Recent Developments in Location-Routing Problems

Deterministic multi-period, multi-echelon, and multi-objective problems

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Abstract

Location-routing problems (LRPs) simultaneously decide on the locations of facilities and routes originating from these facilities to serve a set of customers. This survey describes recent developments in deterministic LRPs, considering multiple planning periods, multiple echelons, or multiple objectives. We give detailed summaries of the papers, focusing on the central properties of the described problems and the proposed solution methods. We identify shortcomings in the current literature, provide recommendations to mitigate them, highlight application cases, and list promising topics for further research.

Keywords: location-routing problem, survey, multi-period, multi-echelon, multi-objective

1. Introduction

The goal of this survey is to provide a broad overview of the progress in the field of location-routing problems (LRPs) since the full-fledged surveys of Prodhon and Prins (2014), Drexl and Schneider (2015), and Schneider and Drexl (2017). We follow the idea of the latter two surveys to provide rather detailed descriptions of most of the included papers. To keep the amount of material manageable, we restrict the scope of the survey to deterministic LRPs. Cavagnini et al. (2025a) cover recent developments in single-period, single-echelon, and single-objective LRPs. In this follow-up survey, we focus on multi-period, multi-echelon, and multi-objective problems. To make this a standalone paper, we repeat the most important points from the introduction of Cavagnini et al. (2025a).

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Location-routing problems (LRPs) are a class of optimization problems in transportation and logistics that simultaneously optimize the following two key decisions.

1. Location decisions: choosing a set of facilities (e.g., warehouses or depots) to open. We use the term "facility" throughout the paper independently of the type of object to be located. The facilities are chosen from a set of potential locations to minimize the cost of satisfying customer demands or meeting other criteria, such as minimizing emissions or maximizing profit.

2. Routing decisions: devising routes for a fleet of vehicles to serve customers from the open facilities. These decisions involve choosing which customers each vehicle should visit and the sequence of these visits.

Our definition of what constitutes an LRP extends the guideline introduced by Drexl and Schneider (2015) and Schneider and Drexl (2017). We focus on problems in which the facilities are the starting and/or ending points of routes. Therefore, we exclude LRPs with intermediate stops for refueling, recharging, or reloading vehicles (see, e.g., Schiffer et al., 2019). Furthermore, we focus on problems in which the routing decisions do not implicitly determine location decisions. The problems we consider arise, for instance, if a cost is incurred for opening a facility, a limited number of facilities must be selected, or the facilities are capacitated. By contrast, when opening a facility incurs no cost, or one can open any number of uncapacitated facilities, solving a routing problem is sufficient to make the location decisions. For this reason, we do not consider, e.g., multi-depot vehicle routing problems (VRPs, Cordeau et al., 1997), VRPs with intermediate depots or refill points (Tarantilis et al., 2008), pickup-and-delivery problems with transshipments (Rais et al., 2014), and VRPs with trailers and transshipments (Drexl, 2012). Furthermore, we exclude problems without location decisions, such as vehicle routing-allocation (also known as median cycle) problems (Labbé et al., 2005) and Hamiltonian p-median problems (Branco and Dias Coelho, 1990). We also exclude problems with no routing decisions, such as pure facility location problems (Fernández and Landete, 2019) and service network design problems (Crainic and Kim, 2007). LRPs also share similarities with districting problems (see Kalcsics and Ríos-Mercado, 2019): the latter require allocating geographic zones to districts subject to balancing constraints, while LRPs involve assigning customers to facilities with (often) limited capacities. However, districting problems are beyond the scope of this survey.

LRPs have been studied for over 40 years and have received a lot of attention in the last 25 years. The more recent surveys include Nagy and Salhi (2007), Lopes Borges et al. (2013), Prodhon and Prins (2014), Drexl and Schneider (2015), Cuda et al. (2015), Albareda-Sambola and Rodríguez-Pereira

(2019), and Schneider and Drexl (2017). Recently, Mara et al. (2021) have presented a taxonomy of LRPs, and Marinakis (2025) provides an encyclopedia-style introduction to LRPs. Multi-objective problems have been reviewed by Tadaros and Migdalas (2022) and hub LRPs by Wandelt et al. (2025).

This survey is aimed at scientists and practitioners with prior experience in location routing. Nevertheless, to support readers new to the topic, Appendix A of the online companion presents mathematical models for what we consider standard variants of a multi-period and a multi-echelon LRP. The survey is restricted to published full-length papers (journal publications or conference proceedings) not already included in the surveys by Drexl and Schneider (2015) and Schneider and Drexl (2017) or in earlier surveys. Thus, we exclude PhD and Master's theses, working papers, and technical reports. Our goal is not to cover the entire literature but to point to the most important works according to our subjective opinion. To this end, we analyzed over 160 papers that fulfilled the above criteria and selected over 70 to be included in this survey. As mentioned above, our paper summaries are rather detailed because we want to provide the reader with an understanding of the papers' main modeling and algorithmic ideas. The lengths of the descriptions vary and depend on many factors such as the methodological complexity, novelty, and length of the original paper, as well as our own subjective opinion about its importance to the field.

In Section 2, we survey LRPs that comprise several planning periods. Section 3 describes multi-echelon LRPs, which are used to model multi-layer supply chains. Section 4 reviews LRPs that consider multiple (conflicting) objectives. In Section 5, we identify shortcomings in the current literature, provide recommendations to mitigate them, highlight application cases, and list promising topics for further research.

Finally, because some papers compare their proposed methods on standard instance sets, we briefly introduce these benchmark sets in Table 1. Irrespective of the names and abbreviations used previously in the literature (sometimes inconsistently), we refer to the instance sets using the name of the first author of the paper that introduced them to increase readability. The table lists all instance sets used in at least two papers. We collected the instances available online as of February 2025 in a GitHub repository to make them permanently and effortlessly available to the research community (Cavagnini et al., 2025b).

Name	Reference	Type	#instances	#depots	#facilities	#customers
Tuzun	Tuzun and Burke (1999)	Standard LRP[1]	36		10–20	100–200
Barreto	Barreto et al. (2007)	Standard LRP[1]	13		5–14	21–150
Prins	Prins et al. (2006)	Standard LRP[1]	30		5–10	20–200
Schneider	Schneider and Löffler (2019)	Standard LRP[1]	202		5–30	100–600
Prodhon	Prodhon and Prins (2008)	PLRP[2]	30		5–10	20–200
Prins2E	Nguyen et al. (2012)	2E-LRP[3]	30	1	5–10	20–200
Nguyen	Nguyen et al. (2012)	2E-LRP[3]	24	1	5–10	50–200
Contardo	Contardo et al. (2012)	2E-LRP[3]	93	2–5	3–20	8–200

Table 1: Benchmark instances. [1]See Section 2 of the survey by Cavagnini et al. (2025a). [2]Periodic location-routing problem, see Section 2.1. [3]2-echelon location-routing problem, see Section 3.1.

2. Multi-period LRPs

Multi-period LRPs (MPLRPs) make decisions for a planning horizon that consists of several periods. Periodic LRPs (PLRPs) are a special case of MPLRPs that include the characteristics of periodic VRPs in an LRP context (for a mathematical formulation, see Appendix A.1 in the online companion). In PLRPs, for each customer, a set of potential visiting patterns is given. A visiting pattern specifies on which days a customer is served and how much of its total demand is covered on each of these days, e.g., Monday (50%)–Wednesday (25%)–Friday (25%). PLRPs decide the facility configuration (valid over all periods), which visiting pattern to use for each customer, and which routes to execute on each day of the planning period. The objective is to minimize the total costs consisting of facility opening costs, vehicle fixed costs, and routing costs. The vehicle fixed costs for each facility are determined by the maximum number of routes operated from the facility on any day of the planning period.

We start with a description of the literature on PLRPs in Section 2.1, other MPLRPs are discussed in Section 2.2. Table 2 summarizes the main characteristics of the surveyed papers on MPLRPs. The columns of the table show, in order, the paper, the elements of novelty, whether the paper includes a mathematical formulation of the problem, the solution approach, and whether the contribution is primarily methodological or application-oriented.

2.1. Periodic LRPs

To enhance readability, we categorize the papers based on whether they address the standard PLRP (Section 2.1.1) or a PLRP variant (Section 2.1.2).

2.1.1. The standard PLRP

Hemmelmayr (2015) proposes four variants of a large neighborhood search (LNS) to address the standard PLRP. All variants generate the initial solution using a savings-based construction heuristic (Clarke and Wright, 1964), improve promising solutions with a local search (LS), and accept solutions based on a simulated annealing (SA) criterion. Three types of destroy operators exist: (1) operators modifying the facility configuration, (2) operators changing the visiting pattern, and (3) operators modifying vehicle routes. Insertion is greedy, and only one type of operator exists. The hierarchical variant of the LNS uses type (1) operators on the first level, then fixes the facility configuration and improves the solution for several second-level iterations using only type (2) and (3) operators. In the sequential variant, all types of destroy operators are used on the same level. The third variant parallelizes the second level of the hierarchical variant, and the fourth variant is a parallel version of the sequential one. The four variants are benchmarked against the previously best-performing method of Pirkwieser (2012) on the Prodhon instances: all four variants achieve better solution quality but require longer runtimes, and a fifth variant (the parallel sequential version with a reduced number of iterations) dominates the comparison method. Furthermore, the non-hierarchical variants dominate their hierarchical counterparts, and the parallel variants dominate their non-parallel counterparts.

2.1.2. Variants of the PLRP

The first group of contributions that we survey consists of papers that provide generalized or unified modeling and solution approaches for variants of the PLRP. Koç (2016) proposes an adaptive large neighborhood search (ALNS) to solve three variants of the PLRP: the homogeneous PLRP with time windows and the heterogeneous PLRP both with and without time windows. The key feature of their ALNS is a post-destroy-and-repair procedure that improves solutions by adjusting customer visit days. On the Prodhon standard PLRP set, the solution quality of their ALNS fluctuates across instances, but many new best known solutions (BKSs) compared to Hemmelmayr (2015) are found. The author also solves instances of the fleet size and mix location-routing problem with time windows (see Section 5 of the survey by Cavagnini et al., 2025a), which is the single-period variant of the heterogeneous PLRP with time windows. Results show that their heuristic achieves competitive performance to the algorithm of Koç et al. (2016), with average gaps below 0.31% over various instance sets.

The second group of contributions addresses PLRPs arising from a specific application context. Hemmelmayr et al. (2016) study a PLRP motivated by collaborative recycling efforts among hunger relief agencies. The problem involves determining facility locations, their capacities, visiting patterns, and associated routes to collect cardboard waste from multiple agencies. Facilities must be selected from a subset of the agencies; the other agencies have their cardboard waste collected from those selected as facilities. Facilities are associated with fixed costs and can have different capacities, which must be sufficient to store the waste collected in the entire planning period. Smaller facilities have lower fixed costs and incur variable costs depending on the amount of cardboard they collect (this is the cost of recycling the collected cardboard). Larger facilities have higher fixed costs but generate revenue depending on the amount of cardboard collected (due to compressing the boxes using a baler and selling the compressed cardboard). Different types of vehicles are available, each with a different capacity and cost. At most one vehicle can be used at each facility. Transport costs include vehicle fixed costs and vehicle-type-dependent routing costs. Therefore, decisions involve which facilities to open, their capacity, which agencies are assigned to which facility (this assignment stays consistent over the planning horizon), what type of vehicle to use (over the entire planning horizon), and transport routes and visit patterns to collect the waste from the agencies. The available visiting patterns for each customer are not restricted to a specific visiting frequency. The authors add an adaptive mechanism to the LNS of Hemmelmayr (2015) and extend the algorithm to the described problem. The resulting ALNS algorithm finds better solutions than CPLEX in a shorter time for instances with five or eight agencies. No comparison is possible for larger instances because CPLEX cannot find any feasible solution within three hours. The authors also perform a sensitivity analysis by changing key instance parameters. One interesting finding is that instances with small vehicles see larger improvements in routing costs when (a) more visiting patterns are available and (b) more potential facility locations are available, even when the total number of open facilities does not change. Moreover, further cost reductions are possible when relaxing operational assumptions, such as allowing to have multiple trips with the same vehicle, to change the vehicle type over the planning horizon, or to change the customer-facility assignment. Finally, the authors present a case study in which they explore the possibility of expanding an existing collaboration network of six agencies to 34 agencies. The results show that excluding some agencies from the network is often optimal, i.e., some agencies should take care of recycling their cardboard and neither send it to other agencies nor receive it from them. Furthermore, limiting the potential facility locations to the initial six agencies is only slightly suboptimal compared to allowing all 34 agencies to act as a facility but presents fewer real-life implementation challenges.

Gläser (2022) introduces a waste collection problem combining a door-to-door “pickup system”, in which vehicles collect waste from individual households, and a "bring system", in which residents deposit waste at central collection sites. The author proposes a mixed system that allows some households to be served by the pickup system while others use the bring system. The problem involves deciding which households should use which system, where to locate central collection sites, how to assign households to these sites, what bin capacities to use, and how to route vehicles to collect waste. The objective is to minimize the total costs, including facility opening costs, equipment costs, routing costs, and compensation payments for residents who must travel to central collection sites. The problem extends the PLRP because the pickup system vehicles collect waste with a given frequency pattern, which must also be determined. If a route is assigned a lower frequency, the households it visits must be equipped with bins with a larger capacity. The author introduces a compact mixed-integer program (MIP) formulation and develops an ALNS algorithm that outperforms CPLEX using the mathematical formulation. Furthermore, the ALNS finds better solutions than a variable neighborhood search (VNS) heuristic introduced by Gläser and Stücken (2021) to tackle a related problem, which can be considered a special case in which all customers are served through the bring system. Computational experiments show that using higher distance limits for residents to reach collection sites can reduce total costs by 32–63% and routing costs by 53–77% on average. On the other hand, doubling the maximum route length for pickup vehicles leads to a higher share of households served with the pickup system and reduces total costs by up to 29%. The results also demonstrate that the share of customers served by the pickup system decreases as the number of customers increases, suggesting that a pure bring system becomes more economical at larger scales. The author concludes that mixed systems can be particularly valuable during transitions from pickup to bring systems, allowing gradual infrastructure investment while maintaining service levels.

PLRPs have also been studied in other application fields like maritime supply chains (Wang et al., 2023) or oil/gas supply chains (Amiri et al., 2019).

2.2. Other multi-period LRPs

MPLRPs differ from PLRPs in that they explicitly model customer demand (and possibly other parameters) as time-dependent over a sequence of distinct periods, rather than assuming a cyclic demand structure. As a result, the explicit temporal demand representation in MPLRPs may create the need for inventory decisions that are often incorporated in the MPLRP literature. Moreover, in MPLRPs, location and routing decisions are planned across periods and may change over time, in contrast to PLRPs, in which the selected facility configuration is kept fixed for the entire planning horizon. In Section 2.2.1, we discuss MPLRPs in which the location decisions may change over time.

Section 2.2.2 describes MPLRPs in which the location decisions remain fixed for the entire time horizon.

2.2.1. MPLRPs with time-dependent facility location decisions

Darvish et al. (2019) study a MPLRP with inventory decisions in a two-echelon distribution network that is faced by suppliers who can purchase on-demand warehousing services. In the first echelon, capacitated vehicles transport goods from a single depot to potential facilities via direct trips. In the second echelon, each rented facility has a single vehicle (identical capacity, one route per day) to deliver the goods to the customers via routes. Facility decisions are made daily. If a facility is rented on consecutive days, it can hold inventory up to a given capacity. Otherwise, any remaining inventory is lost. Customers place orders daily, each requiring fulfillment in a single delivery from any facility within a given due date. Deliveries beyond the due date incur penalties per unit and per day of delay. The decisions include selecting which facilities to rent each day, choosing the fulfillment day for each customer order, allocating customer orders to facilities, and determining the second-echelon routes. The objective is to minimize the total cost, which includes the fixed renting costs of the facilities, shipping costs from the supplier to facilities, routing costs from facilities to customers, and penalties for late fulfillment. The authors present a mathematical model and strengthen it with valid inequalities. They propose an exact method using two algorithms run in parallel: a pure branch-and-bound (B&B) algorithm and an enhanced B&B, which periodically receives primal solutions from the pure one and attempts to improve them using an LS procedure. Interestingly, the improved solutions obtained by the enhanced B&B are not passed back to the pure B&B. After completing the LS procedure, the enhanced algorithm continues exploring the B&B tree and running the LS on each new improving integer solution. If no improving solution is found within a time limit, the enhanced B&B is reinitiated with a solution from the pure B&B. The LS sequentially explores five neighborhoods, each defined by fixing certain variables to the values they take in the incumbent solution while keeping the rest free. The authors generate a new set of instances and compare their method with the pure B&B. The results show that the proposed method outperforms the pure B&B regarding optimality gaps, runtime, and number of instances solved to optimality. The authors evaluate the impact of network design and due date flexibility on total costs. For network design flexibility, they compare their model with a scenario in which the facilities selected on the first day remain unchanged throughout the planning horizon. For due date flexibility, they examine three scenarios: orders must be fulfilled within the day of the issuing of the order, the following day, and within two days. Their findings reveal that combining both types of flexibility leads to total cost savings of up to 30%.

Aloullal et al. (2023) consider an MPLRP, in which, in each period, a subset of nodes can be added as capacitated hubs, and connecting edges to other hubs can be opened. Once opened, hubs and edges remain operational for the remainder of the planning horizon, enabling a gradual setup of the distribution system over time (i.e., an increasing number of facilities may be opened over time). Nodes send and receive goods to/from each other in each period. In each period, each non-hub node is allocated to a single hub, and allocations are allowed to change between periods as new hubs become operational. Each hub operates an uncapacitated vehicle to serve the pickup and delivery requests of their allocated nodes. The decisions in each period include selecting which hubs to open, establishing inter-hub edges, assigning nodes to hubs, determining the amounts of flow from each node routed through hubs, and making routing decisions. The objective is to minimize the total cost over the entire planning horizon, which consists of fixed costs for setting up hubs and hub edges, operational costs per unit of flow entering hubs (both for satisfying demands of associated nodes and for transshipment to other hubs), routing costs, and discounted transportation costs between hubs that reflect economies of scale achieved through consolidation. All costs are time-dependent, and no inventory costs are considered. The authors develop a mathematical model and propose a four-phase matheuristic combining relax-and-fix strategies, variable neighborhood descent, and local branching. The first phase identifies promising hubs by solving a relaxed assignment-based model, iteratively refining the candidate set. The second phase determines the minimum number of hubs required for feasibility, incrementally increasing the upper bound until a valid solution is found. If infeasibility persists, the candidate set is expanded. The third phase improves the last-period solution using variable neighborhood descent and local branching, exploring progressively larger neighborhoods. The fourth phase extends the last-period solution backward to form a complete multi-period solution, with two versions differing in how they handle network design and routing constraints. Version 1 fixes the network design decisions (hub locations and allocations) regarding the last period and includes routing constraints for all periods. Moving iteratively backward in time, it solves a relaxed model for each period in which: (a) variables related to subsequent periods are fixed, (b) variables related to the current period are free and integer, and (c) variables related to previous periods are free and relaxed to be continuous. Version 2 decouples network design and routing decisions. It fixes only the routing variables of the following periods and includes integer routing variables only for the current period and relaxed continuous variables for the previous periods. The authors evaluate their approach on time-dependent extensions of the Australian Post dataset (Ernst and Krishnamoorthy, 1996), comparing it to the CPLEX solver. The matheuristic quickly finds optimal or near-optimal solutions for small instances and outperforms CPLEX on medium and large instances, with Version 2 proving superior. Tests on a problem variant in which transfer and routing costs depend only on distance result in more geographically dispersed hubs. A comparison with a multi-period model in which all decisions are taken in the first period and no incremental hub opening is possible shows that incorporating time-dependent decisions yields an average cost savings of 3.11%.

Wang and Nie (2023) study an MPLRP with inventory arising from a humanitarian relief application. In a post-disaster context, both the potential facilities and the actual demand levels change dynamically over time. Therefore, the facility location decisions are temporary and period-specific. Inventory carryover is only allowed across periods in which a facility stays open. The objective includes both cost and equity measures to guarantee that supplies are delivered efficiently and fairly.

2.2.2. MPLRPs with location decisions fixed over time

Zhang et al. (2014) develop a hybrid heuristic for an MPLRP variant with inventory decisions, where customer demands can be satisfied in periods before demand occurs (then incurring holding costs) or in the actual demand period. Their method achieves mixed results on the standard LRP Barreto instances, the inventory VRP instances of Qin et al. (2014), and also in a comparison with CPLEX on newly generated instances of the introduced problem. Karakostas et al. (2019) extend the MPLRP of Zhang et al. (2014) to a two-echelon setting. The authors propose a VNS metaheuristic that achieves better results for the single-echelon instances of Zhang et al. (2014) but requires higher runtimes. Saragih et al. (2019) propose an SA-based heuristic for solving an MPLRP with inventory in a three-echelon supply chain network that consists of a single supplier, multiple depots, and multiple retailers. González et al. (2023) introduce an MPLRP for deploying mobile clinics (i.e., vehicles) that provide healthcare services to remote villages. The problem involves selecting which villages to serve and which facilities to open at the beginning of the time horizon, and how to route mobile clinics over multiple time periods. The goal is to maximize health benefits across the planning horizon. These benefits are measured through village coverage and the continuity of care for each patient, captured as the proportion of patients in a village receiving repeated treatments over time. Limited resources constrain both the set of villages that can be served and the achievable levels of continuity. No inventory costs are considered.

Paper	**Novelty**	**F?**	**Approach**	**Contribution**
Hemmelmayr (2015)	State-of-the art heuristic for the standard PLRP with problem-specific destroy operators.	No	Heuristic (LNS)	Methodological
Koç (2016)	Three PLRP variants (homogeneous PLRP with time windows, heterogeneous PLRP with and without time windows), derivation of a post-destroy-and-repair procedure to adjust customer visit days.	Yes	Heuristic (ALNS)	Application-oriented
Hemmelmayr et al. (2016)	PLRP variant (arising from a specific application) with facility dimension decision, facility variable costs and revenues, mixed vehicle fleet, and vehicle-type dependent routing costs; design of an effective heuristic, derivation of practical insights.	Yes	Heuristic (ALNS)	Application-oriented and methodological
Gläser (2022)	PLRP variant (arising from a specific application) with decision on which customers must be visited and which customers must bring waste to collection sites on their own, decision on bin capacities, equipment costs, and compensation payments for non-visited customers; design of a heuristic (state-of-the-art method for the special case of the problem studied by Gläser and Stücken, 2021).	Yes	Heuristic (ALNS)	Application-oriented and methodological
Wang et al. (2023)	PLRP variant (arising from a specific application) with inventory decisions and costs, facility capacity decisions, first- and second-echelon routes, vehicle-type decision.	Yes	Heuristic (memetic algorithm)	Application-oriented
Amiri et al. (2019)	PLRP variant (arising from a specific application) with two echelons and time windows, decision on fleet size and composition.	Yes	Heuristic (Lagrangian decomposition-based heuristic)	Application-oriented
Darvish et al. (2019)	MPLRP with two echelons, facility location decisions are done daily, inventory decisions, and penalties for late order fulfillment; derivation of insights on network design flexibility and due date flexibility.	Yes	Exact (B&B and enhanced B&B with LS procedure run in parallel)	Application-oriented
Aloullal et al. (2023)	MPLRP with pickup and delivery, facilities can be opened over time but cannot be closed, transportation between facilities is allowed, customer-facility allocations may change over time, inter-hub edge costs, and discounted transportation costs between facilities.	Yes	Heuristic (relax-and-fix, variable neighborhood descent, local branching)	Application-oriented
Wang and Nie (2023)	MPLRP with time-dependent facility location decisions and inventory decisions.	Yes	Exact (Gurobi)	Application-oriented
Zhang et al. (2014)	MPLRP in which customer demands can be satisfied before demand occurs, and holding costs occur.	Yes	Heuristic (granular tabu search + SA + post-optimization procedure)	Application-oriented
Karakostas et al. (2019)	Variant of the MPLRP of Zhang et al. (2014) with a two-echelon setting; state-of-the-art heuristic for the multi- and the single-echelon variant.		Heuristic (VNS)	Application-oriented and methodological
Saragih et al. (2019)	MPLRP with three-echelon setting and inventory decisions.	Yes	Heuristic (SA)	Application-oriented
González et al. (2023)	MPLRP with profits and partial coverage allowed.	Yes	Exact (CPLEX)	Application-oriented

Table 2: Summary of reviewed papers for the multi-period LRP.

3. Multi-echelon location-routing problems

Multi-echelon LRPs (MELRPs) are used to model multi-layer supply chains. In the common two-echelon setting, the first echelon involves goods traveling from a central depot to a facility. There, they are moved into a different vehicle and, in the second echelon, they are delivered to customers. In this arrangement, the location decisions are at least concerned with the facilities. In an n-echelon problem, there are $n-1$ layers of facilities, and goods are transshipped at least $n-1$ times during their journey.

Because echelon characteristics are closely associated with their distance from the customers, we denote echelons by their proximity to the customers rather than sequentially. In other words, we refer to the echelon closest to (farthest from) the customers and not to the first (last) echelon. For example, the echelon farthest from the customers is the first in problems in which goods are distributed and the last in problems in which goods are collected from customers. Some MELRPs involve both picking up and delivering goods. If this characteristic is predominant and heavily influences the modeling and algorithmic approaches, the corresponding problems are described in Section 3 of the survey by Cavagnini et al. (2025a).

We categorize MELRPs according to two criteria.

The number of echelons: Most of the literature addresses the two-echelon case (for a mathematical formulation, see Appendix A.2 in the online companion), but a few works consider three- or even four-echelon problems. We discuss problems with two echelons in Section 3.1 and problems with three or more echelons in Section 3.2.

How goods are transported: At each echelon, goods are transported on multi-stop routes or by direct shipments. Although various combinations are possible, the most common choices are: (i) multi-stop routes in all echelons or (ii) direct shipments in the echelon farthest from the customers and multi-stop routes in the echelon closest to the customers.

Another important feature of MELRPs is the extent of location decisions. In typical goods distribution settings, shipments start at one or more depots, go through one or more echelons of facilities, and finally reach the customers. Some works only consider the problem of locating the facilities while others also make decisions on depot locations. Finally, MELRPs also differ in the role of the located facilities. Facilities are usually uncapacitated transshipment centers. Some authors explicitly model facility capacities and temporal synchronization or allow goods to be processed at facilities.

Figure 1 shows two exemplary versions of a two-echelon LRP, which highlight how the above features can impact the problem definition and the corresponding solution. The figure on the left shows a problem with a single depot (depicted with a triangle) in which the location decisions only affect facilities (squares). The depot is connected to the facilities via direct shipments (thick solid lines), and customers (circles) are served from the facilities using multi-stop routes (dotted lines). Additionally, direct multi-stop routes from the depot to the customers (dashed lines) are allowed. Replacing the direct shipment between the depot and the facilities with multi-stop routes, we end up with the characteristics that define the problem introduced by Nguyen et al. (2012). The Prins2E and Nguyen instances are based on this problem definition. The figure on the right shows a problem with location decisions concerning both depots and facilities. Multi-stop routes are present in both echelons (thick dashed lines for depot-facility routes and dotted lines for facility-customer routes), and customers cannot be served directly from a depot. This is the problem introduced by Contardo et al. (2012). The Contardo instances are based on this problem definition.

Table 3 summarizes the main characteristics of the surveyed papers on MELRPs.

3.1. Two-echelon location-routing problems

As mentioned above, most two-echelon LRPs (2ELRPs) assume multi-stop routes in the echelon closest to the customers. Within this category, we describe problems with multi-stop routes (Section 3.1.1) or direct shipments (Section 3.1.2) in the echelon farthest from the customers. Some problems instead consider direct shipments in the echelon closest to the customers (Section 3.1.3). Finally, in large-scale problems, routing costs in the echelon closest to the customers are sometimes approximated (Section 3.1.4).

3.1.1. Multi-stop routes in both echelons

Almost all the reviewed papers present heuristic or matheuristic approaches; the few exact solution methods proposed in recent years solve problems heavily characterized by application-dependent features. We first describe the papers on heuristics. Among them, only two papers present extensions of known 2ELRP variants, allowing to benchmark against existing algorithms originally designed for the 2ELRP. We start with these two papers.

Martins Santos Gandra et al. (2021) consider a 2ELRP with two-dimensional vehicle loading constraints. Parcels to be delivered have a given width and length and must be packed into a rectangular truck without overlap. This restriction applies to routes in both echelons. Parcels are unloaded from the back of the truck, and placing a parcel delivered later in front of another one

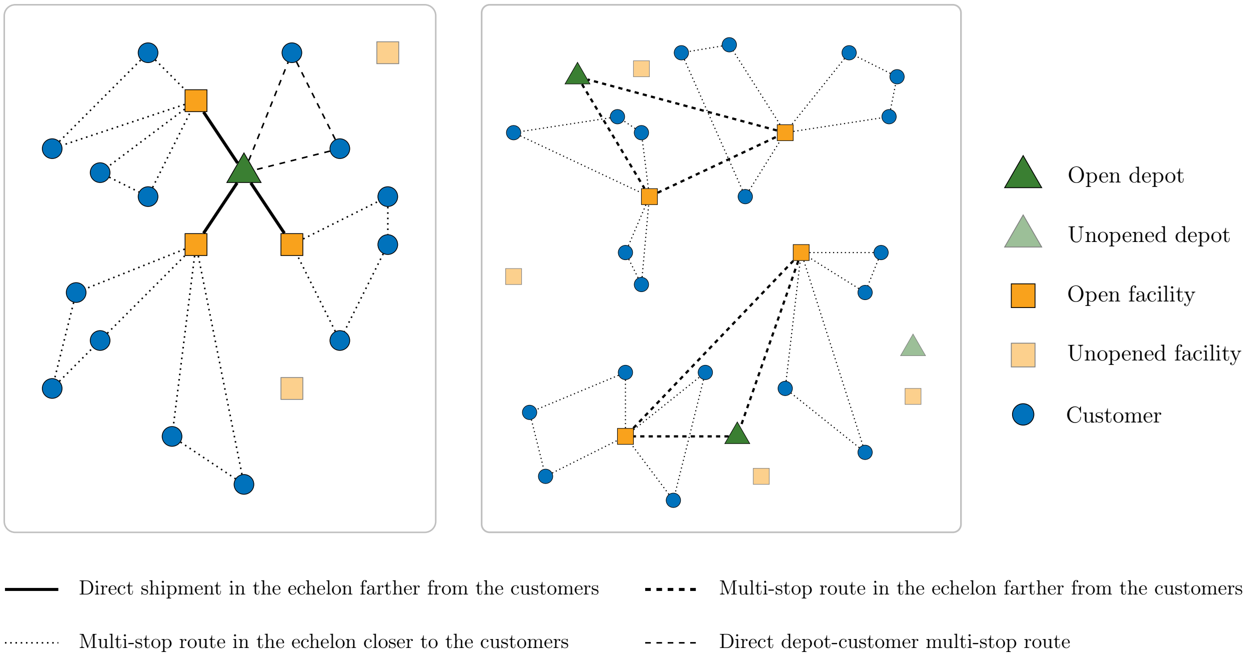

Figure 1: Two exemplary versions of the 2ELRP.

delivered earlier is undesirable. Therefore, and only for the echelon closest to the customers, the service time increases if a parcel blocks the unloading of another one. The authors propose an iterated local search (ILS) algorithm in which a perturbation corresponds to changing the set of open facilities. After the perturbation, a local search (i) first builds routes in the echelon closest to the customers using a ruin-and-recreate mechanism, (ii) generates the corresponding load plans, and (iii) selects suitable routes in the echelon farthest from the customers from a precomputed cache created by enumeration. The authors test the algorithm on a new set of instances derived from real data and apply their approach to the standard 2ELRP as defined by Nguyen et al. (2012), modifying the ILS algorithm to ignore loading plans. On the PRINS2E, NGUYEN, and CONTARDO instance sets, they obtain average gaps to the BKSs of at most 0.32%, while matching 75% of the BKSs and finding 16 new ones.

In the second work, motivated by scenarios in which good transportation is outsourced or crowdsourced, Pichka et al. (2018) study the two-echelon open LRP (2E-OLRP) in which vehicles in both echelons need not end their routes at the start location. In the echelon farthest from the customers (the first echelon), vehicles start at a single depot, visit a number of facilities, and end their trip at the last visited facility. Analogously, in the echelon closest to the customers (the second echelon), vehicles start at a facility, visit a subset of customers, and end their route at the last visited customer. The authors assume that (i) vehicles distribute a single commodity, (ii) each facility is visited by only one first-echelon vehicle and each customer by only one second-echelon vehicle, and (iii) there are no time windows, and, therefore, no need to synchronize first- and second-echelon tours at facilities. Using these assumptions, the authors propose three flow-based mixed-integer compact formulations and a heuristic. The heuristic first tries to determine which facilities to open and how to route first-echelon vehicles using a simulated annealing (SA) algorithm. For each promising partial solution found by SA, a second SA algorithm tries to complete it by solving the second-echelon routing problem. The authors test their approaches both on the PRINS2E instances, which are valid 2E-OLRP instances, and on new instances generated from the BARRETO and TUZUN standard LRP instances. The heuristic matches the optimal solutions of CPLEX on small instances and is competitive with CPLEX on medium-sized ones. The authors also modify their heuristic to solve the 2ELRP defined by Contardo et al. (2012). In this case, however, the heuristic is not competitive with the method of Contardo et al. (2012).

The other papers on heuristics assume very diverse problem settings, including bounds on total travel times and waiting times at facilities (Chen et al., 2024; Yang and Zeng, 2018), temporal synchronization (Agnimo et al., 2023; Mirhedayatian et al., 2019; Sutrisno and Yang, 2023), multimodality in the echelons farthest (Fazayeli et al., 2017) and closest (Zhou et al., 2017) to the customers, and coexisting parallel pickup and delivery networks (Lv et al., 2022).

The heuristic of Arnold and Sörensen (2021) described in Section 2 of the survey by Cavagnini et al. (2025a) is designed to solve the single-echelon standard LRP, but the authors also adapt it to solve 2ELRPs. In a two-echelon setting, the authors use the heuristic to build routes for the echelon closest to the customers and generalize the fixed costs incurred when opening a set of facilities to include an estimate of the routing costs in the echelon farthest from the customers. They estimate these costs for a given set of facilities using the Clarke and Wright savings heuristic. Their method outperforms the LNS of Breunig et al. (2016), the VNS of Schwengerer et al. (2012), and the ALNS of Contardo et al. (2012) producing lower average gaps in shorter computing times.

With respect to exact solution methods, Tian and Hu (2023) use a branch-and-price (B&P) algorithm to solve a problem in which facilities are selected among customers and become transshipment points between trucks (which serve the first echelon) and drones (which serve the second echelon). Soto-Mendoza et al. (2023) describe a branch-and-cut (B&C) algorithm for a problem in which agricultural byproducts are picked up in the first echelon, processed into snacks at facilities, and delivered to public schools in the second echelon.

3.1.2. Multi-stop routes in the echelon closest to customers, direct shipments in the echelon farthest from the customers

Problems featuring direct shipments in the echelon farthest from the customers emphasize the role of facilities as transshipment centers. In delivery problems, for example, full-truckload shipments from the depots arrive at facilities on large vehicles and are transshipped to smaller vehicles for final distribution.

Such systems have often been modeled as one-to-many in the literature, i.e., many customers receive goods from a single depot. Modern online retailers, however, increasingly use many-to-many systems. Their inventory is distributed across multiple depots, and when a customer orders items located at different depots, the order must first be consolidated at a facility. Boccia et al. (2018) model this setting as a multi-commodity 2ELRP in which flows from the depots to the customers are "intercepted" by the facilities. The authors first assume that all commodities travel along a direct path from the depot to the customer, and then they open facilities to intercept nearby paths. The resulting solution includes direct shipments between the depots and the facilities and multi-stop routes starting at the facilities and distributing the goods to the customers. The authors devise a binary integer program and strengthen it with constraints separated using a B&C algorithm. They can solve instances with up to 40 customers. A key tool to improve the results of the B&C algorithm is a primal heuristic used after solving the root node, which uses a rounding of the solution of the continuous relaxation of the model.

Zhao et al. (2017) study a problem in which facilities are used to consolidate the demand of multiple retailers. This topic is timely because municipal, retailer-agnostic facilities (often called urban consolidation centers) are an emerging practice in large cities to reduce the environmental externalities of last-mile delivery. The study of Giampodaki et al. (2023), which identifies 82 European cities that implemented this model, supports the practical relevance of this problem. Deineko et al. (2025) study a similar system and approximate routing costs in the echelon closest to the customers with a microscopic traffic simulation framework. Ozyavas et al. (2025) describe a system in which facilities are parcel lockers, and the proximity of an open locker to an area determines the percentage of customers living in the area who autonomously collect the parcels (thus not requiring a vehicle visit), while the remaining customers are visited by cargo bikes. The authors devise a B&P algorithm that solves instances with up to 35 customers within six hours.

Some authors study hybrid systems in which direct shipments from depots to customers are also allowed. For example, Song and Wu (2023) study such a system in the context of perishable grocery delivery. Consolidation is also important in settings in which goods originate from customers and must be bundled at facilities to be shipped economically toward their final destination. Typical applications include waste collection (Asgari et al., 2017; Cao et al., 2021; Ghezavati and Beigi, 2016) and customer returns (Sheriff et al., 2014).

3.1.3. Direct shipments in the echelon closest to the customers

Direct shipments in the echelon closest to the customers can be the only way to serve a customer, or they can co-exist with multi-stop routes. However, all works considering the latter case assume that the routes start and end at the depot rather than at facilities.

In the following works, goods are transported via direct trips between facilities and customers. Lu et al. (2019) consider a full-truckload distribution problem along the Europe-China "new silk road". Aydemir-Karadag (2018) studies a hazardous waste disposal network in which material handling is the dominating cost, thus justifying approximating routing costs by assuming direct shipments. Solak et al. (2014) describe a problem in nonprofit food distribution in which customers travel to pick up their food via direct trips. In the papers of Vidović et al. (2016) and Han et al. (2024), households dispose of their domestic trash at collection points (a direct trip) later visited by a truck (a multi-stop route). In the paper of He and Wang (2023), employees move on foot to collect abandoned shared bikes and bring them to collection points (a direct trip). Trucks visit these collection points to pick up the bikes (a multi-stop route).

The setting in which customers can be served either from open collection points or using multi-stop routes from the depot is investigated in the context of e-commerce (Wang et al., 2022), medicine distribution (Veenstra et al., 2018), and waste collection (Gläser, 2022, for more details see Section 2.1).

3.1.4. Surrogate routing costs in the echelon closest to the customers

When routing is not the primary operational decision or when problem scale makes explicit routing intractable, routing cost surrogates can replace explicit second-echelon route optimization. These surrogates may appear, e.g., as approximate cost terms used to rank location and allocation decisions. This idea is well-aligned with "cluster-first, route-second" planning and with distribution districting problems (Kalcsics and Ríos-Mercado, 2019), in which districts must satisfy workload constraints even though day-to-day tours are not necessarily optimized in the strategic model. Routing cost surrogates are also attractive when routing optimality is less important (i) because routing costs are shifted to customers (e.g., when locating pickup lockers the customers must travel to), (ii) because there are strong regulations governing daily operations (e.g., in public services such as waste collection or mail distribution), or (iii) because other factors such as robustness and predictability influence operations more than the mere routing costs.

Existing works use three different approaches to compute route surrogate costs: (i) assignment-based surrogates that convert routing into modified customer-facility "distances", often yielding k-median-like models, (ii) closed-form or continuous approximations (see, e.g., Franceschetti et al., 2017) that estimate route length as a function of demand density, vehicle characteristics, and service times, (iii) simulation- or data-driven surrogates that approximate route performance under realistic traffic or operational rules. As seen in Section 3.1.2, Deineko et al. (2025) use the latter approach by integrating a microscopic traffic simulator into their 2E-LRP heuristic. In the rest of this section, we present two studies that use, respectively, the other two approaches.

Batista de Castro Menezes et al. (2016) use a method proposed by Bompadre et al. (2006) to compute, for each facility and customer, the minimum cost incurred if assigning the customer to the facility. They then reduce the original 2ELRP to a k-median problem in which the distance between each facility and customer is replaced by the above cost. The optimal solution of this k-median problem provides an upper bound on the cost of the optimal 2ELRP solution. The authors then devise feasible routes using a Clarke-Wright-based heuristic, assuming that they open the facilities selected using the k-median problem. In this way, they obtain a solution to the 2ELRP. The gap between the cost of this solution and the upper bound is approximately 20% on instances based on a real-world supermarket chain.

Winkenbach et al. (2016) consider urban parcel delivery with static and deterministic data, motivated by a collaboration with the French postal operator La Poste. Large parcels are shipped directly from depots to customers, and small ones are first consolidated at facilities. The size threshold determining if a parcel is large or small is a model parameter: if very low, the model is a single-echelon LRP; if very high, it is a 2ELRP; at intermediate values, two parallel networks coexist. A planner must decide the location of the depots and the facilities, as well as the fleet size and composition. Because of the considerable size of the real-life application, the authors propose an iterative procedure. For different given values of the number of facilities to open, they solve a MIP to optimize all remaining decisions. In this MIP, the authors estimate routing cost with a closed-form approximation that partitions a city into rectangles with uniform demand and accounts for real-life limitations such as parking space, vehicle speed, and loading and unloading times. Using a closed-form approximation of the routing costs allows the authors to obtain good-quality results quickly and perform an extensive sensitivity analysis using two mid-sized French cities. They find that operating two parallel networks is suboptimal, and the operator should use, for any given city, one of the two modes (single- or two-echelon). They further observe that the characteristics that have the highest impact on costs are demand homogeneity and vehicle capacity. Finally, they note that futureproofing the network by building additional facilities and adding fleet capacity comes at a low marginal cost.

3.2. More than two echelons

Problems with more than two echelons are rare and often present very specific features and escape further classification.

Escobar-Vargas and Crainic (2024) tackle a problem arising in city logistics, in which goods flow from suppliers to depots and then to satellites before being delivered to customers. Both depots and satellites are facilities whose location must be determined and where transshipments occur. However, satellites have no storage capacity. Therefore, to allow transshipment, second- and third-echelon routes must be precisely synchronized. The solution methodology relies on a hybrid space-time network that combines continuous and discrete representations of the planning horizon. The authors dynamically adjust the granularity of the discretization, increasing its precision until they can prove that the corresponding solution is within a given tolerance from the optimum.

Wu et al. (2017) consider the problem of resupplying frozen meals to high-speed trains in China. In the first echelon, refrigerated trucks ship food from depots to facilities. The planner must decide which facilities to use and how much capacity to rent at each of them. In the second echelon, other refrigerated trucks deliver food from the facilities to train stations. Finally, the third echelon is used to decide how meals are assigned to trains that stop at the stations. The problem features tight time windows, defined by train arrival and departure times at the stations, and a maximum time that each meal can travel along the supply chain. Shipments from depots to facilities are direct, while there are explicit truck routes from facilities to stations. The assignment of stations to facilities is fixed (each facility serves stations in the same city). The authors derive primal solutions using a heuristic algorithm and dual bounds by relaxing the time windows and maximum meal travel time constraints and solving the corresponding MIP model with a commercial solver.

Dai et al. (2019) present a Clarke-and-Wright-based heuristic for a MELRP with up to four echelons. A comparison on the Prins and Prins2E instances for the 1E- and 2ELRP shows that the heuristic is fast but usually obtains worse results than other methods from the literature. However, this is the only work proposing a standard version of the 3E- and 4ELRP and an algorithm to solve standard versions of 1E-, 2E-, 3E-, and 4ELRP. Future research on MELRPs can, therefore, use this algorithm as a benchmark. Unfortunately, the authors did not make the instances or an algorithm implementation publicly available.

We observe that some problems have a two-echelon structure but include two transshipments, as in three-echelon problems. The problem introduced by Gianessi et al. (2016) and described in Section 3 of the survey by Cavagnini et al. (2025a), and the one presented by Özener (2019) involve goods moving from depots to facilities and then to customers. In both cases, goods can also move between facilities. In the problem described by Validi et al. (2018), goods can instead move between customers. These problems are intermediate between 2E- and 3ELRPs, and they do not have a well-defined classification: Gianessi et al. (2016) compare their setting to 2ELRPs, while Özener (2019) and Validi et al. (2018) include their problems in the 3ELRP category.

Finally, Chen et al. (2023) present a 3ELRP arising in urban last-mile delivery and develop an ILS algorithm with path relinking.

4. Multi-objective location-routing problems

LRPs can be naturally regarded as multi-objective problems because they typically consider multiple cost components (facility opening costs, vehicle usage costs, and routing costs) that may conflict with each other. However, these multiple components are usually aggregated into a single monetary objective function, leading to a formulation typical of a single-objective optimization problem. In this section, we focus exclusively on multi-objective LRPs (MOLRPs), which explicitly model multiple objectives as separate, and often conflicting, criteria. MOLRPs consider additional dimensions beyond the aggregated cost, such as risk, delivery time, or environmental impact. These multiple objectives must be simultaneously optimized to find a set of Pareto-optimal solutions. Table 4 summarizes the main characteristics of the surveyed papers on MOLRPs.

MOLRPs are often found in applications involving the transportation of hazardous materials such as used oil or medical waste. To protect public health and the environment, such LRPs minimize environmental contamination or the population's exposure risks in addition to the traditional cost-oriented objective. Zhao and Verter (2015) consider a bi-objective LRP for used-oil collection, in which the location of facilities dedicated to oil storage, treatment, and disposal, their storage capacities, and the routes of capacitated vehicles must be determined. The two objectives are the minimization of monetary costs (for facility opening, capacity acquisition, routing, and vehicles), and the minimization of the environmental risk, measured as the population's potential exposure to pollutants generated

Two echelons				
Paper	**Novelty**	**F?**	**Approach**	**Contribution**
Martins Santos Gandra et al. (2021)	Includes 2D loading constraints, and unloading a parcel from the back of the truck increases the service time at customers.	No	Heuristic (ILS)	Methodological
Pichka et al. (2018)	In both echelons, routes need not end at their start location (open routes).	Yes	Formulations and heuristic (SA)	Methodological
Tian and Hu (2023)	Facilities are chosen among customers and act as truck-to-drone transshipment points.	Yes	Exact (B&P)	Methodological
Soto-Mendoza et al. (2023)	Agricultural by-products are transformed into snacks at facilities and distributed to schools.	Yes	Exact (B&C)	Application-oriented
Boccia et al. (2018)	Flow-based formulation in which depot-customer flow is "intercepted" by facilities.	Yes	Exact (B&C)	Methodological
Zhao et al. (2017)	Multiple delivery companies collaborate, consolidating demand at the facilities.	Yes	Heuristic	Application-oriented
Deineko et al. (2025)	Urban LMD system in which the echelon closer to the customer is modelled with a microscopic traffic simulation framework.	No	Heuristic and simulation	Application-oriented
Ozyavas et al. (2025)	Facilities are parcel lockers, and a fraction of the customers walk to the locker and thus do not require a vehicle visit.	Yes	Exact (B&P)	Methodological
Song and Wu (2023)	Perishable goods; direct shipments from depot to customers are allowed.	Yes	Heuristic (SA)	Application-oriented
Lu et al. (2019)	Full-truckload shipments along the China-Europe "new silk road".	Yes	Heuristic	Application-oriented
Aydemir-Karadag (2018)	Hazardous waste disposal system with expensive processing costs at facilities and direct shipments.	Yes	Formulation	Application-oriented
Solak et al. (2014)	Nonprofit food distribution in which customers travel to the facilities via direct trips.	Yes	Heuristic and matheuristic based on Benders' decomposition	Application-oriented
Batista de Castro Menezes et al. (2016)	Provide primal solutions and dual bounds based on travel cost approximations.	No	Heuristic	Application-oriented
Winkenbach et al. (2016)	Postal system in which large parcels are shipped directly from the depot; costs in the echelon closer to customers are approximated.	Yes	Formulation	Application-oriented
More than two echelons				
Paper	**Novelty**	**F?**	**Approach**	**Contribution**
Escobar-Vargas and Crainic (2024)	Facilities between the second and third echelon have no storage capacity and thus require tight synchronisation between second- and third-echelon routes.	Yes	MIP-based approximation	Methodological
Wu et al. (2017)	Distribution of frozen meals to high-speed trains; tight time windows induced by the trains' schedules.	Yes	Heuristic and bounds from a relaxed formulation	Application-oriented
Dai et al. (2019)	Flexible Clarke-and-Wright heuristic for systems with up to four echelons.	Yes	Heuristic	Methodological
Chen et al. (2023)	Both facility locations and sizes must be decided in a large urban LMD setting.	Yes	Heuristic (ILS with path relinking)	Application-oriented

Table 3: Summary of reviewed papers for the multi-echelon LRP.

during transportation and by facility operations. The authors formulate a MIP, which is solved with CPLEX using a weighted goal programming approach that balances deviations of both objectives from their respective optimal value obtained by optimizing the MIP under either the cost or the risk objective. On a case study in Chongqing, CPLEX achieves near-optimal solutions for small instances within a two-hour time limit, but solution quality deteriorates for larger instances. Tang et al. (2025) study a bi-level 2ELRP for urban medical waste with infection-control considerations. At the upper level (the echelon closest to the hospitals), the problem involves locating transfer facilities, assigning hospitals to them, and planning waste collection routes with electric vehicles. The objective first maximizes the safety related to the locations of facilities, and then minimizes monetary costs (for facility opening and routing), the distances of the opened facilities to hospitals and a disposal center, and travel times. At the lower level (the echelon farthest from the hospitals), the routes of conventional vehicles are determined to collect the waste from the open facilities within their time windows and transport it to the disposal center. The objective is to minimize travel-time-based transportation costs and infection-diffusion risk during potential incidents, measured by estimating the population directly exposed along each route. The authors formulate a multi-objective bi-level model, solve the upper level to optimality with Gurobi, and address the lower level with an ALNS. This Gurobi+ALNS approach is compared against five alternative methods obtained by varying the solver at each level of the bi-level framework: for the upper level, either Gurobi or a K-means clustering algorithm variant that considers facility capacities is applied; for the lower level, the proposed ALNS, an ant colony optimization (ACO) algorithm, or Gurobi is used. The five comparison methods are therefore Gurobi+Gurobi, Gurobi+ACO, K-means+ALNS, K-means+Gurobi, and K-means+ACO. The results for a randomly generated instance set and two case studies from Chengdu show that the Gurobi+ALNS approach achieves a better solution quality than the comparison algorithms.

Another popular application area of MOLRPs is disaster relief. In this context, objectives often extend beyond cost minimization to include timely distribution of supplies and robustness of relief operations. Vahdani et al. (2016) study a multi-period open MOLRP for post-earthquake relief that integrates emergency roadway repair. The objectives are to minimize monetary costs and traveling times and to maximize route reliability by ensuring that routes used for relief are less likely to be disrupted by road damage due to aftershocks. Wei et al. (2020) study a bi-objective LRP for post-disaster relief distribution. The first objective reflects the critical need for timely supply and minimizes the penalty for violating the soft time windows of each affected area. The second objective minimizes the sum of the facility opening costs, vehicle fixed costs, and routing costs. To approximate the Pareto frontier, the authors propose a hybrid of ACO and particle swarm optimization (PSO). The latter component explores facility opening and facility-area assignment decisions, while the ACO improves the routes. The computational experiments are conducted on a newly generated instance set that is based on the one of Yu and Lin (2015), and the proposed method is compared against three alternative heuristics: a pure PSO, a pure ACO algorithm, and a hybrid of PSO and ACO, in which the ACO determines the facilities to open and the area assignments, while the PSO improves the routes. Compared to the benchmark algorithms, the results show that the proposed method finds more non-dominated solutions, solutions that are closer to the point at which both objectives reach their ideal values, and solutions that are more evenly spaced on the Pareto frontier, thus providing a more diverse set of tradeoff options.

Finally, another important domain where MOLRPs arise is logistics, in which multiple conflicting objectives often need to be balanced, especially when environmental considerations must be taken into account. Wang et al. (2024) study a 2ELRP with carbon emission considerations for a rural logistics network. In the echelon farthest from the customers, fuel trucks transfer goods from a county logistics park to the opened township facilities. In the echelon closest to the customers, multiple types of electric vehicles deliver goods from the opened township facilities to village customers, who have soft time windows. The authors formulate a bi-level optimization model: the upper level decides which township facilities to open and the assignment of villages to them, while the lower level determines the vehicle routing, fleet composition, and departure times. The objectives are to minimize monetary costs, penalty costs for time window violations, and emissions (including static carbon emissions resulting from the construction and operation of township facilities and dynamic emissions from vehicle routing). The authors propose a two-stage hybrid heuristic, and the results obtained for a Shanghai case study show that the proposed algorithm outperforms three multi-objective metaheuristics from the literature that were reimplemented by the authors.

5. Key observations and recommendations

In this section, we first outline our main takeaways from studying the recent literature on relevant LRP variants and then provide specific conclusions and suggestions for future research on multi-period, multi-echelon, and multi-objective LRPs. Some of these remarks were already included in a similar form in the conclusions of the surveys by Drexl and Schneider (2015); Prodhon and Prins (2014); Schneider and Drexl (2017) and have been expanded by Cavagnini et al. (2025a). We quickly summarize them here and discuss their relevance for the variants studied in this paper.

Paper	Novelty	F?	Approach	Contribution
Zhao and Verter (2015)	MOLRP with multiple facility types and facility capacity decisions; minimization of costs and population exposure to pollutants.	Yes	Exact (CPLEX)	Application-oriented
Tang et al. (2025)	2E-MOLRP with mixed vehicle fleet; minimization of costs and infection diffusion risk and maximization of facility location safety.	Yes	Heuristic (ALNS)	Application-oriented and methodological
Vahdani et al. (2016)	Multi-period, multi-commodity MOLRP with split deliveries, open routes, and road repair operations; Minimization of costs, time, and route reliability.	Yes	Heuristic (genetic algorithm, PSO)	Application-oriented
Wei et al. (2020)	MOLRP with time windows; minimization of soft time window violations and costs.	Yes	Heuristic (ACO + PSO)	Methodological
Wang et al. (2024)	2E-MOLRP with static and dynamic carbon emissions and mixed vehicle fleet; minimization of costs and total emissions.	Yes	Heuristic (clustering + swarm search method)	Application-oriented and methodological

Table 4: Summary of reviewed papers for the multi-objective LRPs.

- LRPs mix strategic (location) and operational (routing) decisions. Most recent literature does not explain why mixing these decisions is meaningful in the application cases addressed. Examples are tactical routes or location decisions that are easy to change, e.g., concerning mobile lockers. Unlike other LRP variants, the variants studied in this survey include longer-term routing decisions. In multi-period LRPs, the chosen visiting patterns can be expected to be repeated for longer periods. In multi-echelon LRPs, transportation at one or more echelons is often approximated (either with closed formulas or by assuming direct shipments) and becomes more representative of long-term trends than short-term variations. In MOLRPs, capturing both strategic and operational aspects together is crucial because the tradeoff between conflicting objectives (e.g., costs versus population health risks) can only be meaningfully assessed if both levels of decisions are modeled in an integrated fashion.

- In contrast to research, the integration of strategic and operational planning levels in industrial practice is limited. In many industrial settings, facility location and customer assignment decisions are finalized before routing is addressed, driven by the need for rapid computation and practical organizational constraints. We recognize that fully integrated LRPs pose significant computational challenges, particularly for large-scale, real-world applications. To bridge this gap, we see promising opportunities in approximation-based approaches that balance solution quality with computational efficiency. Moreover, decomposition can allow a hierarchical coordination between location and routing decisions in an iterative fashion, providing partial integration without resulting in prohibitive computational costs. In addition, data-driven techniques (e.g., machine learning) could approximate routing costs quickly and feed these estimations into strategic location models. Finally, to convince practitioners that taking the additional effort of integrated or iterative approaches is recommendable, numerical experiments could be conducted with the goal of showing the immense advantages of such planning approaches when compared to a sequential approach that is based on decision techniques at approximately the same level of sophistication. As far as we are aware, no such experiments have been conducted in the recent literature.

- Many papers are imprecise in their verbal and mathematical model descriptions. This is especially problematic because most recent papers on multi-period, multi-echelon, and multi-objective LRPs do not study problems already described in earlier literature or problems that are only slightly deviating from known problems. This makes concise problem descriptions an absolute necessity, and authors as well as editors should strive to achieve high standards of clarity and precision.

- Computational performance comparisons between algorithms are only possible if the same problem variants are tackled and the same benchmark instances are used. Meaningful comparisons are often also possible if a newly proposed problem extends the previously studied standardized variant. The relevance of this generic recommendation is discussed for MPLRPs in Section 5.1, for MELRPs in Section 5.2, and for MOLRPs in Section Section 5.3.

- Although route length formulas have been successfully used in the heuristic of Winkenbach et al. (2016) for a 2ELRP, recent advances in machine learning may offer a promising alternative: using trained models, such as graph neural networks, to predict routing costs within heuristics represents an interesting avenue for future research (see, e.g., Sobhanan et al., 2025).

Several LRP variants included in this survey align with the United Nations Sustainable Development Goals (UNSDGs). Waste collection routes are often designed using periodic schedules, and therefore, PLRPs (see, e.g., Gläser and Stücken, 2021; Hemmelmayr et al., 2016) can be used to optimize recycling and waste management, thus contributing to the UNSDG 11 "Sustainable Cities and Communities" and the UNSDG 12 "Responsible Consumption and Production". In MELRPs, facilities are often used to consolidate goods (see, e.g., Winkenbach et al., 2016; Zhao et al., 2017), leading to increased vehicle capacity utilization and reduced traveled distances and emissions, which also contirbutes towards UNSDG 12. The 2E-LRP of Solak et al. (2014) studies a non-profit food distribution system, supporting UNSDG 2 "Zero Hunger". Some MOLRPs explicitly address public health aspects such as minimizing the exposure of the population to contamination or infection risks (see, e.g., Tang et al., 2025; Zhao and Verter, 2015), thus addressing UNSDG 3 "Good Health and Well-Being" (in addition to UNSDG 12). The MOLRP of Wang et al. (2024) that jointly minimizes monetary costs and carbon emissions contributes to UNSDG 13 "Climate Action".

Although recent papers have addressed aspects of the UNSDGs, there remains considerable potential for future contributions. For example, to address UNSDG 14 "Life below Water", LRP variants arising in maritime distribution systems should account for vessel-induced underwater noise and for restrictions imposed by marine protected areas. To address UNSDG 6 "Clean Water and Sanitation", a PLRP could be studied in which chemical cleaning agents for the regular maintenance of water filtration units are delivered from facilities to remote villages. Candidate facilities differ in their opening costs, and because routes transport chemical cleaning agents, they must respect safety regulations such as avoiding densely populated areas and maintaining minimum distances from schools or hospitals. Moreover, because this application is more likely to emerge in rural settings, the fragility of the road network could be accounted for, e.g., by considering load restrictions on bridges and other infrastructure limitations.

Finally, the wide applicability of LRPs to real-life applications, which was already noted in previous surveys, also holds for the problem variants discussed in this paper as shown in Table 5. The table summarizes the LRP papers explicitly originating from an application or involving a case study from different industries such as healthcare, retail, (hazardous) waste management, postal services, energy, and humanitarian logistics.

5.1. Observations and recommendations for periodic LRPs and multi-period LRPs

Compared to the survey of Drexl and Schneider (2015), which covered a time frame of similar length as the one covered by this survey, the number of papers on the standard PLRP has decreased. At the same time, the number of papers on practically motivated PLRP variants as well as MPLRPs has significantly increased. On the one hand, this diversity of applications and variants enriches LRP research. On the other hand, the lack of comparisons on standardized benchmark instances makes it hard to assess the methodological contributions of the respective papers. Because the main characteristics of any PLRP variant are covered by the definition of the standard PLRP, it could be meaningful for the research community to revive the investigation of the standard PLRP. For example, it is interesting to see whether the recent algorithmic innovations on the standard

Paper	Problem type	Application
Zhao and Verter (2015)	MOLRP	Location of storage, treatment, and disposal facilities and routing for used oil collection in China, considering costs and environmental risk.
Hemmelmayr et al. (2016)	PLRP	Cardboard waste collection application for hunger relief agencies in Colorado.
Winkenbach et al. (2016)	2E-LRP	Network design for the French national postal operator.
Wu et al. (2017)	3E-LRP	Frozen meals distribution to high-speed trains in China.
Veenstra et al. (2018)	2E-LRP	Medicine delivery to lockers or customers for a healthcare provider in the Netherlands.
Amiri et al. (2019)	PLRP	Onshore purchasing offices location and vessel routing to customers for an offshore oil and gas company in Iran.
Lu et al. (2019)	2E-LRP	China–Europe new silk road.
Saragih et al. (2019)	MPLRP	Depot location and routing to retailers for a food supply chain in Indonesia.
Liu et al. (2019)	MOLRP	Distribution facility location and routing of supplies to affected area for a post-earthquake relief distribution application in China, considering efficiency, fairness, and relief utility.
Gläser and Stücken (2021)	PLRP	Underground waste collection in German cities.
González et al. (2023)	MPLRP	Mobile clinics location and routing for a disaster relief agency in Iraq.
Soto-Mendoza et al. (2023)	2E-LRP	Processing agricultural byproducts into snacks in Mexico.
Wang and Nie (2023)	MPLRP	Points of delivery location over time and covering or routing to affected people in New York City during Hurricane Sandy.
Wang et al. (2023)	PLRP	Hub island selection and size, vessel routing to feeder islands, and shipping schedule determination for a maritime supply chain in the South China Sea with periods of high and low freight demand.
Wang et al. (2024)	MOLRP	Location of township facilities and routing to visit village customers for a rural logistics network in Shanghai, considering costs and total emissions.
Tang et al. (2025)	MOLRP	Transfer center facility location and routing for visiting hospitals for a medical waste collection application in China, considering costs and infection diffusion risk.

Table 5: Applications and case studies of the LRP variants considered in this survey.

LRP (both heuristic and exact) are transferable to the standard PLRP. A close look at the results of the two best-performing PLRP methods on the Prodhon benchmark set also indicates room for additional methodological contributions in PLRP algorithms: the algorithms of Hemmelmayr (2015) and Koç (2016) do not find the same solution on any of the 30 instances. The algorithm of Hemmelmayr (2015) provides the BKSs for 16 instances and the one of Koç (2016) for 14 instances. Often the differences between the two algorithms on individual instances are substantial. Besides the Prodhon instances, Koç (2016) have proposed another set of medium-sized PLRP instances based on the Solomon set for the VRPTW. This could be a first step to spark new research interest in the standard PLRP, and could even be strengthened by the definition of additional more challenging, i.e., larger and structurally more demanding PLRP instances, similar to the proposal of the Schneider set for the standard LRP.

Most MPLRPs consider location decisions as static, and the dynamic aspect is typically limited to the routing component. This is motivated by practical applications in which the costs associated with dynamically opening and/or closing facilities generally outweigh the advantages of increased flexibility. However, there are application settings that motivate research on MPLRPs which explicitly incorporate time-dependent location decisions. First, dynamic markets have stimulated business models in which facilities may be rented rather than owned. This reduces fixed investment costs and avoids long-term commitments. As a result, location decisions can be revised from one period to another, allowing firms to open, close, or relocate facilities over time in response to changing market conditions. Second, the growing frequency of environmental disasters has increased the demand for mobile emergency facilities whose location must be decided on a short-term basis and adapted to changing conditions over time.

Finally, to the best of our knowledge, LRPs with consistency considerations have not yet been studied in the literature. This is in stark contrast to the field of VRPs, where consistency aspects are well researched (Kovacs et al., 2014). In a multi-period context, however, consistency can be highly relevant: facility opening and vehicle routing decisions interact with the requirement that customers should be served by the same driver and/or at approximately the same time across periods. Such consistency simplifies operational planning and enhances service quality, which is particularly important in applications such as healthcare logistics, e-commerce distribution, or regular municipal services. Therefore, investigating LRPs with consistency aspects constitutes a natural and practically motivated variant of MPLRPs.

5.2. Observations and recommendations for multi-echelon LRPs

As remarked in Section 3, even when fixing the number of echelons, ME-LRPs are further characterized by other features. The main two are the transportation system at each echelon (direct shipment or multi-stop routes) and the extent of the location decisions (at which echelon facilities must be located). The papers of Nguyen et al. (2012) and Contardo et al. (2012) are the only ones to provide 2E-LRP instances; however, they do not agree on these decisions. Both papers consider multi-stop routes; however, Nguyen et al. (2012) allows additional direct routes from the depot to the customers (skipping the facilities). Moreover, Nguyen et al. (2012) consider a single depot whose location is fixed, while for Contardo et al. (2012) selecting which depots to open out of a set of possible locations is a decision. Dai et al. (2019), who introduce standard versions of 3E- and 4E-LRPs, also forbid direct routes skipping intermediate facilities and include facility location decisions at all levels. Due to the above considerations, the corresponding problems are different, and neither is a special case of the other. Consequently, it is difficult to assess the quality of a new algorithm on both instance sets, and authors must choose which 2E-LRP version they want to address.

Restricting ourselves to the 2E-LRP, we remark that disregarding depot location decisions can be easily modeled by presenting a single potential location for opening depots. Similarly, direct shipments in an echelon can be obtained by selecting appropriate vehicle capacities and travel costs. Finally, one can always allow routes visiting customers and starting at a depot (instead of a facility), and should they be forbidden, the travel cost between depots and facilities can be set to a very large value. Therefore, a standard 2E-LRP could include location decisions for both facilities and depots, consider multi-stop routes at both echelons and allow depot-to-customer routes. We have to admit that it is unclear whether such a generic 2E-LRP version is really beneficial to assess the quality of future algorithms. Effective solution algorithms might be fundamentally different if direct shipment vs. multi-stop routes are considered, if two sets of location decisions vs. one are required, or if routes skipping facilities are permitted vs. forbidden.

For papers in which routing costs are approximated by surrogates (Section 3.1.4), one must carefully consider whether the surrogate introduces a bias in the solutions, e.g., due to unmet assumptions required to use the surrogate model. For example, closed-form formulas often assume homogeneous spatial demand, and real-life demand patterns should be checked against this assumption. Consequently, a good practice is to validate surrogate accuracy on representative operational instances and treat surrogate-based designs as candidates to be further tested via explicit routing or simulation in a second stage.

5.3. Observations and recommendations for multi-objective LRPs

MOLRPs simultaneously optimize economic, environmental, and humanitarian objectives. Non-monetary objectives address greenhouse gas emissions (Wang et al., 2024), exposure to hazardous material (Tang et al., 2025; Zhao and Verter, 2015), and timely distribution of supplies (Wei et al., 2020). Monetary objectives in general consider facility opening costs (e.g., Tang et al., 2025; Wei et al., 2020; Zhao and Verter, 2015), routing and transportation costs (Wei et al., 2020), vehicle acquisition costs (Tang et al., 2025; Wang et al., 2024; Zhao and Verter, 2015), travel distance and travel time (Tang et al., 2025), or waiting and delay times (Wang et al., 2024; Wei et al., 2020).

The literature on MOLRPs is highly application-specific and contributes little with regard to algorithmic techniques. Most of the proposed solution methods are of heuristic nature, and exact approaches are rare. It is especially noteworthy, how strongly algorithmic evaluation practices lack standardization in this field. First, nearly all experiments rely on newly generated instances or case studies, which forbids cross-paper comparisons and limits the assessment of methodological progress. Second, the different papers report incomparable performance metrics such as the number of non-dominated solutions, distance to the ideal point, diversity, or spacing on the Pareto frontier.

As a consequence, future work (i) could concentrate on the development of exact and matheuristic approaches, (ii) should define and utilize standardized benchmark instances for a set of relevant and well-defined multi-objective LRPs (which could aim to be somewhat generic, as outlined by Cavagnini et al., 2025a), (iii) should establish a consolidated evaluation framework with clear and consistent performance indicators. Such steps would allow the research community to assess methodological contributions more meaningfully and reduce the current bias toward proliferation of new variants.

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