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Review

A Review of Literature on Vehicle Routing Problems of Last-Mile Delivery in Urban Areas

Reza Jazemi [1], Ensieh Alidadiani [2], Kwangseog Ahn [3] and Jaejin Jang [1,*]

[1] Department of Industrial & Manufacturing Engineering, University of Wisconsin, Milwaukee, WI 53190, USA; rjazemi@uwm.edu
[2] Lubar School of Business, University of Wisconsin, Milwaukee, WI 53211, USA; ensieh@uwm.edu
[3] Department of Occupational and Environmental Safety and Health, University of Wisconsin, Whitewater, WI 53190, USA; ahnk@uww.edu
* Correspondence: jang@uwm.edu; Tel.: +1-(414)-229-2978

Abstract: Logistics has long been important in an industrial society. Compared with the traditional structure of distribution, which requires freight to be delivered mostly to warehouses or retail stores, customers now often prefer packages to be delivered to their residences, especially after the delivery challenges during the COVID-19 pandemic. The delivery of parcels to urban residential areas increases the challenge due to the amount of delivery volume, tight delivery schedules, and continuously changing delivery conditions. Last-mile delivery tries to address the challenges, taking advantage of the available automation, sensor and communication technologies, and people's attitudes toward parcel delivery for the benefit of all stakeholders. Various approaches to last-mile delivery have been proposed and analyzed in the literature. This paper reviews the recent literature on vehicle routing for last-mile delivery. The review identified four major categories: crowdshipping, parcel lockers, delivery by sidekicks, and delivery to optional points. The nature of the problems is discussed in five aspects: fleet capacity, time window, fleet option, dynamism of input, and stochastic parameters. The review identifies the achievements and limitations of the research in the areas and proposes a future research agenda.

Keywords: last-mile delivery; vehicle routing; occasional driver; parcel locker; sidekick; optional points of delivery; optimization

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1. Introduction

Logistics has long been important in an industrial society. It is ironic, however, that the advancement of information technology, which allows fast and almost no-cost transmittal of information, increased the complexity and importance of logistics. Compared with the traditional structure of distribution, which requires freight to be delivered mostly to warehouses or retail stores, customers now often prefer packages to be delivered to their residences or even to public places without designated mailing addresses for certain types of product based on the Global Positioning System (GPS). Additionally, the COVID-19 pandemic made people more accustomed to package delivery at their designated locations. The shift in people's habits and expectations resulted in a substantial increase in the demand for delivery services. Also, the emergence and rapid expansion of e-retail companies, such as Amazon, eBay, Alibaba, Walmart+, and Shop BBC, have changed customer attitudes to delivery.

The delivery of parcels to urban residential areas increases the challenge due to the amount of delivery volume, tight delivery schedules, and continuously changing delivery conditions, as discussed in the last-mile delivery (LMD) literature. Naturally, LMD tries to take advantage of the available technologies and people's attitudes toward parcel delivery, both on the supply and demand sides, for the benefit of all stakeholders. The prosperity of the pickup and delivery services by occasional drivers is seen in the cases of Uber and

Lyft. Sometimes, a logistics company delivers to one of its designated places or parcel locker locations. At the same time, LMD utilizes the help of customers on the demand side; customers are flexible and allow optional delivery locations, one of which will be chosen by the logistics company during delivery planning. Automation certainly helps delivery, and drones have already been commercialized. Sooner or later, autonomous vehicles on the land and water will also be used [1,2]. Amazon commercialized its patented flying warehouses, which also carry small drones [3]. Multiple delivery modes can surely be combined for a delivery job.

LMD is the final stage of the parcel delivery process when a customer order is transported from a fulfillment center to a destination, often a residential address [4]. LMD studies discuss diverse issues of delivery [5], including pricing, delivery mode, and security concerns [6]. These studies also investigate innovative solutions, infrastructure setup, staffing, and fleet design in recent years [5,7]. The application of computational intelligence [8], new solution methods [9,10], and the environmental side effects of VRP and LMD [11] are also widely discussed in the literature. Optimization models to employ various types of vehicle in LMD are discussed in [5,12,13].

Researchers have been studying vehicle routing problems (VRPs) to design optimal delivery or pickup routes from one or multiple depots to a number of geographically scattered destinations subject to practical constraints [14,15], playing important roles in logistics [16,17]. Responding to diverse requirements such as working hour limit, fleet capacity, nature of deliverables, and environmental requirements, various VRP models have been discussed, including green VRP and electric VRP. Details of G-VRP [18,19] and E-VRP [20–22] are discussed in many VRP review papers.

Many vehicle routing issues in LMD have long been considered implicitly in conventional VRP [23–25]. Due to the recent changes in social life, customer behavior, pandemic limitations, increased delivery volume, time pressure, and workforce limitations, e-commerce has widely been accepted by both industry and customers, and the research on vehicle routing for LMD has been pervasively investigated [7,26].

Many papers discuss the vehicle routing issues on LMD considering the new infrastructure of the information and automation technologies [10]. However, the literature shows a lack of a comprehensive survey to categorize and characterize the papers. This research summarizes the current problems discussed in LMD vehicle routing. The results of this study can be used to identify the research gaps in LMD vehicle routing and develop future research agendas. In the literature, the same solution procedures of the conventional VRP models are used for the LMD optimization as well. This review paper does not explore details of the solution methods, except listing them for each paper in the summary tables. In-depth discussions of the solution procedures in VRP can be found in the literature including [27–30].

The distinctive characteristics of vehicle routing in LMD in urban areas include more uncertainties and higher dynamicity compared with conventional VRP. The information update occurs more frequently, asking for more frequent real-time adjustments of the delivery plan. It also gives a larger number of visits per route, and the parking lot space and service time at the destination are sometimes considered. The time windows are tighter. The allowed route of a vehicle can be different for different vehicles, e.g., the size of a truck to make a right turn or its weight.

Additionally, vehicle routing in LMD considers the involvement of individuals, for both the supply and demand sides. For the supply side, we can use occasional drives (outsourcing), which makes the operation more efficient at peak times. Considerations of occasional drivers add new issues of the supplier's time window, zoning, and matching of drivers and customers. For the demand side, customers are willing to provide optional delivery points and use regional parcel lockers.

The common characteristics of conventional VRP and LMD include vehicle capacity and fleet options. Also, both the conventional VRP and vehicle routing in LMD problems can utilize modern technology for sidekicks.

This review paper is constructed as follows. Section 2 explains the review methodology. Section 3 describes the framework used for the survey. The framework groups LMD study into four categories based on the focus of the problems: delivery with occasional drivers, delivery to parcel lockers, delivery by sidekicks, and delivery to optional points. Section 4 presents the research on LMD routing in these four subsections. Section 5 concludes the paper by summarizing the study's implications and presenting an agenda for future research.

2. Review Methodology

We reviewed 38 survey papers on VRP to gain a comprehensive understanding of the routing problems and the position of LMD in the VRP area. We incorporated 26 of the survey papers to establish the scope of our survey, to ensure the inclusion of a comprehensive range of relevant study areas and minimize the possibility of overlooking pertinent research findings (Figure 1).

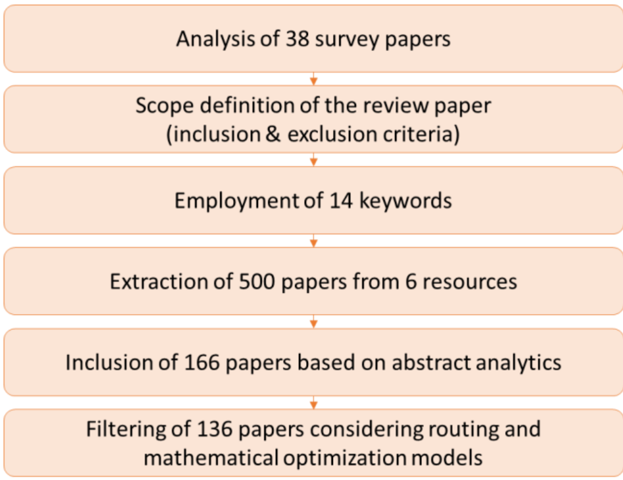

Figure 1. Applied methodology for this review.

The related keywords and phrases offered by the review papers were used as a baseline to find the routing papers in the LMD area. Considering the wide range of vehicle routing problems, we employed the 14 keywords and their combinations derived from surveys [10,26,31–34]: last-mile delivery (LMD), vehicle routing problem (VRP), drone, crowdshipping, crowdsourcing, parcel delivery, human-driven delivery, autonomous delivery, city logistics, smart cities, sidekick fleet, occasional driver, delivery option, traveling salesman. The review papers led us to find the different aspects of LMD that are not discussed in the literature. We found that routing in LMD is an important area that is not discussed in a comprehensive way. After searching the available inventories of Business Source Premier, Google Scholar, Science Direct, Emerald Insight, Scopus, and Web of Science, we found more than 500 papers, which showed us the important characteristics of LMD problems. Based on the initial analysis of abstracts and conclusions, we opted for 166 papers among initial inventories that were mostly concentrated on routing and optimization models in different LMD configurations. After a thorough investigation of their modeling and related considerations of the papers we chose 136 papers and constructed the characteristics of the LMD problems and their common specifications, which were entitled as the nature of the LMD problems.

3. Framework of the Literature Survey

The VRP seeks to find the best fleet and its routes to deliver parcels to customers. The conventional VRP models mostly consider the routes as a closed loop, in which the fleet returns to its depot after delivery, as shown in Figure 2. These models also consider relatively homogenous fleets run by professional operators.

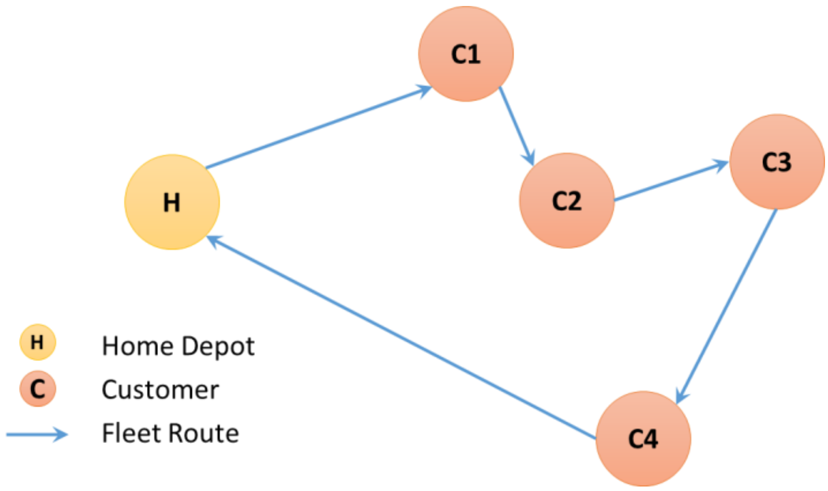

Figure 2. Conventional VRP.

Compared with them, the vehicle routing in LMD considers more diverse issues in city logistics, reflecting the new needs and conditions given to it. To better respond to these issues, LMD planning mostly begins with segmentation or grouping of delivery points. It is then followed by parcel packaging to ensure safe and convenient handling. Subsequently, the delivery fleet is chosen along with its delivery paths. The details of these steps vary depending on the conditions of the delivery requests and the available resources. The following sections provide the categories and nature of the LMD problems considered in the literature.

3.1. Categories of LMD Problems

Due to technological advancements and the effects of pandemics on LMD, much research has been reported on vehicle routing in LMD during the last eight years. Most of the literature on LMD can be grouped into these four categories based on the focus of the problems:

1. Delivery with occasional drivers (crowdshipping): The logistics companies use occasionally available non-professional drivers in addition to their own fleet for parcel delivery.
2. Delivery to parcel locker: Customers' parcels are delivered to specific locations with many lockers, and the customers retrieve their parcels from assigned lockers.
3. Delivery using sidekicks: The delivery uses a main vehicle and one or more sidekick vehicles. The main vehicle brings parcels and sidekicks to intermediate places, whose locations are determined by each delivery plan, and the sidekicks deliver the parcels from the main vehicle to customers' locations.
4. Delivery to optional points: A customer offers multiple delivery locations, and the delivery system delivers the parcel to the best location.

Some papers simultaneously consider two of the above categories. For example, occasional drivers are considered as the sidekicks [35]. Also, crowdshipping and delivery options are considered together in [36]. Some researchers consider different goals using the same approaches. Refs. [37,38] employ drones to reduce emissions in green VRP, and [39] uses drones for cost optimization and delivery time reduction.

3.2. Nature of LMD Problems

Each delivery plan is subject to the different operation conditions given by customers, managerial options, uncertainties, and technical conditions such as real-time demand change, traffic congestion, time window, fleet accessibility, and service times at the points of delivery. The literature often considers these five aspects of the nature of problems as more important:

1. Fleet capacity: Capacitated VRP (CVRP) optimizes routes considering vehicle capacity limits such as weight, volume, and number of parcels [40,41]. Sometimes, however, these limits can be ignored for mail delivery, where the parcel volumes are so small compared with fleet capacity, and perishable item delivery, when vehicles cannot wait for the full load of items [42]. The pickup and delivery problems widely discussed in many conventional VRPs [43] and also in LMD [44,45] are modeled as a problem with vehicle capacity limit.
2. Time window: Time windows require deliveries to be made within specified time horizons [41,46]. LMD additionally considers the time windows of driver availability. Various types of window in a logistics network have been discussed in literature [47].
3. Fleet option: The research considers multiple types of fleet, including a heterogeneous fleet, which involves a fleet of vehicles with different capacities [48]; electric vehicles, which need additional time for charging [49]; and autonomous vehicles [50]. Various autonomous vehicles allow us diverse options for delivery network design. Autonomous vehicles for delivery are discussed in survey papers [1,10,51].
4. Dynamic input: Dynamic VRP (DVRP) considers the changeability of variables (e.g., a customer's change of order quantity) during delivery [41,52].
5. Stochastic parameter: Stochastic VRP (SVRP) considers the randomness or uncertainty of the parameters [41,53].

In the discussion of each paper, these aspects are mentioned only when the paper explicitly considers them.

4. Literature on LMD Vehicle Routing

We grouped the literature on LMD vehicle routing into the following four categories:

4.1. Occasional Drivers (Crowdshipping)

As modern society continues to adapt to the shared economy, occasional drivers (ODs) are likely to play more important roles in future delivery systems. In crowdshipping, individual ODs act as operators in the sharing economy [54]. They make their resources (vehicles and time) available to assist the LMD. Based on the advancement of social media, people had already begun using the concept of crowdshipping to have their friends deliver parcels [55]. It is believed that numerous companies have already been adopting crowdshipping as their foundational business model since 2011. Crowdshipping was popularized by Amazon from 2015 [56]. Crowdshipping takes advantage of ODs, who are sometimes more cost-efficient than company-owned fleets [57]. It especially helps delivery during peak times.

Some research regards crowdshipping as a part of an open VRP, in which the drivers are not required to return to the depot [58,59]. However, crowdshipping considers more issues that are not considered important in the traditional open VRP. While a traditional VRP considers the time windows of customers, LMD considers the time windows of the ODs' availability as well. Also, the segmentation process of LMD considers that some ODs cannot access some customers' sites due to the vehicle characteristics or driver's preferences. In the literature, the terms crowdshipping, cargo hitching [60], crowd logistics [61], passing-by vehicles [62], crowdsourcing [63], and collaborative logistics [55] refer to delivery by occasional drivers.

In Figure 3, crowdshipping groups the customers based on their locations and time requirements, and assigns them to available drivers (matching). Grouping is based on either the driver's destinations [61,64] or customers' neighborhoods [65,66]. Scheduling and matching in crowdshipping involve many challenges [67]. Most research shows that occasional drivers have their own destinations, except for [58]. Different matching mechanisms, such as pure self-scheduling, hybrid and centralized scheduling, route matching, and bulletin-board type matching, are being used by different platform companies [68].

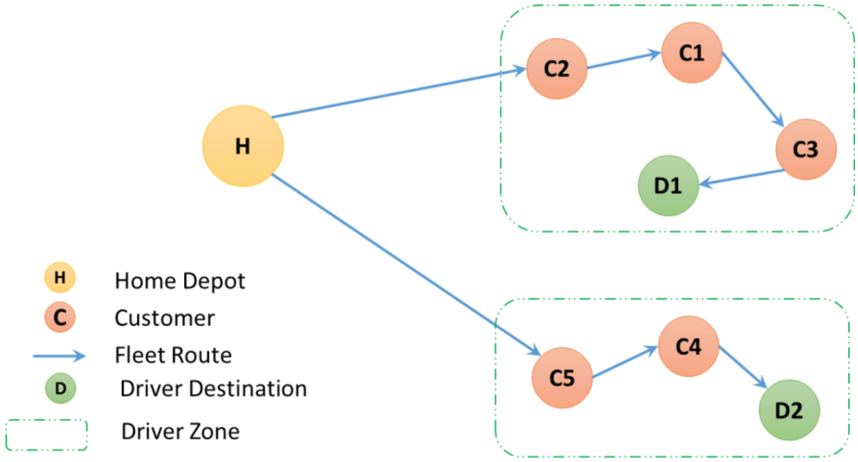

Figure 3. Delivery with occasional drivers (crowdshipping) in LMD.

Table 1 shows the identified publications on crowdshipping. The nature of problems, important considerations, and solution methods are summarized in the table. Crowdshipping naturally chooses a vehicle from available ODs and company fleets (the third nature of the LMD problems). Although all of the natures of LMD problems can be seen in crowdshipping, because of the complexity of the problems, most of the literature considers at most two of them and uses heuristic algorithms for problem-solving and data analytics. In crowdshipping research, occasional drivers have their own vehicles. Vehicle loading capacity (90% of the papers), travel distance, driver's work time, or number of deliveries are commonly considered. Also, various types of time window are considered in the papers, underlining the significance of meeting delivery deadlines. Some papers include waiting time in the customer's desired timespan and penalties for late arrivals. The dynamicity consideration of the variables and parameters is mostly limited to online orders (20% of the papers), and the stochastic nature of the problem (20% of the papers) is confined to travel times and fluctuating customer demands [69,70].

Among the papers in Table 1, just two of them use transactional data to evaluate their model, while most of them use simulated data. Various solution methods, ranging from metaheuristics to machine learning techniques, are used across the studies to deal with the complexities of ODs' logistics. Some contradictory observations are seen in the literature. While some papers advocate crowdshipping for emission reduction [66,71,72], some others argue that crowdshipping does not reduce environmental pollution [73].

Table 1. Literature on delivery with occasional drivers (crowdshipping).

Ref.	Problem Nature	Important Considerations	Objective(s)	Sample Size	Solution Method
[35]	- Capacitated	- Mixed-integer nonlinear model - ODs can only work in the second echelon - ODs can just deliver one request - Limited capacity and mileage for ODs - Own fleet can go on limited routes	Minimize travelling costs of trucks, city freighters, and the employed ODs	- 1 depot, 2 satellites, 12 customers - 1 depot, 2–4 satellites, 21–50 customers	Heuristic (adaptive large neighborhood)
[46]	- Time windowed	- Multi depot - Limited vehicle speed	Minimize distribution cost using company's truck or ODs	- 4 company's truck and 4 ODs	Simulation

Table 1. *Cont.*

Ref.	Problem Nature	Important Considerations	Objective(s)	Sample Size	Solution Method
[58]	- Capacitated - Stochastic	- Each demand can be delivered in more than one parcel - Stochastic assignment acceptance - Limited route duration	Minimize the fixed and variable compensations paid to ODs	- Considers 100 customers in 10 clusters - At most 4 vehicles for each cluster	Heuristic (combined with B&P)
[61]	- Capacitated	- Limited capacity for own fleet - Unlimited capacity for ODs - Limited distance variation for ODs - ODs can perform one delivery.	Minimize total costs of vehicles and ODs' payments	- Different numbers of 13, 25, 50, or 100 ODs	Metaheuristic (Iterated local search & parallel cooperation)
[62]	- Capacitated - Time windowed - Stochastic (fuzzy)	- Heterogeneous vehicles - Different sensitivity of customers following a fuzzy trend - Considering carbon emissions - Limited mass of ODs deliveries	maximize the number of customers served and usage rate of PD and minimize operational cost and unfairness of PD routes.	- -	Heuristic (variable neighborhood search)
[63]	- Capacitated - Time windowed	- Both pickup and delivery requests - Waiting during time window just for own vehicles, not for ODs - Sub-tours are not allowed.	Minimize the cost of trucks, OD's compensation, and late delivery penalty	- 30 customers, 8 ODs, 2 trucks - 100 customers, 15 ODs, 2 trucks	Two-Step exact solution method (B&B + SPDPSTW)
[64]	- Capacitated - Stochastic	- Limited capacity of own fleet - Sub-tours are not allowed - ODs are free to reject delivery assignments - Compensation calculated as stochastic willingness/acceptance	Minimize total costs of vehicles and ODs' payments	- 15 customers	Heuristic (bi-level stochastic model)
[65]	- Capacitated	- Mixed-integer model - Limited stop and duration of ODs	Minimize total costs of vehicles and ODs' payments	- 25–100 customers, 25–100 ODs	Heuristic (adaptive neighborhood)
[66]	- Capacitated	- Heterogeneous capacity - Limited distance for own fleet - Different types of route with different velocities are available. - Different training costs and compensation - Environmental penalty for different velocities	Minimize the consumed energy, environmental penalty, and total cost, and maximize the delivery velocity	- 5 customers, 4 trucks, 3 OD's, 4 types of route	Linearized model and exact methods for problem-solving
[67]	- Time windowed - Dynamicity	- Online dynamic demands with expected time windows - Homogeneous vehicles - Considering the time effect as an amplifying cost element	Minimize the distribution cost of regular vehicles, ODs compensation and penalty	- 5, 15, 25, 100, 200 customers	Heuristic (Iterative variable neighborhood)

Table 1. *Cont.*

Ref.	Problem Nature	Important Considerations	Objective(s)	Sample Size	Solution Method
[69]	- Stochastic - Capacitated - Time windowed - Multiple fleet options	- Using cargo bikes or ODs to deliver parcels with limited capacities - Customers follow stochastic trends - Earliest and latest arrival time considered. - The stochastic requests are assigned to ODs based on distance, capacity, and time window constraints	Minimize the total travel cost and minimize rejections	- With 150, 350, 550 customers and 20 ODs	Heuristic (Monte Carlo simulation & large neighborhood search)
[70]	- Capacitated - Dynamicity	- ODs have limited capacities - Limited detour is allowed for ODs - Online orders follow dynamic trend	Minimize total costs of vehicles and ODs' payments	- -	Simulation (Auction-based matching)
[74]	- Capacitated - Time windowed - Stochastic	- Uncertain travel time - Penalty for probable missed delivery - Limited capacity for own fleet & ODs - Limited numbers of departures for ODs - ODs can perform multiple deliveries	Minimize total costs of vehicles and ODs' payments	- Numbers of Customer: - Small (5, 10, 15) - Big (25, 35, 50)	Heuristic (Bender's two-stage decomposition strategy)
[75]	- Capacitated - Stochastic	- Customer demands and/or customer presence are stochastic. - Vehicles are capacitated. - Detour could occur if they reached the vehicle's capacity	Minimize total costs of vehicles and ODs' payments	- 1 depot and 10, 30, 70, 150, or 300 customers	Reinforcement learning (B&C and integer L-shaped)
[76]	- Capacitated - Dynamicity	- Some limited detour for ODs. - Both pickup and Delivery requests - Dynamic demand during each day	Minimize mean differences of estimated and actual arrival time	- 100 or 1000 locations (delivery nodes)	Heuristic (Two-step Look-ahead Algorithm)
[77]	- Capacitated - Time windowed	- Limited conservations - Limited number of depots	Minimize the cost of vehicle, diesel, emission, and ODs payment, minimize the emission	- 5, 19, 15 customers	Simulation
[78]	- Capacitated - Time windowed	- Limited transshipment nodes - Capacitated ODs - Necessity of usage of ODs/own fleet for specified customers	Minimize total costs of vehicles and ODs' payments	- 400 nodes (customer locations)	Heuristic-generated data
[79]	- Capacitated - Time windowed	- Limited hours of driving - Different shipments for different product groups - Heterogeneous capacity	Minimizing the total cost of shipments	- 25 or 50 customers with total demand of 190 or 388	Metaheuristics
[80]	- Capacitated - Time windowed	- Limited number of departures from each depot - Limited number of ODs/own fleet	Minimize total costs of vehicles and ODs' payments	- 5 to 400 customers	Heuristic (greedy randomized)

Table 1. *Cont.*

Ref.	Problem Nature	Important Considerations	Objective(s)	Sample Size	Solution Method
[81]	- Capacitated - Time windowed	- Mixed-integer linear model - Limited capacity & mileage	Minimize start-up and travel costs for vehicles and ODs order cost	- 1 depot and 100 customers	Heuristic (adaptive ant col.)
[82]	- Capacitated - Time windowed	- Limited transshipment nodes - Heterogeneous vehicles	Minimize total costs of vehicles and ODs' payments	- Customers range 5 to 100 - No. of ODs from 3 to 10	Heuristic (variable neighborhood)
[83]	- Capacitated - Time windowed	- Own fleet should come back. - Each customer should be met only once. - Heterogeneous vehicles	Minimize the costs (fixed and variable costs of ODs and vehicles)	- 30 customers	Heuristic (Multitasking Algorithm)
[84]	- Dynamicity	- Effect of driver's training - Dynamic nature of road and customer demand	Maximize ODs reward (defined based on travel distance)	- 20 customers	Machine Learning
[85]	- Capacitated	- Mixed-integer linear model - Both pickup and delivery - Limited capacity & mileage - Each OD can serve one customer	Minimize total costs of vehicles and ODs' payments	- 50 to 199 Customers - 28 traveling distance cases	Heuristic (SA)
[86]	- Capacitated	- Commuters using public transportation are considered ODs. - ODs' willingness is affected by compensation. - Each parcel should be delivered by one OD - Transshipment locations are parcel lockers near railways - No capacity limitation on lockers - Delivery time limited to do in daytimes	Minimize total operation and compensation cost as well as emission produced	- 100 to 2000 parcels - 1 to 20 areas (parcel locker locations) - 5 vehicles and 100 ODs.	Heuristic, based on real data in Singapore
[87]	- Capacitated	- Limited capacity & work duration - Sub-tours are not allowed - ODs can just win one bidding a day	Minimize vehicles routing and winning bids costs	- 57 customers in 27 locations - 8 ODs	Heuristic, real data from an Oman bookstore
[88]	- Capacitated - Time windowed - Dynamicity	- ODs dynamically join as an available fleet - There are some backup fleets to use, as IDs may not be available - Each OD can deliver one parcel - ODs have limited driving time - Parcels should be delivered upon a specific time schedule	Minimize total costs of ODs and backup vehicles	- 100 nodes - 100 ODs	Heuristic (3-step algorithm)

Table 1. *Cont.*

Ref.	Problem Nature	Important Considerations	Objective(s)	Sample Size	Solution Method
[89]	- Dynamicity - Capacitated	- A group of customers is considered a bundle which can be selected by ODs to deliver - Two grouping approaches: clustering, corridor creation - ODs dynamically appear at regular time intervals - Both ODs and fleet have limited capacity - Company should not use ODs more than its own fleet	Minimize total travel costs of vehicles and ODs' bid	- 20 customers, 10 ODs, 5 vehicles - 40 customers, 20 ODs, 5 vehicles	Metaheuristic (large neighborhood search-based algorithm)
[90]	- Capacitated - Time windowed - Multiple fleet options	- The fleet of other logistic companies is considered as ODs - Each vehicle can go on just one round trip - Each vehicle has limited capacity & driving time - Service time is considered	Minimize the routing cost and number of ODs	- 20 customers	Exact solution (CPLEX)

4.2. Parcel Lockers

Parcel lockers, also called pickup points [91], offer a promising solution to some of the challenges posed by LMD for enhanced efficiency, reduced costs, and minimized environmental side effects [92–94]. In this case, distributors deliver parcels to appropriate lockers and inform the customers. The parcel locker system does not reveal customers' addresses. This system also reduces the risk of parcel damage or loss as customers may not be able to get their products quickly enough [95–97]. Parcel lockers may also help to reduce emissions [92,98]. While parcel lockers usually lead to lower shipment costs for customers, people in urban areas are willing to pay more for this service [99,100].

As shown in Figure 4, the lockers are located in places such as public areas, shopping centers, or residential complexes for customers' convenience. Customers are assigned to parcel lockers, and the vehicle routing is planned. After parcel delivery, recipients receive notifications with locker details and access codes. Recipients visit the locker station and retrieve packages at their convenience. There are different approaches to setting up parcel lockers and assigning customers to them. The lockers can be stationary, temporary, or mobile [101]. The models consider the travel distances of customers as well as those of the fleet. The sizes or other specific technical requirements of the lockers (e.g., refrigerating, chemical restrictions) are commonly considered in the literature. Table 2 details the available literature on the LMD using parcel lockers.

Most studies in this category emphasize the significance of capacity constraints for both lockers and fleets [102,103]. On the contrary, the nature of the parcel locker makes the time windows not as critical as in other cases unless customers specify optional delivery points along with their desired time windows. Multiple fleet options are not discussed extensively in the literature, except for [96], which investigates mobile lockers. Autonomous vehicles and drones can also be considered as fleet options. No research considers the dynamicity; just [104] assumes the stochastic availability of the ODs, in which a combined model of OD and parcel locker are defined.

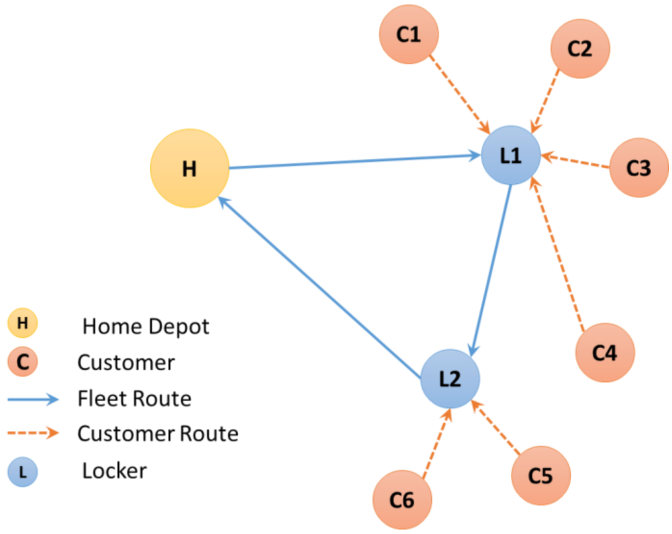

Figure 4. Delivery with parcel locker in LMD.

The solution methods vary from heuristic methods and mathematical optimization to simulation-based approaches [92–94]. Different types of specialized locker for hazardous and perishable items have been suggested [105]. Delivery of a large number of parcels requires big trucks, and lockers are often located in crowded areas; the planning requires consideration of time windows to avoid traffic delays.

Table 2. Literature on delivery to parcel lockers.

Ref.	Problem Nature	Important Considerations	Objective(s)	Sample Size	Solution Method
[91]	- Capacitated	- Can opt for parcel lockers or home delivery - Minimize the number of open locker stations and should cover minimum deliveries - Fleets with different capacities and costs are considered - Fuel consumption and emission is considered	Minimize the number of locker locations	- 3 vehicle types - 606 locker locations - 5–40 vehicles	Statistical analytics
[92]	- Time windowed	- Parcel locker is an option for customers - Route of fleet and customers are considered - Which locker station - Minimize the number of open locker stations - Limited traveling distance for each customer - Limited numbers of fleet	Minimize environmental effect (based on customer and vehicle travel distance)	- 50 or 100 customers - 5, 10, 15 locker locations	Mixed-integer solver (Gurobi application) on 60 benchmarks
[93]	- Time windowed - Capacitated	- Parcel locker is an option for customers - Minimum travel of fleet is considered - Limited capacity of vehicles and lockers	Minimize total travel distance of vehicles	- 25, 50 and 100 customers	Heuristic (SA)

Table 2. *Cont.*

Ref.	Problem Nature	Important Considerations	Objective(s)	Sample Size	Solution Method
[94]	- Capacitated	- Considers automated parcel lockers (APLs) - Capacity of parcel lockers - Lockers are activated based on the needed coverage area - Specified distance range	Minimize customer assignment cost and locker setup, decomposition, & working cost	- Yearly APL demand: 13 K to 28 K - No. of lockers: 52 to 122	Agent-based simulation model
[96]	- Capacitated	- Mobility is considered as a different option for locations of lockers - Total travel distances of flees and customers - Maximum coverage desired by limited numbers of mobile parcel lockers with specific capacities - Problem defined as facility location problem	Maximum coverage, minimum overlap, and minimum idle capacity	- 10 smart parcel lockers - population size: 50, 100, or 150	Heuristic (Taguchi Method and GA)
[98]	- Capacitated	- Parcel locker as a delivery point of customers for different sellers (open parcel lockers) - Home deliveries are not available - Total travel distances of fleet from different sellers and customers are considered as effecting factor of emission	Minimize travel distance and emission	- 3 types of vehicle - Four lockers in two cities	Statistical analytics
[100]	- Time windowed - Capacitated	- Concurrent consideration of home delivery or locker delivery - Grouping locker areas based on postal zones - Limited time spans for delivery - Volume limits on each locker - Limited travel distance for customers - Cost of active locker positions is considered	Minimize the cost and emission	- -	Generic VRP solvers
[102]	- Capacitated - Time windowed	- Parcel locker is an option for customers. - Limited capacity for lockers and fleet - Limiting not to have sub tours	Minimize total travel distance by trucks and customers, and locker opening cost	- 20, 40, 60, 100 customers - lockers are 1/10 of customers	Branch-and-cut algorithm
[103]	- Capacitated	- Lockers as intermediate depots - Traveling distance for fleet - Compensates customers for travel - Considers capacity for fleet and lockers - There are some predetermined lockers	Minimize the transportation cost and compensation to customers	- 4 lockers and 6 customers	Heuristic (SA)

Table 2. *Cont.*

Ref.	Problem Nature	Important Considerations	Objective(s)	Sample Size	Solution Method
[104]	- Capacitated - Stochastic (just for specific customers)	- Use of customers who come to location of lockers as ODs for home delivery requests - Compensates customers if they act as ODs - Limited capacity for the lockers, fleet, and ODs - Sub-tours are not allowed	Minimize the cost of locker supply, OD compensation, and routing	- 40 to 106 customers - 3 to 5 lockers	Exact solve with CPLEX
[106]	- Capacitated	- Waiting time for the customers - Effect of naval services and ferries - Specified capacity for lockers	Minimize parcel waiting time	- 30 customers - 1 locker	Heuristic (GA)
[107]	- Capacitated - time windowed	- Parcel locker is an option for customers - Home delivery is limited to time windows - Multi-size lockers - Compensates customers for travel - Putting multiple parcels in one locker	Minimize the travel distance cost and compensation to customers	- 25, 50, 75 customers - 5 stations with different slots	Heuristic (adaptive large neighborhood search)
[108]	- Capacitated - Time windowed - Multiple fleet options	- Considers mobility of parcel lockers - Using an autonomous vehicle or a human - Limited customer travel distance - Limited capacities for vehicles - Minimum overlap between vehicle waiting time and customer expected time span - Parking space limitation	Minimize fixed & variable costs of lockers, and fixed and swapping costs of drives	- 5, 15, 30, 50 customers - 15 locker locations - 6 types of locker	Holistic MIP Tabu search
[109]	- Capacitated	- Total travel distances of fleet and customers - Limited and multiple fleets with small and medium capacities - Customer grouping based on lockers' locations.	Minimize travel distance cost from depots to virtual centers and distance cost to serve customers	- 65 customer zones - 2 depots - 19 lockers	Metaheuristic (customer clustering & TSP solving)

4.3. Sidekicks

Delivery by sidekicks in LMD is based on drones and real-time navigation technology [110]. Sidekick delivery uses main vehicles, usually trucks, which carry sidekicks and parcels to local areas, where the sidekicks complete delivery. Drones, or Unmanned Aerial Vehicles (UAVs) [51], have evolved from military applications tracing back to the 1930s. As their costs have substantially decreased, they have become readily available to the public and logistics companies in the last 10 years [111].

Sidekicks are often aerial drones with different capabilities and limitations in their carrying capacity, charging time, and coverage area. Sidekick delivery has many other names, such as drone-assisted delivery [112,113], multi-modal delivery [13], carrier-vehicle [12], joint-delivery systems [114], two-echelon delivery [115], and automated delivery robots [116]. Fleet synchronization and collaborative operations between main vehicles and drones are important. Among the 10 categories of two-echelon VRPs in [117], synchronization between two echelons applies to the sidekick delivery. In urban areas, other options, such as bikes and postal couriers, can also be sidekicks.

As shown in Figure 5, there are two different types of route in a sidekick delivery system. To plan the delivery with sidekicks, delivery nodes (customer locations and intermediate depots) are selected along with the routes of the main vehicles and sidekicks. For the delivery, the main vehicle departs from the main depot toward a series of intermediate depots (ID). Sidekicks then depart from the main vehicle at an intermediate depot to deliver the parcels to customers based on the pre-defined collaboration mode. There are three modes of vehicle–sidekick collaborations.

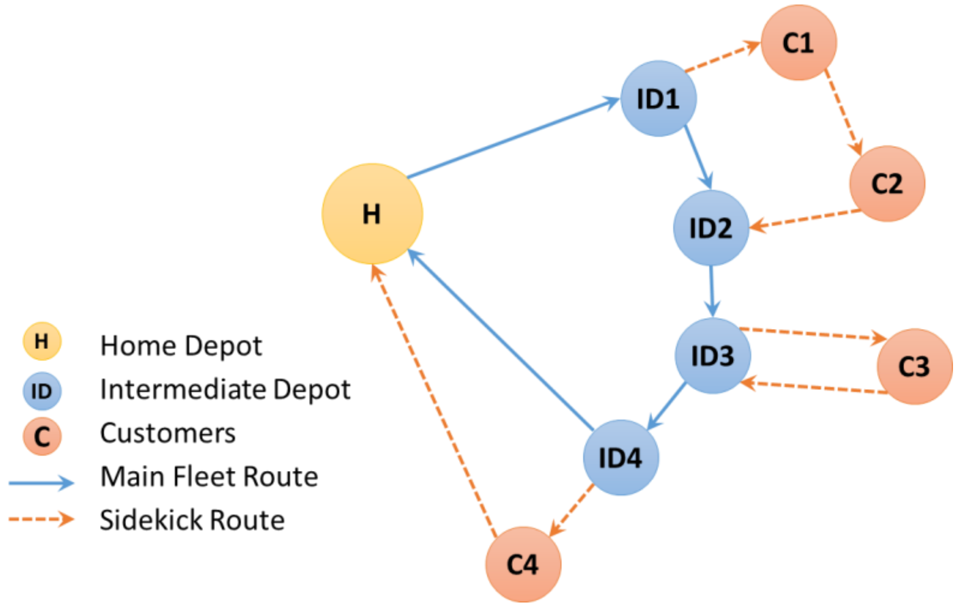

Figure 5. Delivery with sidekick in LMD.

- Mode 1: The main vehicle stays at an intermediate depot until the sidekicks finish their deliveries and return to it [112,115].
- Mode 2: Sidekicks leave the main vehicle at an intermediate depot and join the main vehicle at another intermediate depot. They return to the main depot together [39,118].
- Mode 3: Sidekicks leave the main vehicle at an intermediate depot for delivery and return to the main depot by themselves [113].

In the above cases, the main vehicle may deliver parcels by itself or just act as a carrier.

The literature on sidekicks in Table 3 shares common characteristics and notable differences in the nature of problems. Drones and main vehicles are commonly capacitated except for [119]. The battery life of the drones is also considered as a capacity limit in two references of [120,121]. Some papers on sidekick delivery consider time windows of the main vehicles and sidekicks for the collaboration between fleets [118,122–124]. Autonomous drones are the most common sidekicks, while [119] consider boats as sidekicks. The main vehicles are mostly human operated, except for [116,121]. Autonomous vehicles have the advantages of reduced labor cost and delivery time, increased work safety, and higher accessibility. No paper in this survey considers the dynamic and stochastic natures of the problems. The solution methods in sidekick deliveries vary widely, including mixed-integer programming (MIP) and heuristic search algorithms such as clustering-based genetic algorithms and adaptive large neighborhood algorithms.

Table 3. Literature on delivery using sidekicks.

Ref.	Problem Nature	Important Considerations	Objective(s)	Sample Size	Solution Method
[38]	- Capacitated	- Grouping the customers, then using a drone to reach them - Trucks as conveyors of drones - Drones' capacity affects customer grouping - Drones perform limited travel based on their charge	Minimize cost of distance traveled and waiting time of the main vehicle (AV)	- 100 or 500 customers - 10–100 drones - 8 delivery scenarios	Heuristic (greedy algorithm)
[39]	- Capacitated	- Main vehicle can deliver products - Main vehicles and sidekicks should join before returning to the depot - Two types of sidekick evaluated	Minimize the total truck arrival time	- 8 customer nodes - 1–2 trucks	Mixed-integer problem (MIP)
[50]	- Capacitated	- Customers clustered to intermediate depots - Two-echelon VRP: a van as main and drone as sidekick - Different vans can go to each intermediate depot - Sidekicks should join vans to come back to depot	Minimize total cost of travel and emission	- No. of main vehicles: 2, 4, 5, 10	Heuristic (GA and particle swarm)
[112]	- Capacitated	- Main vehicles and sidekicks should join before returning to the depot - Sidekicks can join the main vehicle in different intermediate depots - Setup time and retrieval time are considered. - Some customers' locations are defined as intermediate depots	Minimize the return time to depot	- 72 problem sets with 10 or 20 customers.	Heuristic (5-step algorithm)
[113]	- Capacitated	- Main vehicles and sidekicks come back independently. - Both trucks and sidekicks can deliver parcels - Sidekicks should meet a truck for each delivery and can ride them in some parts of the path - Intermediate depots can be met many times by trucks or sidekicks - Minimized the latest return to the depot	Minimize the largest return time	- 2 trucks, 1 drone, 10 customers	Mixed-integer problem (MIP) using some algorithm for upper bounding
[115]	- Capacitated	- There are limited main vehicles and sidekicks - Each intermediate depot is considered as a micro-hub - Capacity of vans and drones, as well as battery life limitations for drones, are considered - Each drone joins back to the van at the same location after delivery	Minimize delivery (volume) and emission (weight & speed) costs	- -	Heuristic (cluster-based artificial immune)

Table 3. *Cont.*

Ref.	Problem Nature	Important Considerations	Objective(s)	Sample Size	Solution Method
[116]	- Capacitated	- All vehicles are considered autonomous - Intermediate locations are fixed - Relative effects of distance and compartments	Minimize the cost of customer serving	- 4 depots - 100 customers	Statistical analytics on real data
[118]	- Time windowed - Capacitated	- Parcels will be delivered to/from mobile points (intermediate depots) - Bidirectional delivery (delivery and pick up) - A single parcel can be carried by drones - Runs executed within the required time	Minimize total delivery costs	- 10 customers - 1–3 main vehicles - 1 or 3 mobile points	Heuristic (dedicated GA)
[119]	- Capacitated - Multiple fleet options	- Ship/plane as main vehicle and boat/drone as sidekick - Drones can carry one or more parcels but have limited travel lengths - Main vehicles have no capacity limit - Main vehicles only serve as drone carriers	Minimize the total travel time of main vehicles and drones	- 10 to 200 customers	B&B and cone heuristic algorithm
[120]	- Capacitated	- Drones deliver parcels with limited flight length - Intermediate depots should be in one of the customers' locations, and drones can join trucks in various locations - Trucks also deliver parcels - The truck and drones leave and return to the depot together - No charging time by swapping batteries	Minimize the tour costs of trucks and drones	- 100 nodes - 1–2 depots	Heuristic (two steps of clustering and local search /dynamic programming
[121]	- Capacitated	- Drones (UAVs) can deliver one parcel - Flying length of drones is limited by the speed and parcel's weight - Autonomous trucks (UGVs) also deliver parcels - Waiting time is considered for both trucks and drones	Minimize the total travel time of UGV & UAV	- 10, 50, 100 nodes	Heuristic (two-stages of set covering and allocations)
[122]	- Capacitated - Time windowed	- Main vehicles are mobile during the departure and return of drones - Either main vehicle or drone can deliver parcels - Both types of vehicle should reach destinations at specific durations - Service time is considered - Waiting times are considered for both types	Minimize operation and waiting time costs for both vans & UAVs	- 100 customers	Heuristic (adaptive large neighborhood)

Table 3. *Cont.*

Ref.	Problem Nature	Important Considerations	Objective(s)	Sample Size	Solution Method
[123]	- Capacitated - Time windowed	- Both trucks and drones deliver parcels - Trucks have limited capacities - There are some depots as the start-points - Drones can join trucks in various locations - Trucks may wait for drones to reach them, but the reverse case is not allowed - Drones may independently return to the main depot after the last delivery. - Battery limitation is considered for drones	Minimize travel costs for trucks & UAVs	- 50, 100, 150, 200 customers	Heuristic (adaptive neighborhood)
[124]	- Capacitated - Time windowed	- Both trucks and drones can deliver parcels - Trucks and drones leave and return to the depot together - Both travel and waiting costs are considered	Minimize the transportation and waiting costs, minimize latest return time	- 10–100 customers - 600–25 k deliverables by drone	Heuristic (non-dominated sorting GA)
[125]	- Capacitated	- Drone may serve multiple targets per trip - Battery capacity is defined based on the load and speed of drones - Trucks just act as carriers - Tradeoff between the speed and fuel consumption is considered	Minimize total route time	- 25, 50 customers - 25, 50 depots	Flexible heuristic

4.4. Optional Points

Delivery to optional points quickly became popular in LMD as customers wanted timely and reliable deliveries. Customers provide multiple optional delivery points for pickup along with delivery time windows, and then the delivery plan chooses one of them. This delivery mode can reduce the number of visit locations, mitigate costly detours, and ultimately enhance customer satisfaction while simultaneously minimizing the environmental impact and overall distribution costs [126–129].

Delivery to an optional point is also named as covering options [130], covering locations [131], different delivery locations [127], and delivery options [132]. In general, as shown in Figure 6, customers specify their preferred delivery points. They can prioritize these points along with their possible time windows. Then, the delivery system determines the optimal route along with appropriate delivery nodes for customers, considering both customer preferences and the objectives of the delivery system.

Table 4 summarizes the literature on optional delivery points. While earlier research does not consider customers' preferences on delivery points [133], more recent papers offer customers a broader array of location choices and consider customers' preferences over the delivery points for route planning [129,132]. All papers in the table consider the capacity limit of the fleet. Many references introduce time-windowed constraints (80% of the papers) and consider additional service times at the delivery point to account for the temporal aspects of the deliveries. Multiple fleet options are not widely considered except in two papers [36,131]. Due to the complexity of the solution procedure, the dynamic nature of the problem and unpredictability of the influencing factors are not studied in the literature.

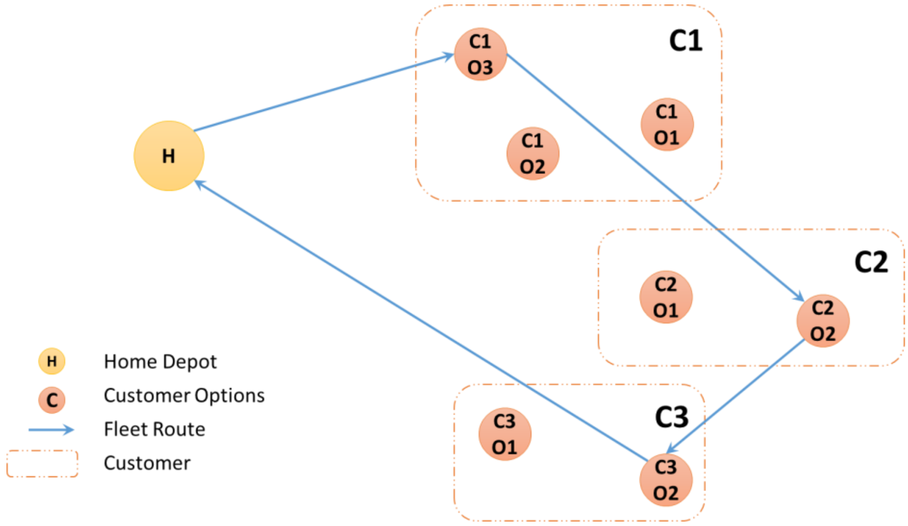

Figure 6. Delivery with optional points in LMD.

Table 4. Literature on delivery to optional points.

Ref.	Problem Nature	Important Considerations	Objectives	Sample Size	Solution Method
[36]	- Time window - Capacitated - Multiple fleet options	- Both vehicles and ODs can be used for deliveries - ODs just take parcels for home delivery - ODs and vehicles have limited capacity but can take more than one parcel based on their capacities - ODs should pick up the parcels from lockers, depots, or both before going to delivery - Time windows are considered for home deliveries - Service time is considered	Minimize the transportation cost and ODs payment	- 25 customers with 3 alternative nodes, and 25 ODs	Heuristic (adaptive large neighborhood search)
[126]	- Time windowed - Capacitated	- Each vehicle can deliver multiple parcels with limited capacity and time for each day - Optional points have location-dependent costs - Lockers, as optional points, have limited capacities - Service time is considered	Minimize the fixed & variable costs of vehicles, and location cost	- 8 stations for 892 urban customers - 18 stations for 1101 rural customers	Heuristic (adaptive large neighborhood search)
[127]	- Time windowed - Capacitated	- Customers can give multiple locations with priorities - Each location is available in a specific time window - Each vehicle delivers just a parcel and returns to depot	Minimize the cost as operation cost and customer priorities	- 10, 25, 50, 100 customers - 3 options for each customer	Comparative ad hoc heuristic

Table 4. *Cont.*

Ref.	Problem Nature	Important Considerations	Objectives	Sample Size	Solution Method
[128]	- Capacitated	- All options for delivery are automatic lockers - Lockers have limited capacities, but vehicles are big enough not to consider the capacity limit - All vehicles should go out and come back to the depot in a specific time span. The assigned parcels to each locker should be carried by at most one truck - Service time is considered for unloading at each locker	Minimize the fixed & variable costs of vehicles, and delivery penalty	- 500, 1000, 1500 parcels - 20, 40, 50 lockers	Heuristic (Tabu search & large neighborhood search)
[129]	- Capacitated	- Delivery options are self-pickup from lockers or home delivery - Customers' priorities are considered - Some lockers may be activated for delivery with some charges - Vehicles and locker stations have limited capacities	Minimize the fixed & variable costs of vehicles, maximize revenue	- 4 to 22 customers	Heuristic (MCDM & tailored mathematics)
[130]	- Capacitated	- Delivery to the nearest locker or customer's home - Home deliveries will be made from lockers with bikes - It is a combination of two separate problems: delivery to parcel locker and sidekick delivery - There are limited numbers of bikes and trucks	Minimize the traveling and connection costs	- -	Heuristic (adaptive large neighborhood search)
[132]	- Time windowed - Capacitated	- Service time is considered, as it affects delivery costs - Direct delivery or pickup facility are the two options - Direct delivery charges for customers - Parcels are delivered to home during a time window or sent to a pickup facility out of those times - Vehicles are limited by capacities and travel distances	Minimize the travel, vertical, service, and penalty costs	- 8–100 customers - 4–30 vehicles - 3–15 lockers	Heuristic (crowding differential evolution)

Table 4. *Cont.*

Ref.	Problem Nature	Important Considerations	Objectives	Sample Size	Solution Method
[134]	- Time windowed - Capacitated	- If a delivery cannot be made in a defined time window, it will be delivered to the other optional point - Customer priorities are considered for delivery points - Vehicles and lockers, as optional points, have limited capacities	Minimize the overall cost of selected routes	- 25–50 requests - Average of 1.5 (2) points of delivery	Exact solve (branch price and cut)
[135]	- Time windowed - Capacitated	- Vehicles have limited volumes - Deliveries should be made within the required time - Deliveries cannot be split between two vehicles - Customers can select to have home deliveries or pickup from lockers near them - For delivery to lockers, distributors should pay penalties	Minimize travel costs and penalty costs	- No. of items 20–20 k - No. of points 5–200 - No. of vehicles 2–20	Heuristic (hybrid CLP/MP)
[136]	- Stochastic - Capacitated - Time windowed	- Two delivery options: home and locker station. - Travel time is considered stochastic - Vehicles have limited capacities - Vehicles are allowed to use limited daily fuel and should come back to depot (GVRP) - Delivery should be made in a specific time span	Minimize the cost of travel time	- 30 to 300 customers - 30, 60, 90, 120 nodes	Heuristic (two-stage with large acceptance strategy

Most researchers use heuristic and metaheuristic approaches to solve the problems, except [134], which uses an exact solution approach. While the ideal concept of optional delivery points would allow customers to use any delivery location, all research assumes only one home address in addition to the pre-determined locker locations. An incentive system for the delivery to parcel lockers is suggested for higher customer satisfaction and reduced delivery costs [103].

5. Implications and Future Research

Last-mile delivery (LMD) is a new request for city logistics that resulted from changes in people's way of life and expectations along with the development of supporting technology of computation, communication, and automation. Continuing or even accelerated global urbanization requires continuous discussion and innovation on LMD.

5.1. Result Summary

This review research identified the problem nature, important considerations, and solution methods in the LMD literature under four categories: crowdshipping, parcel lockers, sidekick delivery, and optional delivery points.

- Crowdshipping utilizes sharing economy platforms for parcel delivery. Occasional drivers make their resources available for parcel delivery, offering cost-effective LMD solutions. This paradigm thrives on the efficiency and flexibility of the drivers. Despite the highly dynamic and stochastic nature of the problem, these issues have not been discussed in depth in the literature. Various matching mechanisms have been proposed.

- Delivery to parcel lockers offers a promising solution for LMD under urban logistics. Distributors place customers' parcels in lockers and notify them for pickup. Parcel lockers are expected to reduce cost and environmental hazards while enhancing security and privacy. The assignment of customers to parcel lockers is an important decision for the network design. Various configurations of lockers are proposed: stationary, temporary, and mobile lockers. Time window consideration for busy areas is another emerging aspect of profit generation and customer satisfaction.
- Delivery by using sidekicks is a specialized category within LMD, taking full advantage of automation, data communication, and sensor technologies. Main vehicles carry sidekicks (mostly aerial drones) and parcels to intermediate locations and deploy sidekicks, getting the benefit of multiple fleet modes. Careful coordination of vehicles is essential. Fleet capacity, battery life, and coverage limitation are considered important.
- Delivery to optional points invites customers to participate in the delivery planning; customers offer alternative drop locations for the shippers to choose from. This option reduces travel distance and distribution costs while enhancing customer satisfaction. The time window considerations are necessary but difficult during implementation. While some research emphasizes a tradeoff between logistics costs and customer satisfaction from nearby and timely pickup, most studies focus on the logistics costs.

This review research noticed that new VRP problems are being formulated to meet very practical and non-traditional needs in the logistics markets. They include not only the development of new communication and automation technology, but also cultural changes in customers' expectations and active involvement in the distribution process. The consideration of people engagement in logistics will continue to be an important consideration in LMD and conventional VRP as well.

5.2. Opportunities for Future Research

The literature survey suggests the need for the following future research in last-mile delivery studies.

1. Last-mile delivery deals with the B2C (business to customer) model of business, which involves a high level of dynamism: frequent updates of the problem environment, including customers' real-time order changes. The urban condition of delivery and the use of automated systems make the problem highly stochastic. Considerations of the dynamic and stochastic nature of the problem environments are needed for more robust logistics planning.
2. Not only autonomous aerial drones and unmanned trucks, but other possible autonomous devices have distinct characteristics of service: speed, size, geographical barriers, and coverage spans. The reliability of the units and local intelligence to cope with unexpected circumstances along with the improvement in the technical characteristics are challenging. The development and creative use of delivery modes will significantly enhance logistics efficiency, especially for urban logistics.
3. Most studies use simulated data. Rigorous integration of academic models and transactional data will improve the validity of the LMD models. Data gathering becomes more challenging, especially to reflect the diverse characteristics of different areas and people.
4. Comprehensive assessments of the environmental impact of various LMD approaches in all four categories of LMD configurations are needed to understand their sustainability implications. People understand that vehicles are responsible for a large portion of pollution. Different delivery approaches may help or harm the environment. Holistic considerations of pollutants generated by both customers and delivery

systems as well as pollution from energy production and the consumption life cycle are warranted.

5. Individuals are willing to help both the supply and demand sides of city logistics by serving as ODs (occasional driers) and providing optional delivery points. The development of various business models utilizing individuals and careful operational planning will improve both customer satisfaction and firms' profitability.
6. The routing problem in LMD is computationally difficult. Innovative ways of using big data analytics, AI-based procedures, heuristic/metaheuristic approaches, and exact solution approaches along with their hybrid methods are warranted.

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