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Location-Routing Problem for Integrated Supply Chain Network Design with First and Last Mile: A Critical Literature Review

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ABSTRACT

Supply chain management includes strategic, tactical, and operational decisions for long, medium, and short-term planning. Strategic decisions, such as network design, and operational decisions, such as last-mile routing, have mutual implications. Therefore, modelling them separately can lead to sub-optimal solutions. The integrated modelling of these decisions has been addressed as a location routing problem (LRP). This paper aims to identify the solution strategies and methods to solve the LRP, as well as related challenges and research opportunities based on a critical literature review. The findings reveal that 46% of the reviewed publications have adopted a multistage modelling approach to address the LRP, sequentially tackling strategic and operational decisions. Moreover, in addition to the challenge of modelling diverse decision levels, the LRP models need to incorporate variables such as time windows, delivery failure rates, demand density, etc. Five research opportunities are proposed: i) modelling the first and last mile with a strategic approach when making strategic network decisions, ii) integrating environmental and social objectives into the modelling framework, iii) applying the solution methods and algorithms to complex real-world cases, iv) exploring competitive and cooperative models in LRP, and v) evaluating the use of emerging technologies.

Keywords: *integrated models, location routing problem, logistics, network design, supply chain management*

1. INTRODUCTION

In traditional supply chains, products move forward from manufacturing sites to retailers (Beamon, 1998). That pattern has changed with trends such as circular supply chain management, which integrates concepts of circular economy and closed-loop logistics (Firdous & Ramish, 2023; A. Zhang *et al.*, 2022). Furthermore, this change not only impacts a company's supply chain but also seeks to enhance sustainable development (Julianelli *et al.*, 2020). Trends such as e-commerce have revolutionized the logistics behind distribution in terms of redesign and relocation of logistic facilities (Xiao *et al.*, 2021). Last-mile distribution has become more relevant and additional efforts are needed to meet consumer expectations (F. Arnold *et al.*, 2018; Dablanc, 2019). Consequently, the effects of logistics challenges in the e-commerce era and the visible last-mile responsibility should be now included in macro strategic decisions regarding network design.

Supply chain management is defined as “the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities” (CSCMP, n.d.). The design of distribution networks is one of the most studied strategic decisions in the logistics and supply chain literature. In traditional supply chain planning, network design seeks to answer questions regarding the number, location and capacity of new facilities, being these long-term decisions (Chopra & Meindl, 2015). Facility location problems (FLP) have been proposed to determine the location of new sites and optimize at least one, typically economic, objective (Farahani *et al.*, 2010). Moreover, multiple branches of the FLP exist to solve location problems with differences in their data nature or problem conception (Farahani *et al.*, 2013).

Last-mile distribution, and analogously, first-mile pick-up, are planned at the operational level since decisions about vehicle routing need to be tackled in the short term (weekly, daily, or even hourly) (refer to **Figure 1**). Typically, the well-known vehicle routing problem (VRP) is proposed to model these operational decisions. Various solution techniques such as exact models, heuristics and metaheuristics have been proposed over time (Laporte, 1992; Tan & Yeh, 2021).

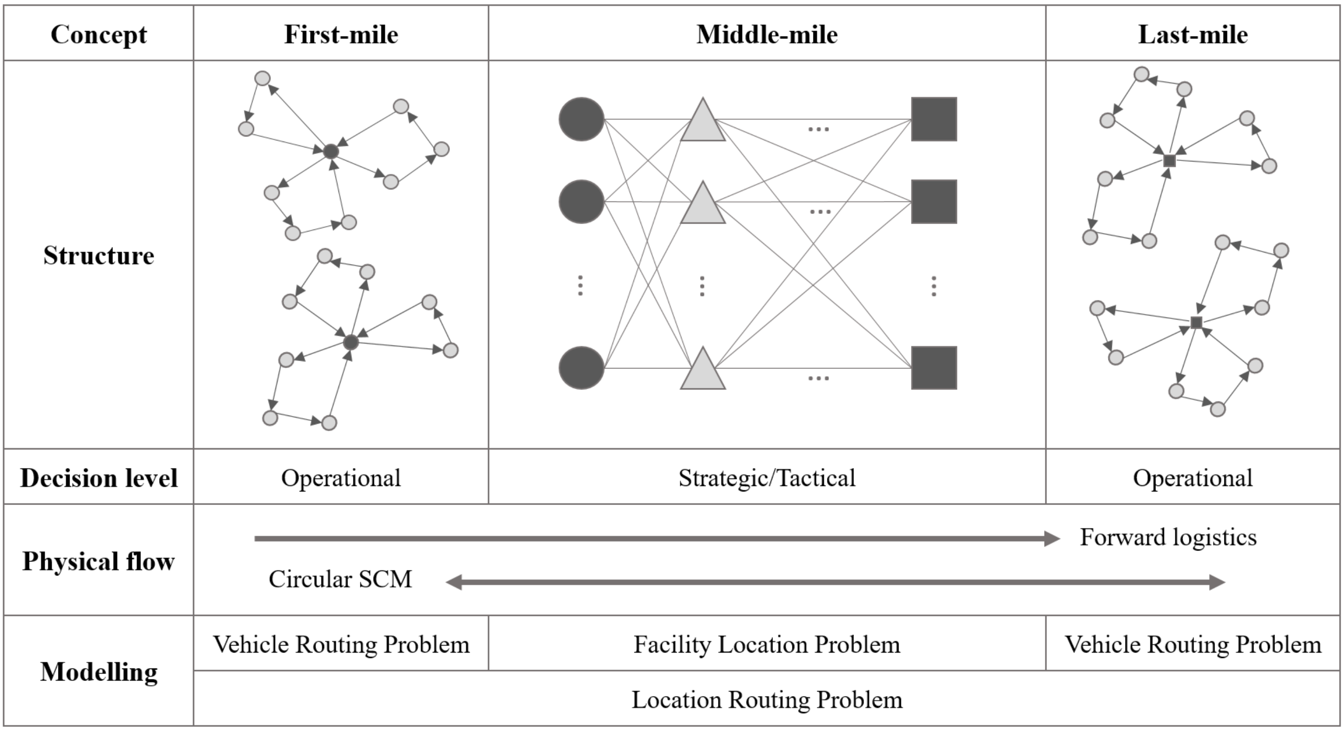

Figure 1 Supply network structure and concepts

Some authors have evidenced the need for integrated modelling of strategic (network design) and operational decisions (first and last mile distribution) since modelling them separately can lead to sub-optimal solutions (Guerrero *et al.*, 2013; Nagy & Salhi, 2007; Salhi & Nagy, 1999). At this point, questions arise about the feasibility of integrated modelling. Nagy & Salhi (2007) highlight the criticism in the literature about integrating strategic and operational decisions when the planning horizons are different. Additionally, integrated modelling requires efficient computational methods and algorithms (Garcia & You, 2015).

In the literature, the problem to integrate network design modelling with last-mile distribution has been denoted as location routing problem (LRP). The LRP is defined as "location planning with tour planning aspects taken into account" (Nagy & Salhi, 2007). In other words, the LRP aims to answer two questions: (1) "Which facilities out of a finite or infinite set of potential ones should be used?" and (2)"Which vehicle routes should be built?" (Drexl & Schneider, 2015). However, the literature on LRP lacks clarity regarding the modelling strategies that effectively integrate these components. Literature reviews on this subject (Drexl & Schneider, 2015; Mara *et al.*, 2021; Nagy & Salhi, 2007; Prodhon & Prins, 2014) underscore the inefficiency of isolating the LRP components within individual models but do not emphasize how scholars have actually addressed this problem. Therefore, this study aims to fill this gap.

This literature review does not intend to be exhaustive but has the ambition to present a critical review of the strategies and methods for integrating strategic (network design) and operational (vehicle routing for first and last-mile distribution) decisions into modelling, as well as critically discuss the challenges and research opportunities. Within this paper, the review methodology is described in section 2. The selected publications are classified by solution strategies and methods, described in section 3. The literature review leads to the discussion and identification of research opportunities described in section 0. Finally, section 5 presents the conclusions and limitations of the paper.

2. METHODS AND MATERIALS: LITERATURE REVIEW

When conducting literature reviews, numerous approaches and methodologies have been documented (Snyder, 2019). Nonetheless, the selection of an appropriate methodology should align with the research requirements at hand. In this case, the objectives of the review are (1) to identify the solution strategies and methods used for integrating strategic (network design) and operational (first and last-mile distribution) decisions into modelling, and (2) to critically highlight challenges and research opportunities. Consistent with these objectives, a semi-systematic review approach is adopted. This methodology follows the search structure of the systematic review (Zunder, 2021), but the analysis is framed within a narrative discussion to understand the "theoretical perspectives, synthesize the state of knowledge, and create an agenda for further research" (Snyder, 2019).

The literature review begins with the definition of the keywords and the search in indexed databases. The words used in the search refer to strategic decisions regarding the *supply network design* and operational decisions in *vehicle routing* for *first and last-mile distribution*. The first search equation applied yielded 261 results in Scopus (

Table 1). This literature is read in the first level, focused on the title, abstract and conclusions. During this first reading, the term location routing problem (LRP) is repeatedly identified. This is then considered the theory in which the integration of strategic and operational decisions in modelling is positioned. Thus, the search equation is restructured to include the *LRP* term anchored to *supply network design* and the *first and last-mile distribution*.

Table 1 Search equations for literature review

No.	Review topic	Search equation	Scopus results
1	Integrating supply chain design and first and last-mile distribution	TITLE-ABS-KEY ((("supply chain" OR "supply network") AND (design)) AND ("first mile" OR "last mile" OR "first-mile" OR "last-mile" OR "vehicle routing"))	261
2	Integrating supply chain and first and last-mile distribution with Location Routing Problem	TITLE-ABS-KEY (("supply chain" OR "supply network") AND ("location-routing problem" OR "location routing problem" OR "LRP") AND ("first mile" OR "last mile" OR "first-mile" OR "last-mile" OR "vehicle routing"))	40

Results from Scopus

The final body of literature (40) is read in-depth, discarding four papers for being written in a language other than English or for being a set of references from proceedings. Out of the 36 remaining papers, one is a literature review study, which has been included in the discussion. The publications are then classified and reviewed.

3. CLASSIFICATION AND REVIEW RESULTS

An analysis of the solution strategies reveals that 54% of the papers address the problem with a single-stage model using mixed integer programming (MIP), empirical heuristics and metaheuristics (See **Table 2**). On the other hand, 37% of the publications develop models in two stages, distinguishing strategic location decisions from operational routing decisions. These models are usually sequential, wherein the initial stage involves determining the optimal location for warehouses, distribution centres, or hubs, followed by the subsequent stage of vehicle routing. Furthermore, the remaining studies (9%) adopt a three-stage strategy, encompassing the same stages as the previous case but including an intermediate stage of allocation, usually referred to as location-allocation-routing. It is noteworthy to mention that at least 46% of the papers divide the LRP into subproblems, despite the prevailing notion that this practice can yield inefficient solutions.

Table 2 Solution strategies and methods to solve the LRP

Solution strategy (# papers)	Decisions made	Solution methods		
		Exact models	Heuristics	Metaheuristics
One stage (19)	Location + Routing	10	2	7
Two stages (13)	Location	4	7	2
	Routing	1	5	7
Three stages (3)	Location	1	2	0
	Allocation	1	2	0
	Routing	1	0	2

Although it is possible to identify the subproblems into which the LRP is divided within the solution strategies, that is not the case with the solution methods. There is a proliferation of techniques and models to solve these problems, in most cases different methods per modelling stage. Consequently, a detailed review of the solution methods is presented below, grouping them into exact models and approximations methods such as heuristics and metaheuristics.

3.1 Exact Methods

Solution approaches based on exact modelling to address the LRP problem rely on mathematical programming. Since the LRP is classified as an NP-Hard problem (Laporte & Nobert, 1987), i.e., complex to solve by a nondeterministic Turing machine in polynomial time, its applications with exact methods focus on small-scale instances (Hashemi *et al.*, 2022). The papers that are classified in this section mainly use Mixed Integer Programming – MIP (

Table 3). In some cases, in which modelling is in more than one stage, the papers may also include heuristics or metaheuristics, these methods will be reviewed in the following sections.

Mixed Integer Programming (MIP) has its origins back in the 1960s from the inclusion of branch-and-bound or branch-and-cut algorithms in the popular Dantzig Linear Programming (LP) method (Bixby, 2012). A general formulation of the LRP as MIP has been proposed by Laporte *et al*. (1983) (Equations (1-(5) and later improved as a capacity problem (Laporte & Nobert, 1987). These seminal formulations define a graph $G = (N, E)$ with N nodes including cities and customers, and E arcs between each pair of nodes. Let K be a set of potential depots within N and c_{ij} be a symmetric matrix of costs for each arc in E. Solutions involving sub-tours are excluded by adding the sub-tour removal constraint (Dantzig *et al.*, 1954), where a tour within a subset $S \subset N$ must leave S at some point.

Table 3 Papers that use exact methods for location-routing problems

Paper	Solution strategy	Solution methods			Language or solver
		Stage 1	Stage 2	Stage 3	
Hashemi *et al.* (2022)	One stage	Multi-objective MILP	/	/	GAMS
Huang *et al.* (2021)	Two stages	Pure Integer Programming	Modified sequential savings approach	/	CPLEX
Zandkarimkhani *et al.* (2020)	One stage	Multi-objective MILP	/	/	GAMS
Leyerer *et al.* (2020)	Three stages	MILP	MILP	MILP	GAMS
Gholipour *et al.* (2020)	One stage	Fuzzy MILP	/	/	GAMS
Elluru *et al.* (2019)	One stage	MIP	/	/	Lingo
Darvish *et al.* (2019)	Two stages	Pure branch-and-bound	Variable Mixed-integer programming neighbourhood descent	/	C++
Dorrington & Olsen (2019)	Two stages	Empirical heuristic	MILP	/	MATLAB
Khalafi & Zarei (2019)	One stage	MILP	/	/	GAMS
Rabbani *et al.* (2017)	Two stages	MILP	Simulated Annealing	/	MATLAB
Ouhader & Elkyal (2016)	One stage	MILP	/	/	MATLAB
J U Sun (2015)	One stage	MIP	/	/	Xpress-MP
Ghani *et al.* (2015)	One stage	MILP	/	/	Unknown
Hamidi *et al.* (2012)	One stage	MIP	/	/	GAMS
Mirzaei & Krishnan (2011)	One stage	MILP	/	/	CPLEX

The problem is formulated as MIP since it includes an integer variable x_{ij} that registers the number of times the arc$_{ij}$ is used and y_k is a binary variable that indicates the opening or closing of a depot with a fixed cost f_k. $\sigma(k)$ is defined as an arc$_{ij}$ where either i or j is in K, that is, at least one of the nodes in the arc is selected as a depot. The objective function (1) is set to minimize variable costs of distribution and fixed costs of opening facilities. Constraint (2) specifies that every non-depot node must be served only once, that means only two connections in/out of the node. Constraint (3) eliminates the possible sub-tours, and constraint (4) limits the number of depots to P. Finally, constraints on (5) define the domain of the variables.

$$\min \sum_{i<j} c_{ij} x_{ij} + \sum_{k \in k} f_k y_k \qquad (1)$$

Subject to:

$$\sum_{(i,j) \in \sigma(k)} x_{ij} = 2 \qquad (k \in N) \qquad (2)$$

$$\sum_{\substack{i<j \\ i,j \in S}} x_{ij} \leq |S| - 1 + \sum_{k \in S \cap K} y_k \qquad (S \subseteq N) \qquad (3)$$

$$\sum_{k \in K} y_k \leq P \qquad (4)$$

$$\begin{aligned} x_{ij} &= \{0,1\} && (i,j \in N - K) \\ x_{ij} &= \{0,1,2\} && (i \text{ or } j \in K) \\ y_k &= \{0,1\} && (k \in K) \end{aligned} \qquad (5)$$

These formulation principles are evident in the literature, each time adjusted and extended to address more complex problems. Sahitya Elluru *et al.* (2019) include time windows for disaster response. Capacitated LRP is found using distribution hubs (J U Sun, 2015) or depots in multi-layer, multi-product distribution networks (Hamidi *et al.*, 2012). Strategic decisions get closer to the operational side and are made in the short term, such as the dynamic selection of distribution centres (Darvish *et al.*, 2019). The authors propose a dynamic network design modelled in two parallel stages by a pure branch-and-bound algorithm and a Variable Mixed-integer programming Neighbourhood Descent algorithm.

Conditions of disruption and uncertainty enhance the LRP models (Huang *et al.*, 2021). MIP models have been used to design supply networks with uncertainty in demand (Khalafi & Zarei, 2019) or dynamic demand when using time windows (Mirzaei & Krishnan, 2011). Models that include uncertainty are also addressed with fuzzy programming. Masoud Rabbani *et al.* (2017) propose a fuzzy LRP model for blood collection with bloodmobiles and transport to storage centres, using the fuzziness to get adequate compromise solutions. A fuzzy solution approach considering demand uncertainty has also been used for the design of green supply networks (Gholipour *et al.*, 2020), including the environmental factor through fuel consumption reduction.

Multi-objective optimization for the design of supply networks for perishable pharmaceutical products (Zandkarimkhani *et al.*, 2020) is solved by applying fuzzy theory and goal programming techniques to convert the problem into a single-objective model. Leila Hashemi *et al.* (2022) designed an urban multi-echelon supply network with a multi-objective MILP model. The authors compare the results of exact modelling with metaheuristics such as swarm optimization and modified genetic algorithms, showing satisfactory solutions compared with the exact method (instance N=100). These applications in Urban Logistics use LRP to determine the location of lockers or hubs in the urban distributions. E-grocery distribution presents challenges regarding the use of refrigerated elements and the last-mile distribution using electric vehicles and cargo bikes (Leyerer *et al.*, 2020).

Ghani *et al.* (2015) demonstrate that allowing transhipment between customers improves system performance and reduces stockouts. Their variant of the LRP with inventory analysis, called Inventory Location Routing Problem – ILRP, studies allocation at a strategic level to manage inventories at each site, dealing with demand uncertainty (Saragih *et al.*, 2022). Collaborative strategies such as pooling in the supply chain are evaluated using MILP models in an LRP formulation (Ouhader & Elkyal, 2016). In this case, pooling is considered horizontal cooperation between companies to distribute products to their customers, the location of exchange platforms and the routing integrate the LRP. The formulation of an asteroid mining problem as an LRP uses MILP to maximize the amount of saleable mass (Dorrington & Olsen, 2019). This application shows additional challenges for calculating distances between nodes with orbital angles.

3.2 Heuristic Algorithms

Solving integrated facility Location Routing Problems with exact methods in a reasonable computational time is only possible for small-size instances (Guerrero *et al.*, 2013). As mentioned above, as the size of the instance grows, the time to solve an NP-hard problem using an exhaustive search becomes forbiddingly large (Woeginger, 2003). It is here where heuristics come in to deliver sufficient solutions for large instances. According to Yang *et al.* (2015), heuristics are "essentially methods by trial and error", which serves to find non-optimal solutions faster. Heuristic-based solution approaches are mainly found in multi-stage models (

Table 4). In these cases, the operational approach is predominant in the use of classic routing heuristics such as the Clarke and Wright saving algorithm (CWS), and the sweep algorithm. The savings algorithm, created by Clarke & Wright (1964), seeks to configure routes by grouping nodes that produce the greatest savings in the distance travelled, that is, eliminating routes to the depot and adding the connections between the nodes.

Table 4 Papers that use heuristics for location-routing problems

Paper	Solution strategy	Solution methods			Language or solver
		Stage 1	Stage 2	Stage 3	
Ben Mohamed *et al.* (2023)	Two stages	Logic-based benders decomposition	branch-cut-and-price algorithm	/	C++
Baytürk *et al.* (2022)	Two stages	Fuzzy c-means	Simulated annealing	/	Unknown
Oudouar & Zaoui (2021)	Two stages	Hierarchical ascendant clustering	Sweep algorithm	/	C++
Florian Arnold & Sörensen (2021)	Two stages	Regret Clarke-Wright	Knowledge-Guided Local Search	/	JAVA
Nataraj *et al.* (2019)	Three stages	Empirical heuristic	Empirical heuristic	Biased-randomized CWS	JAVA
Elalouf *et al.* (2018)	Two stages	Fully polynomial time approximation scheme	Nearest Neighbour algorithm	/	Unknown

Table 5 Papers that use heuristics for location-routing problems (Con't)

Paper	Solution strategy	Solution methods	Language or solver	Paper	Solution strategy
		Stage 1	Stage 2	Stage 3	
Tokgöz *et al.* (2015)	One stage	Empirical heuristic	/	/	Unknown
Guerrero *et al.* (2015)	Two stages	Relax-and-price algorithm	Column Generation	/	C
Guerrero *et al.* (2013)	Two stages	MIP	Randomized extended Clarke and Wright	/	Xpress-IVE

Guerrero *et al.* (2013) decompose the integrated problem in two models: (1) the network's design and (2) the routing from the resulting network. The design is performed with a MIP model, while the routing is optimized with a randomized extended Clarke and Wright algorithm. However, the separation of problems leads to sub-optimal solutions (Nagy & Salhi, 2007). A biased-randomized CWS heuristic is used in the location of urban consolidation centres and the generation of routes (Nataraj *et al.*, 2019).

Table 4). This method uses the polar angles of the nodes to group them starting from the smallest in the single-depot problem (Gillett & Miller, 1974). This procedure groups nodes while not exceeding the capacity of the vehicle. Oudouar & Zaoui (2021) formulate a two-stage LRP model by first location and allocation of the clients with a Hierarchical Ascendant Clustering method and then applying the sweep algorithm. Additionally, an algorithm based on Variable Neighbourhood Descend is used to improve the results. Elalouf *et al.* (2018) implement a heuristic derived from the Nearest Neighbour algorithm for routing and determine the opening of depots with a fully polynomial time approximation scheme. In this way, the authors manage to find solutions for the LRP.

A hybrid procedure between the Column Generation, Local Search and Lagrangian relaxation methods proposed by (Guerrero *et al.*, 2015) addresses the LRP with inventory. In this case, the heuristic seeks to solve the inventory LRP or ILRP by simplifying the procedure and restricting the variables in the optimal solution. (Tokgöz *et al.*, 2015) develop an empirical algorithm to solve the LRP with The authors propose a collaboration scheme where operators share information about customers and storage and transportation capacity. At this cooperative level, strategic supply network decisions are considered as an integrated LRP. This cooperative strategy for urban distribution leads to a reduction of CO_2 emissions.

The sweep algorithm has also been used in other multi-stage models to solve the LRP (

manifold space. The authors refer to location and routing in a Euclidean space. Manifold improves the distance calculation using geodesic distances. The general idea of the algorithm is to project the customer locations from M (manifold surface) to $\mathbb{R}^2$ (Euclidian space), then solve the LRP by a heuristic and then return the solution from $\mathbb{R}^2$ to M. Florian Arnold & Sörensen (2021) propose a heuristic called progressive filtering to address the LRP. The procedure seeks to reduce the number of possible network configurations to some upper bound and then filter the remaining configurations with a low-accurate fast routing algorithm.

3.3 Metaheuristics Algorithms

The metaheuristics to solve the LRP are varied, from trajectory algorithms such as Tabu search or Neighbourhood Search to bio-inspired methods such as genetic algorithms and ant colony or particle swap optimization (**Table 6**). The general idea of bioinspired metaheuristics is to replicate natural behaviours to achieve a higher degree of efficiency (Kar, 2016). In the case of Swarm Optimization, the principle is that collective intelligence is greater than individual intelligence.

Table 6 Papers that use metaheuristics for location-routing problems

Paper	Solution strategy	Solution methods			Language or solver
		Stage 1	Stage 2	Stage 3	
Cao *et al.* (2021)	Two stages	Hybrid Tabu Search	Hybrid Tabu Search	/	C++
Theeraviriya *et al.* (2019)	One stage	Adaptive Large Neighbourhood Search	/	/	Unknown
Quintero-Araujo *et al.* (2019)	One stage	Biased Randomization Variable Neighbourhood Search	/	/	JAVA
Misni & Lee (2019)	Three stages	Empirical heuristic	Empirical heuristic	Harmony search	Unknown
Zhou *et al.* (2019)	One stage	Genetic Algorithm + Simulated Annealing	/	/	MATLAB

Paper	Solution strategy	Solution methods			Language or solver
		Stage 1	Stage 2	Stage 3	
Panicker *et al.* (2018)	One stage	Ant Colony Optimization	/	/	MATLAB
Zhou *et al.* (2016)	One stage	Genetic Algorithm + Local Search	/	/	C++

Table 7 Papers that use metaheuristics for location-routing problems (Con't)

Paper	Solution strategy	Solution methods	Language or solver	Paper	Solution strategy
		Stage 1	Stage 2	Stage 3	
Ji Ung Sun (2015)	Two stages	Endosymbiotic Evolutionary Algorithm		/	C++
Marinakis & Marinaki (2013)	One stage	Particle Swarm Optimization	/	/	Unknown
Ye & Li (2007)	One stage	Genetic Algorithm	/	/	Unknown

Neighbourhood search-based solution approaches have two improvement steps (Abdel-Basset *et al.*, 2018). First, generate the valley of local solutions i or neighbourhood N_i, and second, iterate through the neighbourhood to find a better solution j (Monteiro *et al.*, 2022). Theeraviriya *et al.* (2019) use a Neighbourhood Search metaheuristic to solve an LRP problem in the biomass supply chain. The model proposes the collection and stockpiling of palm oil to minimize costs and then compares the solutions with an exact model for small instances, showing similar objective values. For medium and large-size instances the exact method could only identify feasible and lower bounds with long processing times. A stochastic variant of Neighbourhood Search is the Variable Neighbourhood Search. This method is used by Quintero-Araujo *et al.* (2019), assigning random allocation of depots to potential customers. It is a biased stochastic process to generate customer-depot allocation maps.

A combination of exact methods and metaheuristics is proposed by Cao *et al.* (2021) when solving the LRP in the biomass supply chain. Using a hierarchical heuristic derived from Tabu Search, collection routes of biomass are generated and serve as inputs to an exact facility location model. This is an application of vehicle routing concepts in the first mile within the supply network. Misni & Lee (2019) propose a search algorithm inspired by the improvisation process of the members of an orchestra. The metaheuristic for network design under the LRP creates a set of initial solutions that form the harmony memory. To find a new solution, the algorithm starts from the solutions stored in the memory, like a musician creating a new harmony based on previous experiences.

Genetic Algorithms represent solutions as strings, usually binary values, that evolve stochastically following processes of reproduction, crossover, and mutation (Murray-Smith, 2012). For each temporary set of solutions, the performance or fitness is evaluated according to the objective function of the model. This loop iterates until the last generation with the best solution. Ye & Li (2007) use Genetic Algorithms to solve the stochastic LRP. In this case, the authors determine the initial solution randomly by opening depots and then using the savings method heuristics to find the initial routing.

Zhou *et al.* (2016) implement a combined algorithm between Local Search and Genetic Algorithms in the last-mile distribution. This model seeks to simultaneously address home delivery and collections at pick-up points. This is an example of modelling operational objectives in which the location of pick-up points would require an intermediate planning term. The Genetic Algorithms are called evolutionary algorithms (Murray-Smith, 2012) since they seek to mimic the process of evolution. Strong individuals become stronger while weak ones are eliminated, and the procedure is followed for selecting the fittest solutions. This type of evolutionary algorithms proves to be useful for solving complex combinatorial problems such as LRP. Another variant of evolutionary methods is the endosymbiotic evolutionary algorithm, implemented by Ji Ung Sun (2015) to model a capacitated LRP with multi-hub vehicle routing.

A combination of Genetic Algorithms with Simulated Annealing is proposed by Zhou *et al.* (2019) to locate urban logistics terminals. The authors model the distribution of a bi-level network in which products are delivered to customers or they can pick them up at the terminals. Simulated Annealing mimics the annealing process in metalworking, iterating according to variable temperatures as the metal cools after being heated (Eren *et al.*, 2017). This optimizing algorithm compares a current solution with other solutions in the neighbourhood and saves the best one for the next iteration.

Nature-inspired metaheuristics based on population and swarm intelligence have been used to solve the LRP. Marinakis & Marinaki (2013) propose a multi-level model that supports decision-making regarding facility location and vehicle routing in the supply chain. The authors implement Particle Swarm Optimization as a solution method, which is inspired by the motion of a flock of birds to generate operating rules and find solutions to optimization problems (Banerjee *et al.*, 2022). A population-based metaheuristic such as Ant Colony Optimization is proposed by Panicker *et al.* (2018) to solve the LRP in two stages.

3.4 Review Summary

The literature review shows a wide variety of methods and solution strategies for solving the LRP (**Figure 2**). The

LRP is divided into sub-problems of location, allocation, and routing, as part of some solution strategies. The solution methods could be grouped into three categories: exact methods, heuristics, and metaheuristics. The exact methods are based on mathematical programming to find optimal solutions. On the other hand, heuristics and metaheuristics aim to find approximate solutions. According to the metaheuristics classification by Harifi *et al.* (2021), the metaheuristics found in the literature are classified in trajectory-based metaheuristics, such as local searches, neighbourhood searches or simulated annealing; evolutionary algorithms such as genetic algorithms and harmony search; and, nature-inspired metaheuristics such as those for swarm intelligence.

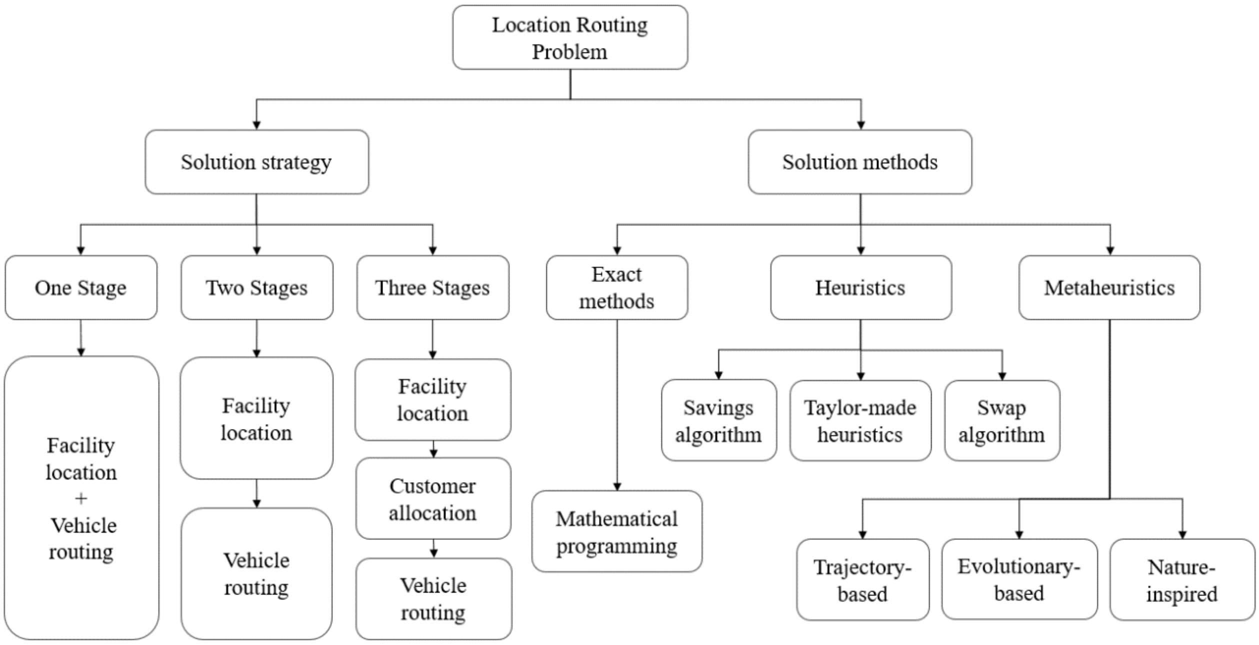

Figure 2 Summary of solution strategies and methods for LRP

4. DISCUSSION

In this section, the literature is critically analysed. Firstly, the contributions to fill the gap mentioned at the beginning of this paper are outlined. Secondly, the challenges globally mentioned in the papers are discussed. Finally, the discussion with a general view of elements such as the modelling objectives and application sectors supports the definition of potential areas for future research.

Concerning the gap identified at the beginning of this article on how the LRP has been approached, the results of the review show three solution strategies by stages. Similarly, the solution methods employed in stepwise modelling further reflect that the exact formulations are in most cases to address strategic location decisions. Heuristics and metaheuristics are used more frequently for the routing problem. However, as Mostafa & Eltawil (2016) highlight, there is no unified body of literature that covers the different decision levels and the integration between different functions in supply networks. Strategic and operational decisions have been approached from modelling, but the protocol to integrate them at a theoretical level is not clear. Although most of the papers address the problem in a single stage, which is the desired scenario, in essence, they are mixing operational decisions of vehicle routing with strategic decisions of network design without contemplating the differences in the planning horizons.

Nagy & Salhi (2007), Prodhon & Prins (2014) and Guerrero *et al.* (2013) identify the main challenge of balancing strategic and operational objectives in modelling. Strategic problems of location and operational problems of routing are interdependent but very complex to solve optimally when they are integrated. Integrated LRP models can lead to the loss of important elements in one of the decision levels as shown by Drexl & Schneider (2015). The authors describe the importance of including elements such as space-time synchronization in integrated models. Although at strategic levels the lack of temporal aspects, i.e., delivery time windows, is justified due to the long-term planning, when making daily operational decisions it is essential.

A more realistic formulation for integral modelling should include unique criteria and constraints in addition to the base LRP. Hashemi *et al.* (2022) mention some elements that pose additional but more realistic challenges. Hard and soft time windows in the retailers, simultaneous deliveries and collections in many cases and dynamic transport costs i.e., purchase or leasing vehicles. Unique characteristics of the sector imply challenges in the design of the network, such as the case of dimension stone industry (Vanteddu & Nicholls, 2020). In the case of the biomass supply chain, the reliability of the chain being modelled has implications related to costs and revenues (Cao *et al.*, 2021). The authors detail these decisions at the strategic, tactical, and operational levels, while the challenge is to improve transversal decision-making at all three levels. Pina-Pardo *et al.* (2022) mention that, in addition to the problem of identifying the number and locations of facilities, the challenge is dealing with uncertainty in demand. Stochastic models then play an important role in this matter.

In addition to the complexity of integrated modelling, Kar (2016) states that a challenge is to find the appropriate algorithm to solve the problem. By this, the authors refer to the heuristics or metaheuristics for solving LRPs. As evidenced in the literature review, there are multiple solution methods and similar algorithms, many of them as nascent proposals. In this regard, one of the conclusions of Prodhon & Prins (2014) is to establish a unified metaheuristic to avoid the emergence of many variants that may be similar.

New concepts in logistics must be adopted in the LRP models. Distribution in Smart Cities under e-commerce environments with electric fleets and cargo bikes (Leyerer *et al.*, 2020), and horizontal cooperation schemes (Quintero-Araujo *et al.*, 2019) imply additional challenges beyond modelling and represent conceptual problems that must be faced. Nowadays the last mile is gaining more and more relevance (Dablanc, 2019), consumer preferences influence all upstream processes and this phenomenon grew with the effects of the pandemic *(*Beckers *et al.*, 2021). In this context, is it correct to assume all last-mile decisions as operational? Traditional routing is strengthened with the location of urban hubs (F. Arnold *et al.*, 2018; Nataraj *et al.*, 2019). At least the location of these new nodes in the network, even if dynamic, could be in a longer planning term.

All dimensions of sustainability should be reflected in integrated models that serve to make decisions at all levels. Gholipour *et al.* (2020) identify the need for ecological and social objectives in the modelling, in addition to the economic ones addressed in the classic LRP. Multi-objective models with a heterogeneous fleet are a challenge proposed for future research (Oudouar & Zaoui, 2021). Complementing this analysis with discussions in previous literature reviews, five research opportunities are proposed below.

4.1 From Operational to Strategic Modelling

When making long-term network design decisions, last-mile distribution information is important, but not to the level of detail as when planning vehicle routing. For this reason, raising the operational analysis of the last mile to support strategic levels is a research opportunity. Literature reviews on LRP have highlighted future research in de-complex routing when it comes to integrated models to make strategic decisions (Drexl & Schneider, 2015; Nagy & Salhi, 2007; Prodhon & Prins, 2014). Modelling the last mile with a strategic approach means leaving aside daily or weekly routing information to aggregate information in long-term scenarios. An example of this are the geographic patters of demand which are not usually considered in operational modelling. Traditional models include the distance between points, but not the context of where those points are located.

Implementing analytical models for route length estimation is an alternative that is worth investigating. Some reviewed articles already include continuous approximations (CA) for the last-mile analysis (Pina-Pardo *et al.*, 2022; Zhou *et al.*, 2019). The initial formulation of CA proposed by Beardwood *et al.* (1959) as $D_n = k\sqrt{An}$ is the base for route length estimation, referring to the distance needed to visit n points in a region of area A using a distance metric constant k. However, this formulation has been enhanced to include failed deliveries (Cardenas *et al.*, 2017) and effects of density and time windows (Arevalo-Ascanio *et al.*, 2023).

Strategic models could include other variables that affect the last-mile analysis in the long term such as the characteristics of the road network (Merchán *et al.*, 2020), or parking inventory for heavy unloading. Exact models can recover usability, with this conceptual reformulation from operational to strategic modelling. Mara *et al.* (2021) concluded as a valuable contribution building models using exact methods that, with new computational advances, are becoming more feasible every day.

4.1. Multi-Dimensional Objectives in Modelling

An overview of the modelling objectives found in this literature review shows that 94% of them stick to the economic dimension when formulating modelling objectives (**Table 8**). Only one paper shows environmental objectives to minimize CO2 emissions in the location of consolidation centres in cities (Nataraj *et al.*, 2019). Similarly, only one paper proposes a social objective, with the maximization of blood collection in a pharma supply chain (Rabbani *et al.*, 2017). Although some articles address the LRP from a multi-objective perspective (Gholipour *et al.*, 2020; Hashemi *et al.*, 2022; Zandkarimkhani *et al.*, 2020), these are not in different dimensions. In this case, multi-objective models that have an impact only on the economic dimension, either by minimizing costs, delivery times or shortages are found.

Table 8 Modelling objectives in LRP literature

Modelling objective	Papers
Economic	**94%**
Cost minimization	34
Delivery time minimization	1
Shortage minimization	1
Production maximization	1
Environmental	**3%**
CO2 emissions minimization	1
Social	**3%**
Blood collection maximization	1

The literature review made by Tadaros & Migdalas (2022) on bi- and multi-objective models reflects this same situation. More than 80% of the papers reviewed by the authors model economic objectives, varying between costs, profit, coverage, and demand. Environmental objectives on emissions and fuel consumption, as well as social objectives such as employment or social effects in general, do not exceed 15% of publications. Likewise, the exhaustive literature review by Tan & Yeh (2021) about LRP models published in 2021 results in only 12% including environmental objectives (6 out of 48 papers).

Although the literature review in this paper focuses on the integration of strategic supply chain decisions with operational decisions in the last mile, it is worth highlighting the use of environmental objectives in other LRP applications. Studies such as those of Tirkolaee *et al.* (2021) and Zabihian-Bisheh *et al.* (2024) propose LRP models that include the minimization of CO_2 emissions in the disposal of medical waste and hazardous waste. In pharma logistics, the work of Dai *et al.* (2023) proposes an LRP model for the location of home health care centres, including routing decisions with electric vehicles. The minimization of CO_2 emissions and relief costs are within the modelling objectives in emergency situations, using LRP models (B. Zhang *et al.*, 2018).

This applications supports the need to include both environmental and social objectives, in addition to the economic objectives, in the modelling of LRPs is highlighted by Gholipour *et al.* (2020). In addition, it is argued that the benefit of the applications of the models must also be for society as well as for the operators (Oudouar & Zaoui, 2021). The opportunity then lies in the need to include all dimensions of sustainability in the modelling objectives. The current relevance of environmental factors and climate change cannot be ignored. As well as logistics systems oriented to society, where social objectives towards food security or the health welfare of the population are fundamental.

4.2 Application Sectors

In 63% of the papers (22), the models are applied with hypothetical data sets. The other publications show applications in urban logistics, pharma logistics, and biomass supply chains, among others (**Figure 3**). The idea behind using numerical examples is to test the performance of the model and solution approach proposed. In the context of optimization models, the performance is seen by the computational time of finding the optimal solution (Oudouar & Zaoui, 2021).

The application of complex methods to real cases represents a greater challenge. Collecting data to parameterize a model is certainly a common challenge in real applications. In the private sector, industry managers are usually not interested in how complex the model is, but in the ability to answer complex questions efficiently. From de modelling point of view, when using numerical examples, the developers define the model assuming that input data is available. In other words, the input is defined by the model. However, in practice, it is the availability of data from where developers start modelling. In this sense, research applied to real cases, including particular restrictions and conditions for each case, would be useful as a reference to replicate them in similar contexts.

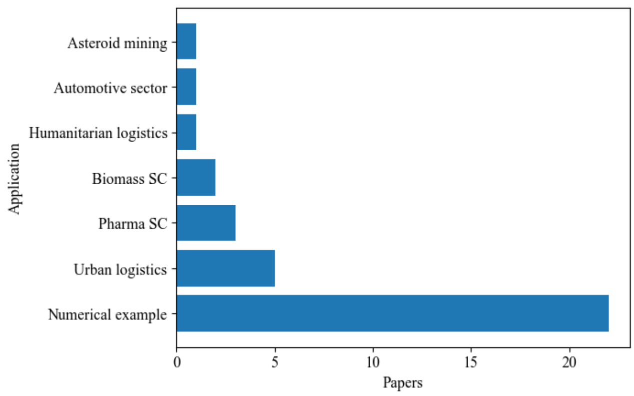

Figure 3 Application sectors of the LRP models

4.3 Competitive LRP

This research direction was proposed by Nagy & Salhi (2007) but it has not been sufficiently explored (Drexl & Schneider, 2015; Prodhon & Prins, 2014). It is interesting to see that nowadays when consumer preferences are most important, competitive and cooperative models have not been studied for the integrated supply chain design with last mile. Applications in last-mile distribution already include game theory in the decision-making process and income distribution of delivery companies that share logistics resources (Chen & Kong, 2023). Cooperative game theory methods allocate the cost savings fairly among the logistics players, taking into account individual rationality (F. Yang *et al*., 2020). Similar applications could be implemented in integrated models.

4.4 Emerging Technologies in Supply Chain for LRP

Another gap in the literature is the lack of mention of emerging technologies in supply chain management processes. Recent studies identify that technologies such as blockchain and big data analytics are a trend in decision-making within supply chains (Biedova & Mahdikhani, 2023). Blockchain technology can facilitate information sharing, traceability and automation in digital transformation (Wang *et al*., 2020), fundamental aspects in cooperative scenarios. Reliable information is key to making strategic decisions. For its part, the management of large volumes of information is something that undoubtedly impacts decision-making at all levels. Big data technologies can boost the way end consumers' information is analysed to detect their preferences and inform strategic models for the design of distribution networks (Jeble *et al*., 2018). Evaluating the use of these technologies in LRP models, as well as in more complex scenarios, is a research opportunity.

5. CONCLUSIONS AND LIMITATIONS

Over the years, academics have approached supply network modelling as a decision-making tool. Two widely known problems such as facility location – FLP and vehicle routing – VRP contribute to network modelling. An integrated approach to simultaneously address strategic network design and operational routing decisions is the location routing problem (LRP). The main goal of the current study was to review the solution strategies and methods to solve integrated strategic network design with operational routing models. The LRP is usually formulated as a mathematical programming model, but its complexity makes it difficult to find optimal solutions in a reasonable time, at least not for large instances. Hybrid solutions using heuristics and metaheuristics divide the LRP into subproblems, even though research shows that tackling these problems separately leads to inefficient solutions (Guerrero *et al*., 2013).

The second aim of this study was to identify the challenges and research opportunities of integrated modelling of strategic, tactical, and operational decisions. In addition to the complexity of modelling different time horizons (strategic long term with operational short term), the challenge is also to find the right solution method. Although some authors claim the need for a unified procedure to solve these types of problems, the literature shows that there is a proliferation of new algorithms. More realistic models should also include some other elements of urban logistics and e-commerce, such as time windows, failed delivery rate, density, etc. Last-mile decisions now go beyond daily planning, many strategies for urban distribution contemplate the use of depots or urban hubs, which, added to the growing relevance of the role of consumers, have major implications for planning at the supply network level.

Five research opportunities are proposed in this literature review. First, rethinking last-mile modelling when making strategic decisions. Bringing last-mile operational decisions to a tactical or strategic level would reduce the uncertainty caused by daily disruptions in medium- and long-term planning. Additionally, as other authors have also concluded, reducing the complexity of the last mile would have advantages when modelling. Second, new integrated models should also consider environmental and social objectives in addition to the traditional economic ones. Long-term decisions should seek sustainable development. Third, applied research with real data broadens the opportunities for replication beyond theoretical applications. While finding new solution methods is important, their applications should be equally relevant. Integrated modelling must be aware of the availability of data in the sector where it is to be applied, and in many cases, data collection is an additional challenge. Fourth, exploring competitive and cooperative models in LRP. Consumer preferences are the focus in distribution, these preferences influence last mile decisions and consequently, the way that logistics actors interact. Fifth, evaluating the use of emerging technologies. Trends in supply chain management include technologies such as blockchain and big data. However, these concepts have not been sufficiently adopted in decision-making models with LRP.

The limitations of this study lie mainly in the search for information. Although the search equation was structured, many of the LRP applications that do not mention network design together with first and last-mile distribution may have fallen outside of the search scope. Second, the literature review with two angles, namely solution strategies and methods, made the review process itself difficult. At the end, it was decided to classify the review by the solution methods, since the strategies were identified from the global reading and the bibliometric analysis. Thirdly, the proposal for future research on modelling objectives and application cases is influenced by the sample of papers reviewed, since it is a quantitative element. In the case of modelling objectives, this limitation was mitigated by also quantitatively analysing the objectives in the review of Tadaros & Migdalas (2022), which supports the conclusion.

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STATEMENTS AND DECLARATIONS

Authors Contribution

All authors contributed to the design of this study. The methodology, literature review and discussion were conducted by Arevalo-Ascanio Rafael. The original draft was written by Arevalo-Ascanio Rafael. All authors read and edited the original draft.

Declaration of Interests

The authors report there are no competing interests to declare.

Data Availability

There are no supporting data associated with this study.

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