo bikes provide several benefits, as they can be used for delivery trips to customers in areas that are difficult to reach by traditional vehicles, areas with limited access (only accessible through sidewalks or pedestrian paths), and areas lacking parking spaces (Anderluh, Hemmelmayr, and Nolz 2017).

Unlike delivery vans, cargo bikes have limited carrying capacity (Fikar, Hirsch, and Gronalt 2018), which hinder their suitability for large deliveries. Cargo bikes thus need to be replenished with parcels several times a day. This process usually takes place in decentralised micro-depots located close to the route of the bike, rather than in the central depot, to avoid long return journeys. These depots are usually located in parking garages or loading docks. Trailers are also a useful option in terms of mobile depots close to the routes of cargo bikes.

Traditional delivery vehicles are used to load mobile depots with shipments. This results in adopting a two-echelon transportation system in which vehicles replenish mobile depots and cargo bikes deliver to customers' locations. The ageing workforce worldwide is a challenge faced by carriers while using cargo bikes, as bikers require a certain level of fitness. If the cargo bike is electric, this barrier is eliminated or minimised.

Self-service techniques (parcel lockers)

Among the different stages of the last mile shipment, home delivery is the most time-consuming operation. A high number of stops for small parcel sizes is inefficient as well as time- and cost-consuming (Molin, Kosicki, and van Duin 2022). The delivery worker must make a stop at each customer's house, walk to the door, and check if someone is at home. If no one is, it is considered a failed delivery and the parcel is returned to the depot for a future delivery attempt or for a customer pickup at an agreed-on location. Alternatively, the delivery person may seek out a neighbour and leave the package with them. In the US, 8% of first-attempt home deliveries fail, which costs retailers $17.20 per order on average, or $197,730 - per year (Edwards 2021). Failed delivery attempts add to the effort and delivery time, and lead to customer dissatisfaction as well.

As a result, some postal service providers are offering self-service options for their customers. Parcel lockers located at hubs or places of storage is another innovative method used in last mile delivery. In this case, parcels are delivered to a decentralised depot that is easily accessible by customers. Usually, public sites such as markets, train stations, universities, and post offices, are preferred locations for parcel lockers. Compared to attended home deliveries where parcels are delivered to individual customers, the consolidation of numerous parcels to a decentralised pickup site saves the postal service provider time and effort (Ghajargar, Zenezini, and Montanaro 2016), making it easier to handle rising parcel volumes at lower costs, and offering relief for the staff. Several studies showed that costs could be significantly reduced when using parcel lockers as opposed to home delivery (Deutsch and Golany 2018).

This, however, is only one aspect of the business. Customers who accept self-service forego convenience, and must go to the relevant locations to pick up their parcels. This may cause a delay in receiving a shipment and necessitate incentives (e.g., lower postal charges) to make sure that customers use the self-service option (Molin, Kosicki, and van Duin 2022). Moreover, the travelling distance saved by the service provider should be compared with the added distance travelled by the customers to collect their shipment. It is not clear if customer self-service delivery reduces the impact of the overall travelling (i.e., both service provider and customer) on the environment. This depends on whether the customer drives or walks between their home and the self-service station. However, some studies in Poland found that carbon emissions produced by parcel locker delivery are only 5% of emissions produced by home delivery (Schnieder, Hinde, and West 2021).

Currently, there are more than 2.4 million parcel shops and stations worldwide, as reported by (Proud and Chapman 2022), where parcel shops are staffed outlets such as convenience stores, and parcel lockers are secured lockers that can be found indoors or outdoors. Usually, the customers will collect their parcels by making a trip to the parcel shop or station at their convenient time. Implementation of the parcel locker solution can reduce costs and cut emissions for less urgent deliveries that consumers do not mind picking up from nearby. According to the authors of the recently published Green Last Mile Europe 2022 report, an estimated 13,845 kg of CO^2 emissions can be reduced by one parcel locker per year (Bradley 2022).

Properly selecting the location of parcel lockers is the most important factor in determining their utilisation efficiency (Iwan, Kijewska, and Lemke 2016). The study in (Veenstra et al. 2018) examined the location of the facility for parcel lockers in the context of the vehicle routing problem for delivering either directly to customers, or to a nearby facility. Parcel lockers are already being used by several large companies, such as DHL (DHL 2021) and InPost (Stevens 2021). They can also serve as micro-hubs for the exchange of shipments between vehicles or bikes. Micro-hubs are consolidation points in high-density areas, which allow deliveries for a specific region to be consolidated to one spot. Once shipments have been delivered to a micro-hub, they can then be distributed to the customers nearby by another method of delivery such as cargo bikes. This approach is supported by Fikar et al. in (Fikar, Hirsch, and Gronalt 2018), who used an agent-based simulation for their study, and showed that the quality of service improves, and delays in food delivery can be avoided, when using cargo bikes in combination with urban consolidation points such as micro-hubs. They discussed that for every parcel, CO2 emissions dropped significantly when using cargo bikes. However, the total travelled distance increased due to the low capacities of the cargo bikes. They demonstrated that implementing urban consolidation however, reduced shipment delays. In (Eliyan, Elomri, and Kerbache 2021), Eliyan et al. presented a study about smart parcel stations. In their work, the authors studied the deployment of smart parcel stations by analysing three mathematical formulations. They modelled their scenario by considering customer satisfaction rate where retailers served customers from the nearest smart parcel station location, and they evaluated their model according to some KPIs, such as travelled distance, cost, and carbon emissions. This study concluded that smart parcel stations would be an effective alternative solution in the last-mile delivery challenge especially in metropolitan areas.

The use of parcel lockers can also be extended by installing them in autonomous vehicles (a truck-robot concept). These vehicles can park in an area close to the customer's house and wait until they collect their shipments. This concept can be very beneficial for regular next day deliveries. The concept of parcel lockers in last mile delivery is a convenient approach for deliveries that are not urgent and for second-time deliveries. Parcel lockers serving as micro-hubs is very similar to the truck–robot scenario discussed above.

Solutions for the near future

Drone parcel delivery

The use of drones, or unmanned aerial vehicles (UAV), is becoming more common in different industries. Despite being in the early stages of implementation and mass adoption, drones provide many benefits due to their ability to operate autonomously, thereby saving considerable time and energy (Intelligence 2021). UAVs can make a major contribution to the environment of smart cities through smart parcel deliveries. Thus, deliveries can easily be scheduled and efficiently distributed to several destinations. Advantages of drone package deliveries include reduced traffic congestion, environmental pollution, delivery times, and transportation costs (Emergen Research 2022).

Parcel delivery is among the most beneficial applications of drones, especially to reach areas that are not easy to access. Additionally, this idea gained popularity especially during the COVID-19 pandemic. A survey revealed that customers were willing to pay more for deliveries made by autonomous vehicles, partly to avoid infection, but also because those deliveries are faster than waiting for delivery trucks to make their rounds (Kreier 2022).

Many leading companies already use drones to deliver their products. In 2013, Amazon's CEO, Jeff Bezos, announced that UAVs would play a significant role in delivering small packages (60 Minutes 2013). This was realised in 2016 with Amazon Prime Air, which aims to deliver packages aerially weighing up to 5 lb within 30 minutes of ordering. Similarly, Google launched its drone delivery service 'WING' in 2017. DHL also provides a drone-based solution to tackle last mile delivery in urban areas of China; it has reduced the time needed for one-way deliveries from 40 minutes to only eight minutes. In comparison with the traditional road delivery method, the application of drones helped DHL reduce the cost per delivery by 80%, in addition to reducing their overall energy consumption and carbon footprint (DHL 2019). A cooperation between Zipline and the government of Rwanda has been set-up to deliver blood and medical supplies to hospitals and other medical destinations in the country (Toor 2016). Currently, the top package drone-delivery companies are Prime Time Air, FedEx, UPS Flight Forward, DHL Parcelcopter, Wing, Matternet, Zipline, Flytrex, Flirtey, and Wingcopter (Emergen Research 2022).

Despite the optimistic vision of the implementation of UAVs, airspace management agencies have serious concerns about their wide use. The necessary terms and conditions for the use of drones need to be set, and unmanned traffic management platforms need to be established in different sectors to better arrange the operation and schedules of drones in the air. Although drones may travel faster than trucks and do not need to adhere to a specific route, the adoption of drones for parcel deliveries are increasingly difficult in urban areas due to regulations concerning their operation and safety (Alfandari, Ljubić, and de Melo da Silva 2022), in addition to their limited capacity and travel range (Chung, Sah, and Lee 2020). Furthermore, the flight endurance of drones is affected by the limited battery capacity, as well as the flight speed and payload (Murray and Chu 2015). Drones are not yet capable of conducting complex multiple deliveries; therefore, many researchers started combing delivery trucks with drones (Kellermann, Biehle, and Fischer 2020).

In the drone–truck delivery system, the truck acts as a mobile charging station that recharges the drone for its next flight. This system is used to meet the demands of customers in rural areas that the truck cannot reach (owing to poor road quality, high delivery costs, or long durations for delivery). After a full recharge from the truck, the drone can operate for a limited amount of time, which will also prevent it from reaching some nodes and fulfilling some customer demands. This concept has been also used in (Sun et al. 2021) where the authors have proposed a delivery system that allows the drone to land on a recharging station located along its route.

In China, JD logistics started delivery operations using drones in Guangam, Sichuan. These drones were able to fulfill a quarter of the city's daily average orders, while saving up to 50% in delivery time. The model of UAVs used is called Y-3, and it can carry a maximum weight of 10 kg and fly 10 km from JD headquarters. Since many customers in rural areas in China are far beyond the distance that the drone can cover, it cannot return to the truck during its flight for recharging. A drone–truck recharging station will be beneficial in such operations by JD logistics for delivery operations in rural Chinese villages (Sun et al. 2021).

Robot-assisted delivery

Delivery robots (or bots) are another form of autonomous delivery. This innovative technology can improve efficiency in terms of cost savings and lower the negative impact on the environment (Taniguchi, Thompson, and Qureshi 2020). Starship Technologies, Amazon Scout, or Robby have already started initiating or selling delivery robots. Delivery robots have both advantages and disadvantages when compared to drones. Bots travel at nearly 6 km/h on sidewalks, and thus are slower. However, they can move heavier packages of up to 10 kg (Swiss Post 2017). Drones need to be constantly monitored and operated by a flight moderator, and are not allowed to operate near airports, military bases, and other restricted areas. Unlike drones, several bots can be operated at the same time by only one moderator (Bakach, Campbell, and Ehmke 2021). While a drone can directly move from point A to point B, this is not possible for the delivery robot, which is restricted to road networks and pathways. One benefit of using robots is that they do not risk violating people's privacy as drones do, and they are less affected by weather conditions. Additionally, robots will provide customers with faster delivery service, and will help reduce delivery costs (Attaran 2020).

Some delivery bots are already being used in the industry. Hermes in Hamburg and London provides parcel deliveries through robots, as well as the German postal system and Amazon. They are also used for food delivery in cities in Germany and the Netherlands (Starship 2017; Bertram 2017; Dormehl 2020).

Solutions for parcel delivery: operations research perspective

Drone routing models

Studies on new delivery techniques normally consider different versions of the travelling salesman and the vehicle routing problems. Researchers have proposed several models to use drones for delivery. In a review conducted by (Rojas Viloria et al. 2021), a UAV routing problem was defined as a problem concerning assigning UAVs to achieve a particular task while optimising some performance measures, including cost, distance travelled, time, and other objectives, and considering some constraints such as weight of parcel carried, battery life, and demand requirements (Rojas Viloria et al. 2021).

In (Murray and Chu 2015), Murray and Chu tackled the travelling salesman problem using drones (TSP-D). Two scenarios were implemented for a delivery system, which consisted of a drone associated with a traditional truck. The first scenario involved the flying-sidekick travelling salesman problem (FSTSP). In this scenario, a truck and a drone leave the depot, or return to it, separately or in tandem. However, while on route, they will travel in tandem to conserve the battery power of the drone. This is depicted in (Figure 9a). Here, a truck and a drone separately leave the depot. While the truck visits customers 5, 3, 9, and 8, the drone visits customer 4 and meets the truck again at customer 8. They separate again at customer 1 and finally meet again at the depot where the route has finished.

The second scenario, presented in (Figure 9b), involved the parallel drone scheduling travelling salesman problem (PDSTSP). There is no synchronisation between the truck and drones in this scenario, as opposed to the previous one. The drones depart and return to the depot, while the truck serves customers along a TSP route. This can be more practical when a distribution centre is close to customers. In both scenarios, there may be customers who are ineligible to be served by a drone and therefore must be served by a truck.

A mixed-integer linear programming (MILP) problem was formulated for each scenario. The objective was to minimise the overall time for delivery to all customers. Two heuristic approaches were discussed to solve the problem with a practical size. This is because MILP solvers are not time effective and would need many hours to solve small-scale formulation instances.

For the FSTSP, the heuristic method first generated a specific route for the truck by solving a TSP where all customers were to be visited by the truck. Subsequently, an iterative procedure was used to allocate the drone to a sub-set of customers. The assumption for the PDSTSP was that the drone served all customers within its maximum allowable range, while the truck served the remaining customers. This resulted in two sub-sets of customers: one served by the drone and the other by the truck. The sub-set of customers to be served by the drones were scheduled by minimising the make span of a parallel machine-scheduling (PMS) problem. The flight time needed to serve the customers and return was represented by the 'processing time', and each customer was considered a 'job'.

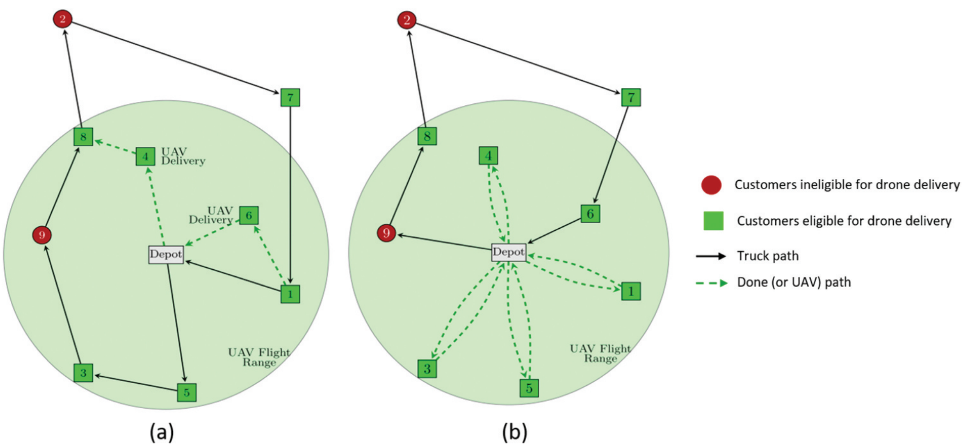

Figure 9. Two optimal solutions for the same delivery problem: FSTSP (a) and PDSTSP (b); retrieved from (Murray and Chu 2015).

A vehicle routing problem with drones (VRPD) model was proposed by (Wang, Poikonen, and Golden 2017) involving several trucks and drones. The main objective was to minimise the time required for delivery vehicles to deliver all packages and return to the central hub. In the models presented, the customers were served by either a drone or a truck.

Kim and Moon (Kim and Moon 2019) proposed minimising the total delivery time for both trucks and drones. In their model, the trucks acted as drone stations at the beginning and end of the drone delivery operation. The problem was thus a travelling salesman problem with a drone station (TSP-DS). In (Kim, Moon, and Jung 2020), the authors examined drone delivery on the rooftops of buildings. Urban areas face considerable challenges in terms of traffic congestion during delivery, owing to their dense population and layout. Increasing the number of delivery vehicles in the face of rising demand would have negative impacts in terms of more pollution, traffic congestion, and accidents (Demir et al. 2015). As drones are operated by batteries, it is beneficial to rely on them for the delivery process, while tackling possible barriers and challenges related to their use. Drone delivery on rooftops has a significant advantage over other drone-based operations, as rooftops are an ideal location for drones to land on, and depart from. Rooftops are fixed destinations that can provide safe accessibility for the drone as opposed to, for example, a moving truck in a truck–drone delivery system. In several experiments, augmented reality and real-time identification have been applied through downward-facing cameras to provide accurate visual guidance to land drones on rooftops (Castagno, Yao, and Atkins 2019).

One study presented a MILP-based mathematical model for scheduling a drone for parcel delivery on a rooftop. The objective function was to maximise the number of parcels delivered, which is a unique objective as most studies seek to minimise the overall cost or time. The different models discussed in this section, as well as other research on drone-based parcel delivery are summarised in Table 1 including other models such as Integer Programming (IP) and Dynamic Programming (DP).

Robot-assisted delivery models

The structure of the decision problem for robots is impacted by the fact that delivery robots are suitable only for attended home delivery. This is the main difference between drone-based and robot-based delivery. The concept of robot depots was presented in (Boysen, Schwerdfeger, and Weidinger 2018), where they evaluated the case of a system consisting of a single vehicle and several depots serving 40 customers, with pre-defined drop-off points.

It is also possible to arrange early deliveries whenever there is a deadline for each delivery. Unlike the case for drones, delivery robots are not expected to return to the delivery truck. The authors of (Boysen, Schwerdfeger, and Weidinger 2018) considered a truck carrying a certain number of delivery bots that were launched for delivery, as shown in Figure 10. To minimise the time for which the truck needs to wait for the delivery bots to return, they proposed that robots return to decentralised robot depots where they remain until picked up by the truck later.

To this end, they optimised the route of the truck along a path close to where the bots were picked up and dropped off. Furthermore, they proposed a scheduling heuristic that minimised the number of late deliveries. The model with a truck and decentralised robot depots outperformed the one where the trucks waited for the robots in terms of average lateness.Figure 11 illustrates this concept.

Jennings and Figliozzi (Jennings and Figliozzi 2019) proposed a similar truck-and robot system where the truck would drop off a delivery bot at several occasions in areas with a parcel delivery, pick it up when done and return to the depot (Jennings and Figliozzi 2019). They estimated travel distances and delivery times by applying continuous estimation without optimising the routing, and evaluated their model in terms of delivery time and fleet size. They also investigated circumstances in which the model can be used to improve the traditional mode of delivery, which is performed by a truck driver from a warehouse to the final customer.

Authors in (Sonneberg et al. 2019) proposed a location routing problem using multi-compartment robots as well as time windows for customers. The robots began the delivery process from the depots, and could perform several deliveries to customers before returning to the depot to end their tour. The model avoided waiting times by assuming that robots could change their own batteries. The model proposed was an MILP, which selected which robot depots to open. The objective was to minimise the total cost of operations.

In an Uncapacitated Routing-Scheduling Problem (URSP), (Alfandari, Ljubić, and de Melo da Silva 2022) devised a generic Mixed Integer Linear Programming (MILP) model where a delivery truck carrying parcels is deployed from a central distribution depot at a specific time. It travels to a subset of facilities where parcels are unloaded and then transported by autonomous robots to their respective customers. Three models were considered, each with an objective that minimised a tardiness indicator, namely the maximum tardiness, the total tardiness, and the number of late deliveries. The model was solved using the Benders decomposition approach. A feasible solution from an instant of the model is shown in Figure 12. Customer deadlines are in

Table 1. Overview of approaches to drone delivery in the literature.

Author	Objective Function	Approach	Heuristic	Type	Customers
Es Yurek and Ozmutlu (2018) (Es Yurek and Ozmutlu 2021)	Minimise Total Time	MILP	✓	FSTSP with drone and recharging policy	10 Customers
Dell'Amico et al. (2021) (Dell'Amico, Montemanni, and Novellani 2021)	Minimise completion time	MILP, DP	–	FSTSP with multiple drones	10 customers, 72 instances
Dell'Amico et al. (2020) (Dell'Amico, Montemanni, and Novellani 2020)	Minimise maximum working time among all vehicles	MILP	✓	TSP Parallel drone scheduling	Two scenarios: 20 Customers – 48 to 229 customers
(Sun et al., 2020) (Sun et al. 2021)	minimise the total time cost of the truck	MILP	–	TSP with drone and recharging station	–
(Huang et al., 2020) (Huang, Savkin, and Huang 2020)	minimise the total delivery time of a given set of parcels	2 exact algorithms	–	Drone and train delivery system	5 to 40
(Kim et al., 2020) (Kim, Moon, and Jung 2020)	maximise the number of parcels delivered	MILP	✓	Rooftop-based drone operations	Integer value randomly selected from 1–5 for each location. Instances include 10, 20 and 50 locations
(Di Puglia Pugliese et al., 2020) (Di Puglia Pugliese, Macrina, and Guerriero 2021)	minimise the total transportation cost	MILP	✓	VRP with drones and trucks	15
(Dayarian et al., 2020) (Dayarian, Savelsbergh, and Clarke 2020)	Compare different algorithms of drone resupply	Exact algorithms	–	VRP with drone resupply	–
(Agatz et al., 2018) (Agatz, Bouman, and Schmidt 2016)	Minimise the total costs of the delivery tour	IP,DP	✓	TSP with drone	12
(Song et al., 2018) (Song, Park, and Kim 2018)	maximise the weighted sum of two objectives, the total number of covered tasks, and the total travelling distance	MILP	✓	scheduling model for a UAV system's provision of persistent delivery service	–
(Dorling et al., 2017) (Dorling et al. 2017)	Two objectives: minimise costs subject to a delivery time limit – minimise the overall delivery time subject to a budget constraint	MILP	✓	Multitrip VRP for drone delivery	–
(Murray & Chu, 2015) (Murray and Chu 2015)	minimise the overall time for delivery to all customers	MILP	✓	Flying side kick of TSP, Parallel drone scheduling TSP (optimal routing and scheduling of unmanned aircraft)	Up to 10 customers
(Wang et al., 2016) (Wang, Poikonen, and Golden 2017)	minimise the time required to deliver all packages and let all vehicles go back to the central hub	Theorems to prove Several best case/ worse case scenarios	–	VRP with drones	–
(Kim and Moon 2019) (Kim and Moon 2019)	minimise the total delivery time for both trucks and drones	MILP	✓	TSP Parallel drone scheduling with drone station	Up to 80 customers

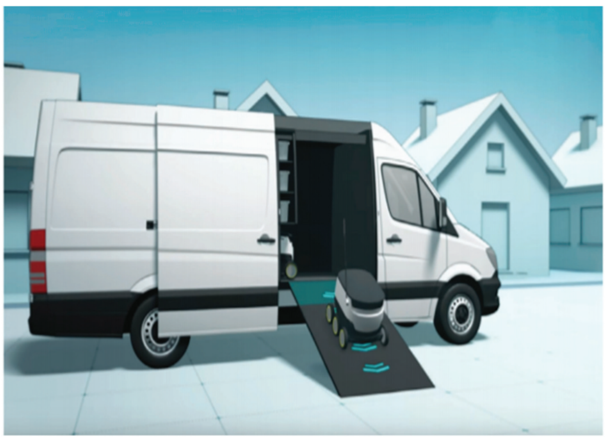

Figure 10. Van releasing a robot (Ostermeier, Heimfarth, and Hübner 2022).

brackets while the travel times are under/on the arcs. Here, 6 customers were served late, the maximum tardiness being 3 units and the cumulative tardiness being 10 units.

Another robot delivery model was assessed in (Poeting, Schaudt, and Clausen 2019), with two scenarios presented in simulations. The first involved the travelling salesman problem with precedence constraints (TSPPC), and the other one was an orientation problem with multiple time windows (OPMTW). Packages were first transported to the local depot where robots were present to deliver them to customers. A two-tier system was used, where robots were employed in the second tier. The authors assumed that each depot had a single robot, and that the parcels had already been assigned to the

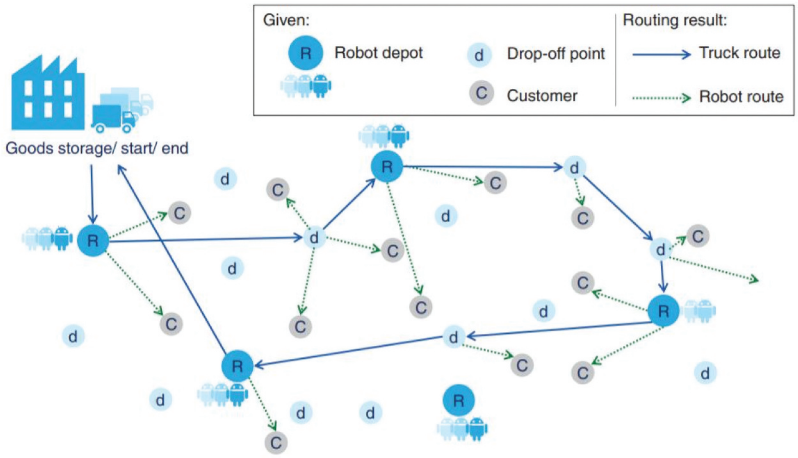

Figure 11. Illustration of the routes of the truck and the robot (Ostermeier, Heimfarth, and Hübner 2022).

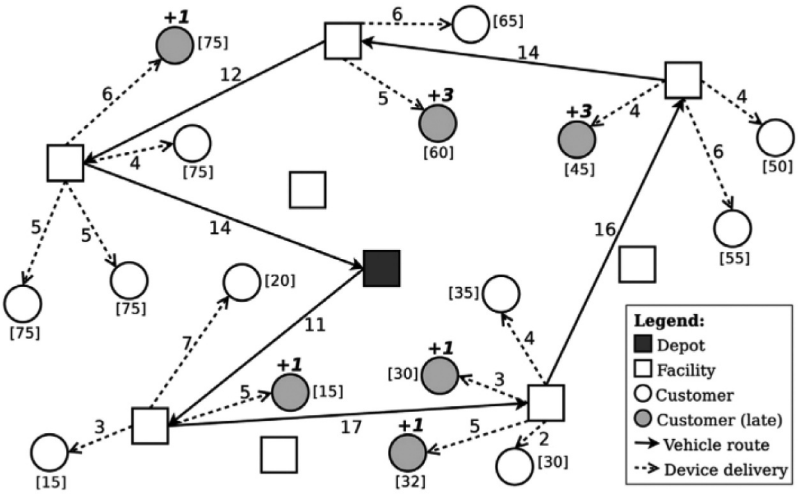

Figure 12. Uncapacitated Routing-Scheduling Problem feasible solution illustrating tardiness (Alfandari, Ljubić, and de Melo da Silva 2022).

Table 2. Overview of robot-assisted approaches to delivery in the literature.

Author	Objective Function	Problem Characteristics	Factors Considered in Optimisation	Number of Robots	Customers
Hubs and Robots					
(Poeting et al., 2019) (Poeting, Schaudt, and Clausen 2019)	Minimise the distance of the truck tour	Two tier system; robots present at the second tier	Time windows, Place of storage of robots	–	–
(Bakach et al., 2021) (Bakach, Campbell, and Ehmke 2021)	Minimise the number of robot hubs	Two tier system; robots present at the second tier	, Time windows, Storage of robots, Time windows, Place of storage of robots	95	300
(Sonneberg et al., 2019) (Sonneberg et al. 2019)	Minimise robots transport costs	Different robot sizes	Time windows, Place of storage of robots, storage of robots, costs	3	10
Trucks and Robots					
(Jennings & Figliozzi, 2019) (Jennings and Figliozzi 2019)	continuous estimation for tour length	Dropping off and collecting robots through sequential tours	–	–	–
(Boysen et al. 2018) (Boysen, Schwerdfeger, and Weidinger 2018)	Minimise number of delays	Deadlines	Time windows(deadlines), robots are transported by truck, Place of storage of robots	40	40
(Ostermeier et al., 2021) (Ostermeier, Heimfarth, and Hübner 2022)	Minimise total cost of delivery tour	Time windows	Time windows, robots are transported by truck, Place of storage of robots, Storage of robots	125	125
(Alfandari et al., 2022) (Alfandari, Ljubić, and de Melo da Silva 2022)	Minimise tardiness based on delivery deadlines of customers	Two tier system; robots present at the second tier	Travel time, delivery deadlines, autonomous robot assignment to customer	–	{25, 50, 75. 100}

depots. The objective was to maximise the number of vehicle visits to the depots. Consequently, the total number of packages delivered by the robots was also maximised. Table 2 classifies research on robot-assisted delivery.

Conclusion and future research

This review examined the prevalent methods used for last mile delivery from the perspectives of the industry and operations research. Non-traditional services for parcel delivery have sparked considerable interest in literature, and work is underway to find new solutions as well as improve existing ones. Most of the literature reviewed covered solutions of the routing problem of parcel delivery. This makes sense, as routing is a necessary concept in last mile delivery. However, we identified some gaps, and we think that future work should also investigate the following areas.

Territory design

Territory design is a well-investigated topic in the context of traditional truck-based delivery (known also as zoning). It involves dividing large-scale territories into smaller areas, each to be served by an allocated tour. In this regard, questions persist around what techniques can be applied (and how) when novel modes (such as truck–drone delivery and smart parcel stations) are introduced to the system. In addition, managing delivery time windows and aligning them with preferred customer times have not yet been considered in novel modes of delivery. Some studies on delivery robots have used deadlines and time windows, but examining the management of time windows beyond the domain of routing should be pursued in future research.

Applying more realistic constraints and configurations

Models should be formulated using scenarios and parameters that are more realistic for drones and robots. Formulated problems should deal with realistic configurations and constraints, specifically related to costs, battery life, and range of operations. These may include accessible and restricted flight and operational zones, various safety concerns, and pedestrian paths (for robot applications).

Dealing with uncertainties and dynamic systems

Uncertainties concerning dynamic customer demand, order management, and vehicle travel, should be considered in more realistic routing models that incorporate novel last-mile delivery methods. Dynamic ordering behaviours are closer to reality in such problems, where how many customers will be ordering, and what, is unknown over a specific period. Examining ways of dealing with such orders (day by day ordering, or coupling orders over a rolling horizon) is an interesting challenge for future work.

Other real-world uncertainties are related to the loading and unloading of parcels. Such operations are important to consider when modelling parcel delivery problems for novel modes of delivery, especially given that unloading parcels is not always smooth, and there might be unsuitable locations for drones or robots to drop off their parcels. Dealing with these factors, and evaluating their impacts on the overall process is another interesting challenge. Finally, the effect of different weather conditions on the operation of vehicles should be considered – rain, dust, and stormy weather can significantly hinder the routing of drones and robots.

Adaptation to current systems

When implementing novel modes of delivery within the current distribution systems, many of them require major modifications. These may include the relocation of certain facilities or depots, installation of recharging stations or robot hubs, modifications to the infrastructure for the new vehicles, automation in storage, and the necessary adaptations to new regulations for navigation systems. These changes as well as their effect on distribution systems and the logistics of delivery operations is another important issue for future research.

Future research should seek to obtain the optimal mix of distribution systems. Each concept of delivery has its advantages and disadvantages about its mode of implementation, constraints, and performance. The most efficient combination can achieve the best distribution operation, such that each concept used is specialised for a specific customer segment. For example, truck-drone delivery systems may be the most convenient choice for rural areas, with large spaces for drones to safely land in to drop parcels. Delivery robots with trucks or cargo bikes may be a good option for areas with dense population and inner cities. Parcel lockers are the most convenient for price-sensitive customers who work long hours, have non-urgent orders, or are not willing to pay a lot for delivery. Segmenting customers and assigning them the most convenient means of delivery, or even using a complex mixture of innovative solutions (truck–drone–robot, for example) are important issues to explore in future research.

Through this review paper, the aim was to provide both an academic and industrial perspective on innovative last mile solutions. However, it might be interesting to provide deeper insights into and classification of the mathematical models presented. Additionally, providing the type of heuristic or meta-heuristic used in the models can be beneficial for future development in this research area.

Acknowledgments

Open Access funding provided by the Qatar National Library.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes on contributors

Eng. ***Wassen AM Mohammad*** is currently a PhD student in Logistics and Supply Chain Management at the College of Science and Engineering at Hamad Bin Khalifa University (Qatar) carrying out research on Last Mile Delivery and Urban Logistics. She holds an MSc in Engineering Management and a BSc in Industrial Engineering from Qatar University (Qatar).

Eng. ***Yousef Nazih Diab*** holds a MSc degree in Logistics and Supply Chain Management from the College of Science and Engineering at Hamad Bin Khalifa University (Qatar) and a BSc degree in Electrical Engineering form Texas and A University (Doha campus).

Dr. ***Adel Elomri*** is an Assistant Professor in the division of Engineering Management and Decision Sciences at the College of Science and Engineering at Hamad Bin Khalifa University (Qatar). He holds Ph.D and MS degrees in Operations Management (with Highest Honors) from CentraleSupélec Paris (France) and a BS degree in Industrial Engineering from the National Engineering School of Tunisia. Dr. Elomri's research interests lie at the interface of operations research, operations economics, and engineering management. Currently Dr. Elomri has projects underway in the areas of healthcare operations management, sustainable supply chain management, smart logistics, and production and operations management.

Dr. ***Chefi Triki*** is a Senior Lecturer of Operations Research and Logistics Systems at Kent Business School (University of Kent, UK). He holds a PhD in Systems Engineering and Informatics from the University of Calabria (Italy) and an Electro-Mechanical Engineering Degree from the National Engineering School of Tunis (Tunisia). Dr Triki has a strong background in developing optimization tools for network design with application to the transportation procurement, freight distribution, waste collection, groundwater management, and to the food and tourism industries. Along his carrier, he was awarded several research, teaching and service recognitions for his academic commitment. His teaching activities consists of a wide range of undergraduate and graduate courses on logistics, simulation, informatics and optimization for business, engineering, mathematics, computer science and management science students.

ORCID

Adel Elomri http://orcid.org/0000-0003-1605-9800
Chefi Triki http://orcid.org/0000-0002-8750-2470

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

References

60 Minutes, "Amazon Unveils Futuristic Plan: Delivery by Drone," *CBS News*, 2013. https://www.cbsnews.com/news/amazon-unveils-futuristic-plan-delivery-by-drone/ (accessed 19 December 2021

Agatz, N., P. Bouman, and M. Schmidt, "Optimization Approaches for the Traveling Salesman Problem with Drone," 2016. http://ssrn.com/abstract=2639672

Alfandari, L., I. Ljubić, and M. de Melo da Silva. 2022. "A Tailored Benders Decomposition Approach for last-mile Delivery with Autonomous Robots." *European Journal of Operational Research* 299 (2): 510–525. doi:10.1016/j.ejor.2021.06.048.

Anderluh, A., V. C. Hemmelmayr, and P. C. Nolz. 2017. "Synchronizing Vans and Cargo Bikes in a City Distribution Network." *Central European Journal of Operations Research*. 25(2): 345–376. doi:10.1007/s10100-016-0441-z.

Arnold, F., I. Cardenas, K. Sörensen, and W. Dewulf. 2018. "Simulation of B2C e-commerce Distribution in Antwerp Using Cargo Bikes and Delivery Points." *European Transport Research Review* 10 (1). doi:10.1007/s12544-017-0272-6.

Arroub, A., B. Zahi, E. Sabir, and M. Sadik. 2016. "A Literature Review on Smart Cities: Paradigms, Opportunities and Open Problems," in *Proceedings - 2016 International Conference on Wireless Networks and Mobile Communications, WINCOM 2016: Green Communications and Networking*, Morocco, pp. 180–186 doi:10.1109/WINCOM.2016.7777211.

Attaran, M. 2020. "Digital Technology Enablers and Their Implications for Supply Chain Management." *Supply Chain Forum* 21 (3): 158–172. doi:10.1080/16258312.2020.1751568.

Bakach, I., A. M. Campbell, and J. F. Ehmke. 2021. "A two-tier Urban Delivery Network with robot-based Deliveries." *Networks*. 78(4): 461–483. doi:10.1002/net.22024.

Bertram, I., "Hermes Starts Testing Starship Robots in London," *Hermes*, April. 13, 2017. https://newsroom.hermesworld.com/hermes-startet-test-mit-starship-robotern-in-london-12325/ (accessed 27 June 2021

Boussier, J.-M., T. Cucu, L. Ion, D. Breuil, and J. Colin. 2011. "Simulation of Goods Delivery Process." *International Journal of Physical Distribution & Logistics Management*. 41(9): 913–930. doi:10.1108/09600031111175852.

Boysen, N., R. de Koster, and F. Weidinger. 2019. "Warehousing in the e-commerce Era: A Survey." *European Journal of Operational Research* 277 (2): 396–411. doi:10.1016/j.ejor.2018.08.023.

Boysen, N., S. Fedtke, and S. Schwerdfeger. 2021. "Last-mile Delivery Concepts: A Survey from an Operational Research Perspective." *OR Spectrum* 43 (1): 1–58. doi:10.1007/s00291-020-00607-8.

Boysen, N., S. Schwerdfeger, and F. Weidinger. 2018. "Scheduling last-mile Deliveries with truck-based Autonomous Robots." *European Journal of Operational Research*. 271(3): 1085–1099. doi:10.1016/j.ejor.2018.05.058.

Bradley, N., "Could Parcel Lockers Represent a Remedy for CO^2 Emissions Stemming from e-commerce?," 2022. https://www.logisticsmanager.com/could-parcel-lockers-represent-a-remedy-for-co%C2%B2-emissions-stemming-from-e-commerce/ (accessed 09 November 2022
Brandt, M., "Parcel Shipments Reach New Record," *Statista*, June. 27, 2019. https://de.statista.com/infografik/9992/in-deutschland-von-den-paket-und-kurierdiensten-befoerderten-sendungen (accessed 18 December 2021
Bretzke, W.-R. 2013. "Global Urbanization: A Major Challenge for Logistics." *Logistics Research* 6 (2–3): 57–62. doi:10.1007/s12159-013-0101-9.
Butler, S., "Amazon e-cargo Bikes to Replace Thousands of van Deliveries in London," 2022. https://www.theguardian.com/technology/2022/jul/04/amazon-e-cargo-bikes-deliveries-london (accessed 27 August 2022
Castagno, J., Y. Yao, and E. Atkins, "Realtime Rooftop Landing Site Identification and Selection in Urban City Simulation," 2019. http://arxiv.org/abs/1903.03829
Chung, S. H., B. Sah, and J. Lee. 2020. "Optimization for Drone and drone-truck Combined Operations: A Review of the State of the Art and Future Directions." *Computers & Operations Research* 123. doi:10.1016/j.cor.2020.105004.
Coppola, D., "Annual Retail e-commerce Sales Growth Worldwide from 2017 to 2025," *Statista* 2021. https://www.statista.com/statistics/288487/forecast-of-global-b2c-e-commerce-growth (accessed 18 December 2021
Dablanc, L., D. Diziain, and H. Levifve. 2011. "Urban Freight Consultations in the Paris Region." *European Transport Research Review*. 3(1): 47–57. doi:10.1007/s12544-011-0049-2.
Dablanc, L., E. Morganti, N. Arvidsson, J. Woxenius, M. Browne, and N. Saidi. 2017. "The Rise of on-demand 'Instant Deliveries' in European Cities." *Supply Chain Forum: An International Journal* 18 (4): 203–217. doi:10.1080/16258312.2017.1375375.
Dayarian, I., M. Savelsbergh, and J.-P. Clarke. 2020. "Same-Day Delivery with Drone Resupply." *Transportation Science* 54 (1): 229–249. doi:10.1287/trsc.2019.0944.
Dell'Amico, M., R. Montemanni, and S. Novellani. 2020. "Matheuristic Algorithms for the Parallel Drone Scheduling Traveling Salesman Problem." *Annals of Operations Research*. 289(2): 211–226. doi:10.1007/s10479-020-03562-3.
Dell'Amico, M., R. Montemanni, and S. Novellani. 2021. "Modeling the Flying Sidekick Traveling Salesman Problem with Multiple Drones." *Networks*. 78(3): 303–327. doi:10.1002/net.22022.
Demir, E., Y. Huang, S. Scholts, and T. van Woensel. 2015. "A Selected Review on the Negative Externalities of the Freight Transportation: Modeling and Pricing." *Transportation Research Part E: Logistics and Transportation Review* 77: 95–114. doi:10.1016/j.tre.2015.02.020. May.
Deutsch, Y., and B. Golany. 2018. "A Parcel Locker Network as A Solution to the Logistics Last Mile Problem." *International Journal of Production Research* 56 (1–2): 251–261. doi:10.1080/00207543.2017.1395490.
DHL, "DHL Locker One Yellow Wall to Streamline Shipping." https://www.dhlparcel.nl/en/consumer/dhl-locker (accessed 27 June 2021
DHL, "DHL Express Launches Its First Regular Fully-Automated and Intelligent Urban Drone Delivery Service," 2019. https://www.dhl.com/tw-en/home/press/press-archive/2019/dhl-express-launches-its-first-regular-fully-automated-and-intelligent-urban-drone-delivery-service.html#:~:text=DHL%20Express%2C%20the%20world's%20leading,tackle%20the%20last-mile%20delivery(accessed 19 December 2021
Di Puglia Pugliese, L., G. Macrina, and F. Guerriero. 2021. "Trucks and Drones Cooperation in the last-mile Delivery Process." *Networks*. 78(4): 371–399. doi:10.1002/net.22015.
Dorling, K., J. Heinrichs, G. G. Messier, and S. Magierowski. 2017. "Vehicle Routing Problems for Drone Delivery." *IEEE Transactions on Systems, Man, and Cybernetics: Systems*. 47 (1): 70–85. doi:10.1109/TSMC.2016.2582745.
Dormehl, L., "Amazon's Scout Delivery Bots are Rolling Out in Two New Cities," *digitaltrends*, July. 21, 2020. https://www.digitaltrends.com/news/amazon-scout-franklin-atlanta/ (accessed 27 June 2021
Durach, C. F., and A. Wieland, "A New Paradigm For Systematic Literature Reviews In Supply Chain Management," 2017.
Edwards, R., "Research Reveals the Cost of Failed Deliveries," *Enterprise Times*, March. 09, 2021. https://www.enterprisetimes.co.uk/2021/03/09/research-reveals-the-cost-of-failed-deliveries/ (accessed 16 August 2022
Eliyan, A., A. Elomri, and L. Kerbache. 2021. "The last-mile Delivery Challenge: Evaluating the Efficiency of Smart Parcel Stations." *Supply Chain Forum* 22 (4): 360–369. doi:10.1080/16258312.2021.1918532.
Emergen Research, "Top 10 Companies in the Drone Package Delivery Industry," 2022. https://www.emergenresearch.com/blog/top-10-companies-in-the-drone-package-delivery-industry (accessed 27 August 2022
Es Yurek, E., and H. C. Ozmutlu. 2021. "Traveling Salesman Problem with Drone under Recharging Policy." *Computer Communications* 179: 35–49. doi:10.1016/j.comcom.2021.07.013.
Fan, W., H. Xu, X. Xu, and B. Hu Li. 2009. "Simulation on Vehicle Routing Problems in Logistics Distribution." *COMPEL - the International Journal for Computation and Mathematics in Electrical and Electronic Engineering*. 28(6): 1516–1531. doi:10.1108/03321640910992056.
Fikar, C., P. Hirsch, and M. Gronalt. 2018. "A Decision Support System to Investigate Dynamic last-mile Distribution Facilitating cargo-bikes." *International Journal of Logistics Research and Applications*. 21(3): 300–317. doi:10.1080/13675567.2017.1395830.
Ghajargar, M., G. Zenezini, and T. Montanaro. 2016. "Home Delivery Services: Innovations and Emerging Needs." *IFAC-PapersOnLine* 49 (12): 1371–1376. doi:10.1016/j.ifacol.2016.07.755.
Hjørland, B. 2013. "Facet Analysis: The Logical Approach to Knowledge Organization." *Information Processing & Management* 49 (2): 545–557. doi:10.1016/j.ipm.2012.10.001.
Huang, H., A. V. Savkin, and C. Huang. 2020. "A New Parcel Delivery System with Drones and A Public Train." *Journal of Intelligent and Robotic Systems: Theory and Applications* 100 (3–4): 1341–1354. doi:10.1007/s10846-020-01223-y.
Hu, W., J. Dong, B. Gang Hwang, R. Ren, and Z. Chen. 2019. "A Scientometrics Review on City Logistics Literature: Research Trends, Advanced Theory and Practice." *Sustainability (Switzerland)* 11 (10). doi:10.3390/su11102724.
Intelligence, "Drone Technology Uses and Applications for Commercial, Industrial and Military Drones in 2021 and the Future," 2021. https://www.businessinsider.com/drone-technology-uses-applications (accessed 19 December 2021
International Post Corporation, "Delivery Choice - Parcel Lockers 2020 Overview," 2020. https://www.ipc.be/services/markets-and-regulations/e-commerce-market-insights/e-commerce-articles/2020-parcel-lockers?fbclid=

IwAR2bfJOQ2lN9aSBSJ7jClyFQeTh85xtzKXwz_TvM921DRGTo5pKpMKBWioA (accessed 27 August 2022
Iwan, S., K. Kijewska, and J. Lemke. 2016. "Analysis of Parcel Lockers' Efficiency as the Last Mile Delivery Solution - the Results of the Research in Poland." *Transportation Research Procedia* 12: 644–655. doi:10.1016/j.trpro.2016.02.018.
Jennings, D., and M. Figliozzi. 2019. "Study of Sidewalk Autonomous Delivery Robots and Their Potential Impacts on Freight Efficiency and Travel." *Transportation Research Record*. 2673(6): 317–326. doi:10.1177/0361198119849398.
Jiang, L., and H. Mahmassani. 2014. "City Logistics." *Transportation Research Record: Journal of the Transportation Research Board*. 2410(1):85–95. doi:10.3141/2410-10.
Jovanović, A. D., D. S. Pamučar, and S. Pejčić-Tarle. 2014. "Green Vehicle Routing in Urban Zones - A neuro-fuzzy Approach." *Expert Systems with Applications*. 41(7): 3189–3203. doi:10.1016/j.eswa.2013.11.015.
Kellermann, R., T. Biehle, and L. Fischer. 2020. "Drones for Parcel and Passenger Transportation: A Literature Review." *Transportation Research Interdisciplinary Perspectives* 4. doi:10.1016/j.trip.2019.100088.
Kim, S., and I. Moon. 2019. "Traveling Salesman Problem with a Drone Station." *IEEE Transactions on Systems, Man, and Cybernetics: Systems*. 49(1): 42–52. doi:10.1109/TSMC.2018.2867496.
Kim, J., H. Moon, and H. Jung. 2020. "Drone-based Parcel Delivery Using the Rooftops of City Buildings: Model and Solution." *Applied Sciences (Switzerland)*. 10 (12). doi:10.3390/app10124362.
Kreier, F., "Drones Bearing Parcels Deliver Big Carbon Savings," 2022. nature.com/articles/d41586-022-02101-3 Accessed 27 August 2022
Lee, K., J. Chae, and J. Kim. 2019. "A Courier Service with Electric Bicycles in an Urban Area: The Case in Seoul." *Sustainability (Switzerland)* 11 (5). doi:10.3390/su11051255.
Li, B., M. W. Riley, B. Lin, and E. Qi. 2006. "A Comparison Study of Customer Satisfaction between the UPS and FedEx: An Empirical Study among University Customers." *Industrial Management and Data Systems* 106 (2): 182–199. doi:10.1108/02635570610649844.
Mangiaracina, R., A. Perego, A. Seghezzi, and A. Tumino. 2019. "Innovative Solutions to Increase last-mile Delivery Efficiency in B2C e-commerce: A Literature Review." *International Journal of Physical Distribution & Logistics Management*. 49(9): 901–920. doi:10.1108/IJPDLM-02-2019-0048.
McKinnon, A. C., and D. Tallam. 2003. "Unattended Delivery to the Home: An Assessment of the Security Implications." *International Journal of Retail & Distribution Management*. 31(1): 30–41. doi:10.1108/09590550310457827.
Molin, E., M. Kosicki, and R. van Duin. 2022. "Consumer Preferences for Parcel Delivery Methods: The Potential of Parcel Locker Use in the Netherlands." *European Journal of Transport and Infrastructure Research* 22 (2): 183–200. doi:10.18757/ejtir.2022.22.2.6427.
Murray, C. C., and A. G. Chu. 2015. "The Flying Sidekick Traveling Salesman Problem: Optimization of drone-assisted Parcel Delivery." *Transportation Research Part C: Emerging Technologies* 54: 86–109. doi:10.1016/j.trc.2015.03.005. May.
Narayanan, S., E. Chaniotakis, and C. Antoniou. 2020. "Shared Autonomous Vehicle Services: A Comprehensive Review." *Transportation Research Part C: Emerging Technologies* 111: 255–293. doi:10.1016/j.trc.2019.12.008.
Nguyễn, Thu Ba T., Bektaş, Tolga, Cherrett, Tom J., McLeod, Fraser N., Allen, Julian, Bates, Oliver, Piotrowska, Marzena, Piecyk, Maja, Friday, Adrian, and Wise, Sarah. 2019. "Optimising Parcel Deliveries in London Using dual-mode Routing." *Journal of the Operational Research Society*. 70(6): 998–1010. doi:10.1080/01605682.2018.1480906.
Olsson, J., D. Hellström, and H. Pålsson. 2019. "Framework of Last Mile Logistics Research: A Systematic Review of the Literature." *Sustainability (Switzerland)* 11 (24): 1–25. doi:10.3390/su11247131.
Ostermeier, M., A. Heimfarth, and A. Hübner. 2022. "Cost-optimal truck-and-robot Routing for last-mile Delivery." *Networks*. 79(3): 364–389. doi:10.1002/net.22030.
Peterson, H., "Missing Wages, Grueling Shifts, and Bottles of Urine: The Disturbing Accounts of Amazon Delivery Drivers May Reveal the True Human Cost of 'Free' Shipping," *Insider*, September. 11, 2018. https://www.businessinsider.com/amazon-delivery-drivers-reveal-claims-of-disturbing-work-conditions-2018-8 (accessed 27 June 2021
Poeting, M., S. Schaudt, and U. Clausen. 2019. "Simulation of an Optimized last-mile Parcel Delivery Network Involving Delivery Robots." *Advances in Production, Logistics and Traffic* 17: 1–19.
Poggi, N., D. Carrera, R. Gavaldà, E. Ayguadé, and J. Torres. 2014. "A Methodology for the Evaluation of High Response Time on E-commerce Users and Sales." *Information Systems Frontiers*. 16(5): 867–885. doi:10.1007/s10796-012-9387-4.
Proud, F., and P. Chapman, "Global Parcel Shops and Locker Networks/Out of Home Delivery: Market Insight Report 2022," 2022. https://apex-insight.com/product/global-parcel-shops-and-locker-networks-out-of-home-delivery-market-insight-report-2022/#:~:text=We%20have%20identified%20more%20than,than%200.5m%20locker%20locations (accessed 14 August 2022
Punakivi, Mikko, Hannu Yrjo Èla, and Holmström, Jan. 2001. Solving the last mile issue: Reception box or delivery box?. *International Journal of Physical Distribution & Logistics Management* 31: 427–439. doi:10.1108/09600030110399423 .
Rojas Viloria, D., E. L. Solano-Charris, A. Muñoz-Villamizar, and J. R. Montoya-Torres. 2021. "Unmanned Aerial vehicles/drones in Vehicle Routing Problems: A Literature Review." *International Transactions in Operational Research*. 28(4): 1626–1657. doi:10.1111/itor.12783.
Schnieder, M., C. Hinde, and A. West. 2021. "Sensitivity Analysis of Emission Models of Parcel Lockers Vs. Home Delivery Based on Hbefa." *International Journal of Environmental Research and Public Health* 18 (12). doi:10.3390/ijerph18126325.
Song, L., T. Cherrett, F. McLeod, and W. Guan. 2009. "Addressing the Last Mile Problem: Transport Impacts of Collection and Delivery Points." *Transportation Research Record: Journal of the Transportation Research Board* 2097 (1): 9–18. doi:10.3141/2097-02.
Song, B. D., K. Park, and J. Kim. 2018. "Persistent UAV Delivery Logistics: MILP Formulation and Efficient Heuristic." *Computers & Industrial Engineering* 120: 418–428. doi:10.1016/j.cie.2018.05.013. June.
Sonneberg, M.-O., M. Leyerer, A. Kleinschmidt, F. Knigge, and M. H. Breitner, "Autonomous Unmanned Ground Vehicles for Urban Logistics: Optimization of Last Mile Delivery Operations," 2019. https://hdl.handle.net/10125/59594
Starship, "Starship Technologies Launches Pilot Program with Domino's Pizza Enterprises," 2017. https://www.starship.xyz/press_releases/starship-technologies-launches-pilot-program-with-dominos-pizza-enterprises/#:~:text=Starship%20robots%20will%20start%20delivering,selected%20German%20and%20Dutch%20cities.&text=

Starship%20recently%20announced%20%2417.2%20million,in%20Europe%20and%20the%20US (accessed 27 June 2021

Stevens, B., "Amazon Has Delivered 3.5 Billion Parcels in 2019 Smashing Estimates," *Charged*. 2019. https://www.chargedretail.co.uk/2019/12/23/amazon-has-delivered-3-5-billion-parcels-in-2019-smashing-estimates/ (accessed 09 January 2022

Stevens, B., "InPost to Double Number of smart-lockers at London Stations," *Charged*, 2021. https://www.chargedretail.co.uk/2021/03/19/inpost-to-double-number-of-smart-lockers-at-london-stations/ (accessed 09 January 2022

Sun, D., X. Peng, R. Qiu, and Y. Huang. 2021. "The Traveling Salesman Problem: Route Planning of Recharging Station-Assisted Drone Delivery," in *Proceedings of the Fourteenth International Conference on Management Science and Engineering Management,* ICMSEM 2020. doi:10.1007/978-3-030-49889-4_2, .

Swiss Post, "Factsheet Starship Delivery Robot," 2017. https://www.post.ch/-/media/post/ueber-uns/medienmitteilungen/2017/factsheet-lieferroboter.pdf?la=en (accessed 27 June 2021

Taniguchi, E., R. G. Thompson, and A. G. Qureshi. 2020. "Modelling City Logistics Using Recent Innovative Technologies." *Transportation Research Procedia* 46: 3–12. doi:10.1016/j.trpro.2020.03.157.

Toor, A., "This Startup Is Using Drones to Deliver Medicine in Rwanda," 2016. https://www.theverge.com/2016/4/5/11367274/zipline-drone-delivery-rwanda-medicine-blood (accessed 29 April 2021

Ulmer, M. W., and S. Streng. 2019. "Same-Day Delivery with Pickup Stations and Autonomous Vehicles." *Computers & Operations Research* 108: 1–19. doi:10.1016/j.cor.2019.03.017.

Veenstra, M., K. J. Roodbergen, L. C. Coelho, and S. X. Zhu. 2018. "A Simultaneous Facility Location and Vehicle Routing Problem Arising in Health Care Logistics in the Netherlands." *European Journal of Operational Research*. 268(2): 703–715. doi:10.1016/j.ejor.2018.01.043.

Wang, X., S. Poikonen, and B. Golden. 2017. "The Vehicle Routing Problem with Drones: Several worst-case Results." *Optimization Letters*. 11(4): 679–697. doi:10.1007/s11590-016-1035-3.

Yaman, H., O. E. Karasan, and B. Y. Kara. 2012. "Release Time Scheduling and Hub Location for next-day Delivery." *Operations Research*. 60(4): 906–917. doi:10.1287/opre.1120.1065.

Yu, Y., X. Wang, R. Y. Zhong, and G. Q. Huang. 2017. "E-commerce Logistics in Supply Chain Management Implementations and Future Perspective in Furniture Industry." *Industrial Management and Data Systems* 117 (10): 2263–2286. doi:10.1108/IMDS-09-2016-0398.