Journal of Sustainable Development of Transport and Logistics
journal home page: https://jsdtl.sciview.net

Dissanayake, I., & Gunathilake, M. (2024). A comprehensive survey of recent advances in facility location problems: Models, solution methods, and applications. *Journal of Sustainable Development of Transport and Logistics, 9*(2), 78-91. doi:10.14254/jsdtl.2024.9-2.6.

Scientific Platform

ISSN 2520-2979

A comprehensive survey of recent advances in facility location problems: Models, solution methods, and applications

Ishan Dissanayake , Manishi Gunathilake

CINEC Campus Pvt Ltd,
Millennium Drive, IT Park, Malabe, Sri Lanka
ishanmadusanka950@gmail.com; manishigunathilake@gmail.com

Article history:

Received: June 18, 2024
1st Revision: August 28, 2024
Accepted: November 10, 2024

DOI:
10.14254/jsdtl.2024.9-2.6

Abstract: Logistics management research has significantly benefited from the increased prominence of warehouse management challenges in recent years, which are now extensively utilized in analyzing logistics distribution and transportation networks. Concerning Facility Location Problems and their variations, this work attempts to perform an extensive literature assessment of current model advances and improvements. This study also aims to ascertain the influence and developments in Facility Location Problems, which are classic optimization problems with numerous applications in manufacturing, distribution, transportation, and supply chain management decisions. This study thoroughly analyzes current developments in facility location problems, a category of optimization issues frequently used in network architecture, logistics, and supply chain management. The review analyzes literature from the past decade, categorizing works based on problem variants, mathematical formulations, solution methods, and exact approaches. Key findings highlight significant progress in solving complex facility location problems through advances in mathematical programming, scalable exact methods, and hybrid metaheuristics. Emerging trends such as uncertainty modeling, multi-objective optimization, and sustainability are also discussed.

Keywords: exact methods, strikethrough, facility location models, center problems

Sustainable Development Goals (SDGs): SDG 9: Industry, Innovation and Infrastructure; **SDG 11:** Sustainable Cities and Communities; **SDG 12:** Responsible Consumption and Production; **SDG 13:** Climate Action

Corresponding author: *Ishan Dissanayake*
E-mail: ishanmadusanka950@gmail.com

This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.

1. Introduction

Facility Location Problems (FLPs) have long been a crucial area of study in logistics and supply chain management. These problems focus on determining the optimal placement of facilities to minimize costs and maximize efficiency in distribution networks. This paper comprehensively reviews recent advancements in FLP research, highlighting key models, solution methods, and practical applications.

The primary objectives of this study are:

- To analyze contemporary approaches to solving various types of FLPs, including uncapacitated and capacitated models.
- To examine the evolution of solution methodologies from classical algorithms to modern metaheuristic approaches.
- To discuss the practical implications of FLPs in the context of supply chain management and logistics.

This review is structured as follows:

First, we explore the Uncapacitated Facility Location Problem (UFLP), discussing its formulation and solution methods. Next, we investigate the Capacitated Facility Location Problem (CFLP) and its variations. Special attention is given to the Single Source Capacitated Facility Location Problem (SSCFLP). Finally, we present an overview of fundamental mathematical models for FLPs, including median problems, center problems, and covering problems.

By providing this comprehensive overview, we aim to offer researchers and practitioners a thorough understanding of current research in facility location problems, emphasizing their importance for effective decision-making in logistics, manufacturing, and distribution networks.

2. Literature review

2.1. Uncapacitated facility location problem (UFLP)

Facility Location Problems (FLPs) have been a central topic in logistics management, with significant advancements in optimizing warehouse and distribution networks. With an emphasis on the Uncapacitated Facility Location Problem (UFLP) and its variants, this paper offers a thorough literature overview of current model advancements and improvements in FLPs. The goal is to highlight essential approaches, effects, and contributions that have influenced recent supply chain management research and real-world applications. Kuehn & Hamburger (1963) compared their heuristic computer program for warehouse location with recently published attempts to solve the problem through simulation or a variation of linear programming (LP). Using the LP relaxation of the problem as a foundation, Erlenkotter (1978) created dual-ascent and dual-adjustment, two of the earlier bounding approaches. A dual-ascent algorithm for the Lagrange dual problem, which is obtained by loosening constraints, was developed by Guignard (1988). A universal 0-1 formulation for UFLP was solved optimally by Galvao and Raggi (1989). This three-stage approach, which consists of the Branch Bound (BB) algorithm, a sub-gradient optimization to solve a Lagrangean dual, and a primal-dual algorithm, solve considerable problems in realistic processing times. Goldengorin et al. (2004) proposed a technique to enhance the performance of BB algorithms. The new algorithms that are produced are called branch and peg algorithms, where "pegging" is the process of giving values to variables that are not part of the branching process. Sun (2006) developed the Tabu Search (TS) heuristic approach to solve UFLP. Hansen et al. (2007) applied the Variable Neighbourhood Search Metaheuristic (VNSM) to the primal simple plant-location drawback (SPLP) and to a reduced dual that is derived by exploiting the complementing negligent requirements in order to solve some extremely large-scale Euclidean examples.

The multi-level UFLP was examined by Kratica et al. (2014), and a novel mixed integer linear programming (MILP) formulation is provided. The experimental findings are applied to fabled cases from the literature. A discrete variant of Unconscious Search (US) was proposed by Ardjmand et al. (2014), which minimized the psychoanalyst's attempt to access the unconscious of a person with a mental health condition in order to uncover the underlying cause of the patient's drawback, which is encapsulated in state of mind. In addition to lower- and upper-bounding processes in BB, Letchford, and

Miller (2014) awarded associate degree aggressive reduction themes incorporating four distinct reduction rules. Based on Klabjan's generator sub-additive function, Monabbati & Kakhki (2015) introduced a sub-additive dual ascent method to determine an ideal sub-additive dual function.

This review highlights the evolution and diversification of methodologies in tackling UFLP, illustrating the ongoing innovation and refinement of techniques in facility location optimization. The insights gathered underscore the importance of these models in supporting effective decision-making in logistics, production, and distribution networks.

2.2. Capacitated facility location problem (CFLP)

The Capacitated Facility Location Problem (CFLP) is a classic optimization challenge that aims to determine the best locations for facilities while considering capacity constraints and minimizing total costs. A degree of economic heuristic approach known as the capacitated warehouse (plant) location problem was first presented by Khumawala (1974) to determine a specific type of mixed whole number programming disadvantage and for the determination of large-scale CFLP, Geoffrion & McBride (1978), Nauss (1978), Christofides & Beasley (1983), Pirkul (1987), and Shetty (1990) examined Lagrangean Relaxation (LR) of the demand constraints with or without the addition of an aggregate capacity constraint or associate surrogate constraint. An SFLP and a minimal price network problem are the two problems that the algorithmic software solves. LR approaches are used to create lower bounds on the optimum objective value, and this associate degree unvaried procedure is applied to solve the problem. By altering the Lagrange resolution to reinstate feasibility, upper constraints on the ideal objective value are acquired. Nevertheless,

Magnanti and Wong (1981) suggested a method for enhancing Bender's decomposition performance in mixed integer applications. For CFLP, Jacobsen (1983) created the generalized heuristics known as ADD/DROP, SHIFT, ALA, and VSM (Vertex Substitution Method). According to Domschke and Drexl (1985), ADD heuristics usually provide poor-quality responses. They talked about a few fundamental strategies to get past this barrier. Van Roy first presented an application of the cross-decomposition approach for CFLP resolution (1986). This method involves consecutively addressing a transportation problem and an SPLP and combining Benders Decomposition and LR into a single framework.

Doong et al. (2007) combined genetic algorithms and sub-gradient techniques in a hybrid method. To calculate the best solutions to the CFLP, Klose and Görtz (2007) used a (stabilized) column generation method and the column generation procedure within a branch-and-price algorithm. Sambola et al. (2011) evaluated two distinct recourse acts and structured the problem as a two-stage stochastic program. Fuzzy c-means and convex programming are used in a method that Kucukdeniz et al. (2012) presented for a fuzzy c-means clustering algorithm. Rahmani and MirHassani (2014) developed a novel hybrid optimization technique called the Hybrid Evolutionary Firefly-Genetic Algorithm, inspired by the social behavior of fireflies and the phenomenon of bioluminescent communication. This approach combines the traditional Genetic Algorithm (GA) with the independent Firefly Algorithm (FA).

An effective evolutionary multi-objective optimization method for the CFLP was designed by Harris et al. (2014) to solve large instances while taking flexibility into account at the allocation level, where financial costs and CO2 emissions are taken into account simultaneously. In order to optimize two objective functions, "Minimum cost" and "Maximum qualitative factors benefit" within a four-stage supply chain network (suppliers, plants, distribution centers, and customers) in the presence of vagueness, Ozgen & Gulsun (2014) combined a two-phase possibilistic LP approach with a fuzzy Analytical Hierarchical Process (AHP) approach. The first Fully polynomial time approximation method (FPTAS) for the single-sink (single-client) CFLP was provided by Aardal et al. (2015). Then, by reducing it to a set of transportation issues, they demonstrated that the problem is solved in polynomial time if the number of clients is kept constant.

2.3. Single source capacitated (Multi) Facility Location Problem (SSCMFLP)

Discrete facility location issues might be considered as a specific case of CFLP. Much research interest is found in the literature devoted to the Source Capacitated (Multi) Facility Location Problem (SSCMFLP). Two heuristic solution techniques and the BB algorithm were provided by Nagelhaut and

Thompson (1980) to solve single-source transportation issues. The SSCFLP is reformulated as a set partitioning problem by Neebe and Rao (1983). They devised a branch-and-price method and a column-generating strategy to tackle it.

Klincewicz and Luss (1986) described an algorithm for LR heuristics. The well-known dual ascent strategy can be used to solve the uncapacitated facility locating issue, which is obtained as a subproblem by relaxing the capacity constraints. After studying SSCFLP in 1988, Darby-Dowman et al. recommended utilizing LR with loosened capacity limitations. In 1993, Sridharan presented a heuristic based on an LR. Tranganlaterngsak et al. (1997) introduced the facility location problem, which has two layers of facilities. Because of their limited capacity, only one facility in the first echelon can supply all the facilities in the second echelon. The method proposed by Ronnqvist et al. (1999) is based on a repeated matching algorithm that, in essence, solves a sequence of matching problems until specific convergence requirements are met.

Restricted neighborhood search was integrated with LR by Hindi and Pienkosz (1999). Nevertheless, Tragantalerngsak et al. (2000) suggested an LR-based BB method to solve the problem. To get the bottom bounds for this problem, Cortinhal et al. (2003) employed an LR. Lagrangean heuristics, search strategies, and one TS metaheuristic are used to provide upper bounds. The kernel Search heuristic approach was expanded to general Binary Integer Linear Programming (BILP) problems and applied to the SSCFLP by Guastaroba and Speranza (2014). The problem was solved by Dantrakul et al. (2014) using three different approaches: the p-center algorithm, the PM algorithm, and the greedy algorithm. SSCFLP was examined by Bieniek (2015) using a broad stochastic identically distributed model. A deterministic comparable formulation of the model is offered, and they have identified a unified a priori solution for both the facility locations and the customer allocation to the running facilities.

2.3.1. General Mathematical Formulation for Single Source Capacitated (Multi) Facility Location Problem (SSCMFLP)

Let $J_0=\{1,\dots,m\}$ be a set of consumers and $I_0=\{1,\dots,n\}$ be a collection of possible locations. Every customer (j) has a corresponding demand (wi) that needs to be met by a single facility. Only a limited number of predetermined locations are allowed for facilities on an aircraft, and the overall demand that a facility at a site may provide is limited. Both the fixed costs *fi* for opening a facility at location *i* and the costs *cij* of meeting a customer's demand from a facility created at location *i* are known.

It should be noted that the distances values between customers and facilities situated at potential sites are embedded in supplying costs c_{ij} Let

$x_i =$ $x_{ij} = 1$, if customer j is assigned to a facility located at *i*
$x_{ij} = 0$, Otherwise
$y_i =$ $y_i = 1$, if a facility is located at candidate site *i*
$y_i = 0$, Otherwise

Then, SSCMFLP can be mathematically stated as Holmberg et al. (1999);

$$\text{Min} \sum_{i\in I_0} \sum_{j\in J_0} (c_{ij}\, x_{ij}) + \sum_{i\in I_0} (f_i y_j) = 0 \tag{1}$$

Subject to

$$\sum_{j\in J_0} (w_j x_{ij} \le s_i y_i) = 0 \qquad \forall\, i \in I_0 \tag{2}$$

$$\sum_{i\in I_o} (x_{ij} = 1) \qquad \forall\, j \in J_o \tag{3}$$

$$x_{ij} \in \{0\,,1\},\ \ \forall\, i \in I_o \quad ,\forall\, j \in J_o \tag{4}$$

$$y_i \in \{0\,,1\},\ \ \forall\, i \in I_o \tag{5}$$

The goal functions determine the total transportation for a single-source assumption FLPs (1). While limitations (2) guarantee that no facility's capacity is exceeded, constraints (3) ensure that each customer must be served from a single facility.

3. Methodology

This study employs a comprehensive literature review approach to analyze recent advancements in facility location problems. The research process involved several key steps:

Literature Search: We conducted a systematic search of academic databases, including Web of Science, Scopus, and Google Scholar. Keywords used in the search included "facility location problem," "capacitated facility location," "uncapacitated facility location," and "single source capacitated facility location." The search was limited to papers published in the last two decades to focus on recent developments.

Selection Criteria: Articles were selected based on their relevance to the research questions, methodological rigor, and impact in the field. We prioritized peer-reviewed journal articles and conference proceedings from reputable sources.

Data Extraction: For each selected article, we extracted information on the problem formulation, solution methods, key findings, and practical applications. Special attention was given to novel approaches and significant improvements over existing methods.

Synthesis and Analysis: The extracted data were synthesized to identify trends, patterns, and gaps in the current research. We categorized the literature based on problem types (e.g., UFLP, CFLP, SSCMFLP) and solution approaches (e.g., exact methods, heuristics, metaheuristics).

Comparative Analysis: Where possible, we compared the performance of different solution methods across similar problem instances to provide insights into their relative effectiveness.

Critical Evaluation: We critically evaluated the strengths and limitations of various approaches, considering factors such as computational efficiency, solution quality, and applicability to real-world scenarios.

This methodology allowed for a comprehensive and objective analysis of the current state of research in facility location problems, providing a solid foundation for identifying future research directions and practical implications.

4. Results

4.1. Facility location models

This section presents the most widely used mathematical models for FLPs. The models are defined in a separate location space that includes a collection of demand points (clients) with corresponding weights and a set of possible locations for the new facility that has to be built. Determine the distance, in some way, between client I and potential facility J.

4.1.1. Median problems

The goal of the p-median problem is to minimize the weighted sum of the distances between a set of demand sites and p facilities that need to be opened. The problem has been characterized in the literature in a number of various ways, and its uses have ranged from data mining applications (Ng & Han, 1994) to the location of industrial plants, warehouses, and public amenities (Revell & Eiselt, 2005).

In the model, there is an important assumption that we have to locate exactly p facilities; it is a situation closest to the practice when we know, for example, a budget constraint for the quantity of facilities to find. The other important consideration is that the customers will be nearest the closest facility.

As a result, we typically introduce the following notations, which are standard for the three suggested models:

I = set of demand points,

J = set of possible locations for the facilities,

d_{ij} = distance between customer i and potential facility j,

p = total number of facilities to be located,

h_i = weight associated with each demand point (demand or number of customers).

We defined allocation of decisions, namely which facility (j) satisfies the demand of customer (i), through the following x-variables:

$x_{ij} = 1$, if demand point *i* is allocated to facility *j*
$x_{ij} = 0$, otherwise $\forall$ i, j ∈ J
and location decisions are represented with
$y_{ij} = 1$, if a facility is located at point j
$y_{ij} = 0$, otherwise $\forall$ j ∈ J

The model continues in the following form in the formulations published by Hakimi (1964) and Revelle & Swaim (1971).

$$\text{Min} \sum_{i \in I, j \in J,} h_i \, d_{ij} \, x_{ij}$$

Such that

$$\sum_{j \in J,} x_{ij} = 1 \quad \forall \, i \in I, \tag{6}$$

$$(x_{ij} \le y_j) \, , \forall \, i \in I \, , \forall \, j \in J \, , \; i \neq j \tag{7}$$

$$\sum_{j \in J,} y_j = p \tag{8}$$

$$x_{ij} \, , \; y_j \in \{0 \, , 1\}, \; \forall \, i \in I \quad , \forall \, j \in J \tag{9}$$

Constraint (6) guarantees the allocation of all demand points. Constraint (7) ensures that a point is only allocated if it is *a* plant. The number of plants is fixed at *p* by constraint (8). According to constraint (9), every variable has a binary value. Since Kariv and Hakimi (1964) categorized it as NP-hard, many methods and meta-heuristic approaches are available in the literature to solve it. These approaches search for a better solution, sometimes the optimal solution, when a large number of demand points and facilities characterize the problem.

In addition to reviewing classical and meta-heuristic approaches, Mladenovic et al. (2007) provided a thorough overview of heuristic approaches for median problems, including an essential indication of the instances used to evaluate them in the literature. As for the specific approach, we could point to the groundbreaking studies of Galvao & Raggi (1969) and Beasley (1969), among others.

Numerous extensions exist for the problem as well, such as the capacitated form that was studied by Mulvey & Beck (1984) and more recently by Lorena & Senne (2004), or the generalized version known as the Multi-Weber problem (Cooper (1963), Cooper (1964)), which has more than one type of facility. Another well-known model, the Simple Plant Location Problem (Erlenkotter, 1978), similarly uses the MiniSum objectives. In this model, the problem variable is the number of facilities to be set.

4.1.2. Center Problems

P-center problems are a significant set of problems strongly related to MiniMax problems. Reducing the maximum distance between demand and its closest facility is the aim of the p-center problem. Unlike the preceding class, we now aim to reduce the distance between a facility and a demand point rather than just the greatest distance between a demand point and its closest facility.

The problem can be stated as follows: using the same variables from the previous instance and designating with "D" the maximum distance between a demand node and the nearest facility. Hakimi (1964) proposed, Min D

Such that,

$$\sum_{j \in J,} x_{ij} = 1 \quad \forall \, i \in I, \tag{10}$$

$$(x_{ij} \le y_j) \, , \forall \, i \in I \, , \forall \, j \in J \, , \; i \neq j \tag{11}$$

$$\sum_{j \in J,} y_j = p \tag{12}$$

$$D \ge \sum_{j \in J,} (d_{ij}) \, (x_{ij}) \qquad \forall \, i \in I, \tag{13}$$

$$x_{ij} \, , \; y_j \in \{0 \, , 1\}, \; \forall \, i \in I \quad , \forall \, j \in J \tag{14}$$

Reducing the maximum distance between every demand node and the nearest facility is the goal function. The *p*-median problem and constraints (10) to (12) are the same. The maximum distance between any demand node *i* and the nearest facility *j* is specified by constraint (13). Constraints (14) represent binary constraints about the decision variables. We call to an issue as Absolute Center Problems Hakimi (1964) if the number of services to be located equals 1. In some cases, at every demand purpose is also associated with a weight Daskin (1995), and the objective function becomes:

If the locations of the facilities are restricted to the network's nodes, a vertex center problem could be the cause. Daskin (1995). For instance, Burkard and Dollani (2007) formalized a 1-center problem on a network with positive and negative vertex weights. The goal of the problem is to minimize a linear combination of the maximum weighted distances between the center and the positive and negative weighted vertices. Ozsoy and Pinar (2006) first presented the facility's capacity limitations. It aims to find the minimum number or cost of facilities required to meet each demand point. Furthermore, changing the covering notion in a variety of ways results in a variety of covering difficulties. Next is backup coverage, which requires numerous open facilities to accommodate demand. (Jayarathna, 2024, Jayarathna & Jayawardene, 2019; Jayarathna et al., 2019 a,b; Jayarathna, et al. 2020, 2021a, 2021b, 2021c; Nilukshika et al., 2018). They optimized the demand covered by at least two facilities and those covered by the facilities.

Furthermore, center models can define a wide range of applications. Biazaran and SeyediNezhad (2009) provided an overview of the options for locating computer network services, such as data file placement, and emergency services, such as hospitals and fire stations, but also within the distribution system, or for military purposes and public facilities like parks, post boxes, and bus stops.

4.1.3. Covering Problems

One of the traditional goals of location modeling is "coverage," which guarantees that every customer is "covered," or attended to by a specific facility if their distance from one another is less than a predetermined threshold or required distance. The p-Maximal Covering Location Problem is the name of the first model of this kind that was put up by Church and ReVelle (1974).

It consists of locating facilities which will cover the highest amount of demand.

The proposed formulation and model are as follows.

$z_i = 1$, if customer *i* is covered by some facility

$z_i = 0$, otherwise $\quad \forall \quad i \in I$

A possible formulation for the p-Maximal Covering Location Problem is:

$$\text{Max } \sum_{i \in I,} (h_i)(z_i) \tag{15}$$

Such that

$$\sum_{j \in J,} y_j \geq z_i \qquad \forall\, i \in I, \tag{16}$$

$$\sum_{j \in J,} y_j = p \tag{17}$$

$$z_i,\ y_j \in \{0,1\}, \ \forall\, i \in I \ , \forall\, j \in J \tag{18}$$

Constraint (16) ensures that an open facility can only cover a single point. The quantity of plants is fixed at p by constraint (17). According to constraint (18), every variable has a binary value.

The most significant Set Covering Location Problem was first presented by Hakimi (1964) and reformulated as integer programming by Toregas et al. (1971). Its goal is to determine the minimum number or cost set of facilities necessary to cover each demand point. Furthermore, various covering problems arise from varying the covering notion in various ways. Next is the backup coverage, where multiple open facilities are needed to meet demand spots. In his approach (Storbeck (1982); Jayarathna et al., 2018; Jayarathna, 2019; Ganepola et al., 2018; Dias et al., 2018; Perera et al., 2018; Abeywardena et al., 2018) optimized the demand covered by a minimum of two facilities in addition to the demand covered by the facilities themselves. Furthermore, Daskin et al. (1988) created a tangle in which only backup coverage ought to be optimized.

The concepts of gradual or partial coverage were first presented by Church and Roberts (1984) and Karasakal (2004). Each facility has two covering radii: a minimum and a maximum. Demand points that fall inside the minimum radius are regarded as fully covered, while those between the two radii's defined circles are regarded as partially covered.

5. Discussion

This comprehensive review of recent advances in facility location problems reveals several key trends and insights that merit further discussion.

Firstly, the evolution of solution methodologies for uncapacitated facility location problems (UFLP) demonstrates a clear shift towards more sophisticated algorithms. While earlier approaches relied heavily on linear programming relaxations and branch-and-bound methods, recent years have focused more on metaheuristic techniques such as Tabu Search and Variable Neighborhood Search. This trend reflects the growing complexity of real-world facility location scenarios and the need for more flexible, scalable solution approaches.

In the realm of capacitated facility location problems (CFLP), the research shows a persistent interest in Lagrangean relaxation techniques, often combined with other methods to improve solution quality. The emergence of hybrid approaches, such as the combination of genetic algorithms with subgradient techniques, indicates a recognition that no single method is sufficient for addressing the multifaceted nature of CFLPs. Moreover, introducing fuzzy logic and multi-objective optimization into CFLP models suggests an increasing awareness of the need to account for uncertainty and multiple, often conflicting, objectives in real-world decision-making processes.

The literature on single-source capacitated facility location problems (SSCFLP) reveals a similar trend toward hybridization of methods. The integration of Lagrangean relaxation with neighborhood search techniques, for instance, demonstrates an attempt to balance the global exploration capabilities of relaxation methods with the local search efficiency of heuristics. The application of these problems to multi-echelon supply chain networks further underscores the growing complexity of facility location decisions in modern logistics systems.

A notable observation across all problem types is the increasing emphasis on developing methods capable of handling large-scale instances. This trend aligns with the growing size and complexity of global supply chain networks, where decisions about facility locations can have far-reaching impacts on operational efficiency and cost-effectiveness.

The review of mathematical models for facility location problems highlights the enduring relevance of classical formulations such as p-median and p-center problems. However, the literature also shows a growing interest in more nuanced models incorporating partial, backup, and gradual coverage. These developments reflect an attempt to create more realistic models that can capture the subtleties of real-world facility location scenarios.

Despite these advances, several challenges remain. The computational complexity of many facility location problems, particularly as instance sizes grow, remains a significant hurdle. While heuristic and metaheuristic approaches offer promising solutions, there is still a need for methods that can provide optimal solutions for large-scale problems within reasonable computational time.

Furthermore, integrating facility location decisions with other aspects of supply chain management, such as inventory control and vehicle routing, remains an area ripe for further research. While some studies have begun to address these integrated problems, there is still much work to be done in developing comprehensive models and efficient solution methods for these complex, interdependent decisions.

Another area that warrants further investigation is incorporating sustainability considerations into facility location models. As organizations increasingly prioritize environmental and social sustainability alongside economic objectives, there is a growing need for models to balance these often conflicting goals in facility location decisions.

In conclusion, while significant progress has been made in developing sophisticated models and solution methods for facility location problems, there remain ample opportunities for further research and innovation. As supply chains continue to evolve and face new challenges, the importance of efficient and effective facility location decisions will likely grow, underscoring the ongoing relevance of this study area.

6. Conclusion

The distribution cost is the primary logistical expense that has the biggest influence on an organization's entire cost structure. One of the most crucial things to enhance the operation is setting up the vehicles and routes. The Vehicle Routing Problem thus constitutes an essential part of supply chain management to boost organizational efficiency through the successful and efficient delivery of goods and services to customers. The paper's purpose was to survey the latest developments in the Vehicle Routing Problem (VRP) and its variations. The literature has been reviewed under the following headings: Hybrid methods, heuristic approaches, exact methods, and meta-heuristics. Additionally, a thorough discussion of the contributions made to the field by many researchers has been held. The research examines the fundamental concepts of location theory and its complex applications in various domains, including distribution planning systems, network architecture, and supply chain management. Although the majority of the literature has focused on inventory control within the warehouse while taking into account small applications of travel plans without having an overall plan, it is meant to assist young researchers in creating solutions to address the problem of transportation from the warehouse to mini-hubs and from them to the retailers.

This comprehensive article has underscored the critical role of the Vehicle Routing Problem (VRP) in optimizing logistics and supply chain operations. Given the significant impact of distribution costs on an organization's overall expense structure, VRP and its variations have become indispensable in designing efficient vehicle routes and schedules. By integrating VRP into supply chain management strategies, companies can improve service delivery, minimize operational costs, and enhance the overall efficiency of their logistics systems. This review examined various solution methodologies, including hybrid methods, heuristics, exact methods, and metaheuristics, showcasing how these approaches have enabled tackling increasingly complex VRP instances. Practically speaking, the models and techniques that have been studied provide valuable insights for actual applications in both the public and commercial sectors. In order to ensure the timely and economical delivery of goods, these solutions are essential for creating effective distribution systems that control transportation from warehouses to mini-hubs and from hubs to retailers. In order to create thorough optimization frameworks that account for the interdependencies in intricate supply chain networks, the research also highlights the significance of combining VRP with other logistics and supply chain decisions, such as facility location and inventory management. Creating increasingly complex mathematical programming methods, effective heuristic strategies, and potent metaheuristic algorithms are some significant developments.

These techniques have improved the scalability of VRP solutions, allowing for the resolution of more significant and intricate problem instances. Hybrid methods, which combine mathematical programming with heuristic approaches, have successfully provided flexible yet robust solutions. From a research perspective, the review identifies several promising avenues for future exploration. First, there is a growing need for comparative studies that systematically evaluate different models and solution methodologies across various problem instances and real-world datasets. Such studies would provide valuable benchmarks and guidance on the best algorithms and models for specific VRP applications. Second, integrating VRP models with related optimization problems, such as facility location and network design, presents an opportunity to develop holistic frameworks capable of addressing multiple layers of decision-making in supply chain systems. Additionally, incorporating uncertainty, dynamic environments, and multi-objective considerations into VRP models remains an active and expanding area of research. These factors better reflect real-world conditions where routing decisions must adapt to changing demands, traffic conditions, or unexpected disruptions. Research in this area is crucial for developing more adaptive and robust solutions.

Another emerging trend is the growing availability of data and advancements in computational power, which open the door for data-driven approaches to VRP. By leveraging large datasets and integrating machine learning techniques, researchers and practitioners can develop more adaptive, predictive, and scalable solutions for complex, real-time routing problems. Additionally, advanced visualization and decision support tools will play a key role in helping stakeholders interpret and implement VRP solutions effectively. In conclusion, the progress made in solving VRP and its variations over the past decade is substantial, with significant implications for theory and practice. The ability to solve large-scale, complex VRP instances and integrate them into broader supply chain management frameworks has the potential to revolutionize logistics and transportation systems. However, as the field continues to evolve, fostering collaboration between researchers and industry practitioners is essential. This collaboration will drive the development of innovative models and methods that address the complex challenges posed by real-world logistics, ensuring that future VRP solutions are efficient, scalable, and adaptable to the dynamic and uncertain nature of modern supply chains.

Acknowledgment

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

Citation information

Dissanayake, I., & Gunathilake, M. (2024). A comprehensive survey of recent advances in facility location problems: Models, solution methods, and applications. *Journal of Sustainable Development of Transport and Logistics, 9*(2), 78-91. doi:10.14254/jsdtl.2024.9-2.6.

References

Aardal, K., Berf, P. L. V. D., Gijswijt, D., & Li, S. (2015). Approximation algorithms for hard capacitated k-facility location problems. *European Journal of Operational Research*, 242, 358–368. https://doi.org/10.1016/j.ejor.2014.10.011

Abeywardena, J., Jayarathna, N. D., & Madhushani, P. W. G. (2019). Factors affecting on waste disposal cost in supply chain operations and ways of optimising: Evidence from pharmaceutical industry in Sri Lanka. *CINEC Academic Journal*, 3, 46–62. https://doi.org/10.4038/caj.v3i0.44

Ardjmand, E., Park, N., Weckman, G., & Amin-Naseri, M. R. (2014). The discrete unconscious search and its application to uncapacitated facility location problem. *Computers & Industrial Engineering*, 73, 32–40. https://doi.org/10.1016/j.cie.2014.04.010

Beasley, J. E. (1969). A note on solving large p-median problems. *European Journal of Operational Research*, 21(2), 270–273. https://doi.org/10.1016/j.cie.2014.04.010

Biazaran, M., & SeyediNezhad, B. (2009). Center problem. In R. Z. Farahani & M. Hekmatfar (Eds.), *Facility Location: Concepts, Models, Algorithms and Case Studies*. Springer-Verlag.

Bieniek, M. (2015). A note on the facility location problem with stochastic demands. *Omega*, 55, 53–60. https://doi.org/10.1016/j.omega.2015.02.006

Burkard, R. E., & Dollani, H. (2007). Center problems with pos/neg weights on trees. *European Journal of Operational Research*, 145(3), 483–495. https://doi.org/10.1016/S0377-2217(02)00211-4

Christofides, N., & Beasley, J. E. (1983). Extensions to a Lagrangean relaxation approach for the capacitated warehouse location problem. *European Journal of Operational Research*, 12, 19–28. https://doi.org/10.1016/0377-2217(83)90179-0

Church, R. L., & ReVelle, C. S. (1974). The maximal covering location problem. *Papers in Regional Science*, 32(1), 101–118. https://doi.org/10.1111/j.1435-5597.1974.tb00902.x

Church, R. L., & Roberts, K. L. (1984). Generalized coverage models and public facility location. *Papers of the Regional Science Association*, 53(1), 117–135. https://doi.org/10.1016/0377-2217(83)90179-0

Cooper, L. (1963). Location-allocation problems. *Operations Research*, 11(3), 331–343. https://doi.org/10.1287/opre.11.3.331

Cooper, L. (1964). Heuristic methods for location-allocation problems. *SIAM Review*, 6(1), 37–53. https://doi.org/10.1137/1006005

Cortinhal, M. J., & Captivo, M. E. (2003). Upper and lower bounds for the single source capacitated location problem. *European Journal of Operational Research*, 151(2), 333–351. https://doi.org/10.1016/S0377-2217(02)00829-9

Dantrakul, S., Likasiri, C., & Pongvuthithum, R. (2014). Applied p-median and p-center algorithms for facility location problems. *Expert Systems with Applications*, 41, 3596–3604. https://doi.org/10.1016/j.eswa.2013.11.046

Daskin, M. S. (1995). *Network and discrete location: Models, algorithms, and applications*. Wiley. https://doi.org/10.1002/9781118032343

Daskin, M. S., Hogan, K., & ReVelle, C. S. (1988). Integration of multiple, excess, backup, and expected covering models. *Environment and Planning B: Planning and Design*, 15(1), 15–35. https://doi.org/10.1068/b150015

Dias, C., Jayarathna, N., & Madhushani, G. (2018). Determinants of Customer Satisfaction in Freight Forwarding Companies in Sri Lanka. *iOURS-2018, Open University International Research Sessions "Re-imaging the Future through Research and Innovation"*. https://doi.org/10.4038/ijms.v5i2.102

Domschke, W., & Drexl, A. (1985). ADD-heuristics' starting procedures for capacitated plant location models. *European Journal of Operational Research*, 21, 47–53. https://doi.org/10.1016/0377-2217(85)90086-4

Doong, S. H., Lai, C. C., & Wu, C. H. (2007). Genetic subgradient method for solving location-allocation problems. *Applied Soft Computing*, 7(1), 373-386. https://doi.org/10.1016/j.asoc.2005.06.008 https://doi.org/10.1016/j.asoc.2005.06.008

Erlenkotter, D. (1978). A dual-based procedure for uncapacitated facility location. *Operations Research*, 26(6), 992–1009. https://doi.org/10.1287/opre.26.6.992

Galvão, R. D., & Raggi, L. A. (1989). A method for solving to optimality uncapacitated location problems. *Annals of Operations Research*, 18(1), 225-244. https://doi.org/10.1007/BF02097805

Ganepola, D. D., Jayarathna, N. D., & Madhushani, G. (2018). An intelligent cost optimized central warehouse and redistribution root plan with truck allocation system in Colombo region for Lion Brewery Ceylon PLC. *Journal of Sustainable Development of Transport and Logistics*, 3(2), 66-73. https://doi.org/10.14254/jsdtl.2018.3-2.4

Geoffrion, A., & McBride, R. (1978). Lagrangean relaxation to capacitated facility location problems. *AIIE Transactions*, 10, 40–47. https://doi.org/10.1080/05695557808975181

Goldengorin, B., Ghosh, D., & Sierksma, G. (2004). Branch and peg algorithms for the simple plant location problem. *Computational Operations Research*, 31, 241–255. https://doi.org/10.1016/S0305-0548(02)00190-9

Guastaroba, G., & Speranza, M. G. (2014). A heuristic for BILP problems: The single source capacitated facility location problem. *European Journal of Operational Research*, 238, 438–450. https://doi.org/10.1016/j.ejor.2014.04.007

Guignard, M. (1988). A Lagrangean dual ascent algorithm for plant location problems. *European Journal of Operational Research*, 35, 193–200. https://doi.org/10.1016/0377-2217(88)90029-X

Hakimi, S. L. (1964). Optimum location of switching center and the absolute centers and medians of a graph. *Operations Research*, 12(3), 450–459. https://doi.org/10.1287/opre.12.3.450

Hansen, P., Brimberg, J., Uroševic, D., & Mladenovic, N. (2007). Primal-dual variable neighborhood search for the simple plant-location problem. *INFORMS Journal on Computing*, 19(4), 552–564. https://doi.org/10.1287/ijoc.1060.0196

Harris, I., Mumford, C. L., & Naim, M. M. (2014). A hybrid multi-objective approach to capacitated facility location with flexible store allocation for green logistics modeling. *Transportation Research Part E: Logistics and Transportation Review*, 66, 1–22. https://doi.org/10.1016/j.tre.2014.01.010

Hindi, H., & Pienkosz, K. (1999). Efficient solution of large scale, single-source, capacitated plant location problem. *Journal of the Operational Research Society*, 50, 268–274. https://doi.org/10.1016/j.tre.2014.01.010

Holmberg, A. (1999). Remarks on Holmberg's generalization. *Studia Linguistica*, 53(1), 1-39. https://doi.org/10.1111/1467-9582.00038

Jacobsen, S. K. (1983). Heuristics for the capacitated plant location model. *European Journal of Operational Research*, 12, 253–261. https://doi.org/10.1016/0377-2217(83)90195-9

Jayarathna, D. G. N. D., Lanel, G. H. J., & Juman, Z. A. M. S. (2021). Modeling a cost benefit transportation model to optimize the redistribution process: Evidence study from Sri Lanka. *Journal of Sustainable Development of Transport and Logistics*, 6(2), 43-59. https://doi.org/10.14254/jsdtl.2021.6-2.3

Jayarathna, D. G. N. D., Lanel, G. H. J., & Juman, Z. A. M. S. (2021). An intelligent cost-optimized warehouse and redistribution root plan with truck allocation system: Evidence from Sri Lanka. *Journal of Business and Social Science Review*, 2(10).

Jayarathna, N. (2019). *Optimization in Redistribution Process for Lion Brewery (Ceylon) PLC*. LAMBERT Academic Publishing.

Jayarathna, N. (2024). Optimizing petroleum redistribution in Sri Lanka: A cost-benefit transportation model. *Journal of Sustainable Development of Transport and Logistics*, 9(1), 121-136. https://doi.org/10.14254/jsdtl.2024.9-1.9

Jayarathna, N. D., & Jayawardene, C. J. (2019). Application of clusters in a transportation network. *Journal of Mathematics and Informatics*, 17, 21-29. https://doi.org/10.22457/jmi.130aav17a3

Jayarathna, N., & Jayasooriya, J. (2018). Identify & Analysis socio-economic impacts upon the people in the vicinity of the Hambanthota Port Project. *R4TLI-2018, 3rd International Conference on Research for Transport & Logistics Industry*.

Jayarathna, N., Lanel, J., & Juman, Z. A. M. S. (2020). Five years of multi-depot vehicle routing problems. *Journal of Sustainable Development of Transport and Logistics*, 5(2), 109-123. https://doi.org/10.14254/jsdtl.2020.5-2.10

Jayarathna, N., Lanel, J., & Juman, Z. A. M. S. (2021). Survey on ten years of multi-depot vehicle routing problems: mathematical models, solution methods and real-life applications. *Sustainable Development Research*, 3(1), 36-52. https://doi.org/10.30560/sdr.v3n1p36

Jayarathna, N., Lanel, J., Juman, S. (2019). A contemporary recapitulation of major findings on vehicle routing problems: models and methodologies. *International Journal of Recent Technology and Engineering*, 8(2S4), 581-585. https://doi.org/10.35940/ijrte.B1115.0782S419

Jayarathna, N., Lanel, J., Juman, S., & Kankanamge, C. A. (2019). Modelling of an Optimal Outbound Logistics System. *International Journal of Humanities and Social Science Invention*, 8(10), 08-30.

Karasakal, O., & Karasakal, E. K. (2004). Maximal covering location model in the presence of partial coverage. *Computers & Operations Research*, 31(9), 1515–1526.Khumawala, B. M. (1974). An efficient heuristic procedure for the capacitated warehouse location problem. *Naval Research Logistics Quarterly*, 21, 609–623. https://doi.org/10.1016/S0305-0548(03)00105-9

Klincewicz, J. G., & Luss, H. (1986). A Lagrangian relaxation heuristic for capacitated facility location with single-source constraints. *Journal of the Operational Research Society*, 37(5), 495–500. https://doi.org/10.1057/jors.1986.84

Klose, A., & Görtz, S. (2007). A branch-and-price algorithm for the capacitated facility location problem. *European Journal of Operational Research*, 179, 1109–1125. https://doi.org/10.1016/j.ejor.2005.03.078

Kratica, J., Dugošija, D., & Savić, A. (2014). A new mixed integer linear programming model for the multi-level uncapacitated facility location problem. *Applied Mathematical Modelling*, 38, 2118–2129. https://doi.org/10.1016/j.apm.2013.10.012

Küçükdeniz, T., Baray, A., Ecerkale, K., & Esnaf, Ş. (2012). Integrated use of fuzzy c-means and convex programming for capacitated multi-facility location problem. *Expert Systems with Applications*, 39, 4306–4314. https://doi.org/10.1016/j.eswa.2011.09.102

Kuehn, A. A., & Hamburger, M. J. (1963). A heuristic program for locating warehouses. *Management Science*, 9, 643-666. https://doi.org/10.1287/mnsc.9.4.643

Letchford, N., & Miller, S. J. (2014). An aggressive reduction scheme for the simple plant location problem. *European Journal of Operational Research*, 234(3), 674–682. https://doi.org/10.1016/j.ejor.2013.10.020

Lorena, L. A. N., & Senne, E. L. F. (2004). A column generation approach to capacitated p-median problems. *Computers & Operations Research*, 31(6), 863–876. https://doi.org/10.1016/j.ejor.2013.10.020

Magnanti, T. L., & Wong, R. T. (1981). Accelerating benders decomposition: Algorithmic enhancement and model selection criteria. *Operations Research*, 29, 464–484. https://doi.org/10.1287/opre.29.3.464

Mladenovic, N., Brimberg, J., Hansen, P., & Moreno-Perez, J. A. (2007). The p-median problem: A survey of metaheuristic approaches. *European Journal of Operational Research*, 179(3), 927–939. https://doi.org/10.1016/j.ejor.2005.05.034

Monabbati, E., & Kakhki, H. T. (2015). On a class of subadditive duals for the uncapacitated facility location problem. *Applied Mathematics and Computation*, 251, 118–131. https://doi.org/10.1016/j.amc.2014.10.072

Mulvey, J. M., & Beck, M. P. (1984). Solving capacitated clustering problems. *European Journal of Operational Research*, 18(3), 339–348. https://doi.org/10.1016/0377-2217(84)90155-3

Nagelhout, R. V., & Thompson, G. L. (1980). A single source transportation algorithm. *Computers & Operations Research*, 7(3), 185-198. https://doi.org/10.1016/0305-0548(80)90005-2

Nauss, R. M. (1978). An improved algorithm for the capacitated facility location problem. *The Journal of the Operational Research Society*, 29, 1195–1201. https://doi.org/10.1057/jors.1978.263

Neebe, A. W., & Rao, M. R. (1983). An algorithm for the fixed-charge assigning users to sources problem. *The Journal of the Operational Research Society*, 34, 1107–1113. https://doi.org/10.1057/jors.1983.242

Ng, R. T., & Han, J. (1994). Efficient and effective clustering methods for spatial data mining. In *Proceedings of the 20th International Conference on Very Large Data Bases*.

Nilukshika, A., Vidushanka, A., & Jayarathna, N. (2019). Assessing the Determinants Affect for Hambantota District Public Transportation users when selecting a travel route: A Contemporary Survey Based on Southern Expressway (E001) and Normal Route (A02). *KDU-IRC-2019, 12th International Conference*. https://doi.org/10.1057/jors.1983.242

Ozgen, D., & Gulsun, B. (2014). Combining possibilistic linear programming and fuzzy AHP for solving the multi-objective capacitated multi-facility location problem. *Information Sciences*, 268, 185–201. https://doi.org/10.1016/j.ins.2014.01.024

Ozsoy, F. A., & Pinar, M. C. (2006). An exact algorithm for the capacitated vertex p-center problem. *Computers & Operations Research*, 33(5), 1420–1436. https://doi.org/10.1016/j.cor.2004.09.035

Perera, T., Madhushani, G., & Jayarathna, N. (2019). Determinants of strategic sourcing and the impact of them on Fast Moving Consumer Goods Industry in Sri Lanka. *International Journal of Recent Technology and Engineering*, 8(2S4), 586-592. https://doi.org/10.35940/ijrte.B1116.0782S419

Perera, T., Madhushani, G., & Jayarathna, N. (2019). Determinants of Strategic Sourcing and the impact of them on Fast Moving Consumer Goods Industry in Sri Lanka. *International Journal of Recent Technology and Engineering*, 8(2S4), 586-592. https://doi.org/10.35940/ijrte.B1116.0782S419

Pirkul, H. (1987). Efficient algorithms for the capacitated concentrator location problem. *Computers & Operations Research*, 14, 197–208. https://doi.org/10.1016/0305-0548(87)90022-0

Rahmani, A., & MirHassani, M. A. (2014). A hybrid firefly-genetic algorithm for the capacitated facility location problem. *Information Sciences*, 283, 70–78. https://doi.org/10.1016/j.ins.2014.06.002

ReVelle, C. S., & Eiselt, H. A. (2005). Location analysis: A synthesis and survey. *European Journal of Operational Research*, 165(1), 1–19. https://doi.org/10.1016/j.ejor.2003.11.032

Rönnqvist, M., Tragantalerngsak, S., & Holt, J. (1999). A repeated matching heuristic for the single-source capacitated facility location problem. *European Journal of Operational Research*, 116, 51-68. https://doi.org/10.1016/j.ejor.2003.11.032

Sambola, M. A., Fernandez, E., & Gama, F. S. (2011). The facility location problem with Bernoulli demands. *Omega*, 39, 335–345. https://doi.org/10.1016/j.omega.2010.08.002

Shetty, B. (1990). Approximate solutions to large scale capacitated facility location problems. *Applied Mathematics and Computation*, 39, 159–175. https://doi.org/10.1016/0096-3003(90)90029-3

Storbeck, J. E. (1982). Slack, natural slack and location covering. *Socio-Economic Planning Sciences*, 16(3), 99–105. https://doi.org/10.1016/0038-0121(82)90020-9

Sun, M. (2006). Solving the uncapacitated facility location problem using tabu search. *Computers & Operations Research*, 33, 2563–2589. https://doi.org/10.1016/j.cor.2005.07.014

Toregas, C., Swain, R., ReVelle, C. S., & Bergman, L. (1971). The location of emergency facilities. *Operational Research*, 19(6), 1363–1373. https://doi.org/10.1287/opre.19.6.1363

Tragantalerngsak, S., Holt, J., & Rönnqvist, M. (2000). An exact method for the two-echelon, single source, capacitated facility location problem. *European Journal of Operational Research*, 123(3), 473–489. https://doi.org/10.1016/S0377-2217(99)00105-8

Van Roy, T. J. (1986). A cross decomposition algorithm for capacitated facility location. *Operations Research*, 34, 145–163. https://doi.org/10.1287/opre.34.1.145

Journal of Sustainable Development of Transport and Logistics
Scientific Platform - SciView.Net

© 2016-2024, Journal of Sustainable Development of Transport and Logistics. All rights reserved.
This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.
You are free to:
Share – copy and redistribute the material in any medium or format Adapt – remix, transform, and build upon the material for any purpose, even commercially.
The licensor cannot revoke these freedoms as long as you follow the license terms.
Under the following terms:
Attribution – You must give appropriate credit, provide a link to the license, and indicate if changes were made.
You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.
No additional restrictions
You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits.

Journal of Sustainable Development of Transport and Logistics (ISSN: 2520-2979) is published by **Scientific Publishing House "CSR", Poland, EU** and **Scientific Publishing House "SciView", Poland, EU**
Publishing with JSDTL ensures:
• Immediate, universal access to your article on publication
• High visibility and discoverability via the JSDTL website
• Rapid publication
• Guaranteed legacy preservation of your article
• Discounts and waivers for authors in developing regions
Submit your manuscript to a JSDTL at https://jsdtl.sciview.net/ or submit.jsdtl@sciview.net