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A Survey of the Integration of the Coverage Concept in Routing Problems

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ABSTRACT

Many academics and business professionals have developed vehicle routing models to solve multiple logistical challenges. Due to their significance in resolving several real-world problems, these problems have been given a lot of attention in the study. The most frequent problems in operations research are vehicle routing problems (VRP), traveling salesman problems (TSP), and location routing Problems (LRP). Several constraints and variants were treated and introduced to the routing problems, such as time window, capacity constraints, and a heterogeneous fleet of vehicles. These variants have multiple impacts that can affect, for example, the environment. For this, the researchers treat the problems according to their needs, and in this case, they introduce the green VRP or any other problem according to the situation. Scientists were interested in routing problems because of their capacity to solve the majority of real cases, which aims to minimize routing costs and maximize profit, and this the objective of all the routing problems. Sometimes it's hard or impossible to visit every node due to limitations on some resources, such as time, budget, and energy. This idea allows us to indirectly satisfy the demand of unvisited customers by visiting them.

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1. Introduction

Over the past six decades, routing problems have been the focus of extensive research. These issues have gotten a lot of attention in combinatorial optimization, particularly in operations research and transportation. The routing problem consists of a set of restricted capacity vehicles, a set of locations and sometimes a central depot. The goal is to determine the optimum routes to visit the selected locations with minimum costs. Moreover, it is important to know that these problems have been proved to be NP-hard in the literature. All the decision problems are classified according to their complexity theory into two classes: either P or NP classes. First of all, we have the problems collected in class P these which can be solved using a deterministic polynomial time approach thus it's are easy to solve. Secondly, the NP class is a collection of problems that can be solved using a non-deterministic polynomial time approach. Any problem belonging to the first class also belongs to the second one. However, this classification is not only because the second class is composed of two subclasses: NP-complete and NP-hard. The most important part of this class is the NP-complete, which is the hardest problem and the NP-hard class contains the most difficult optimization problems. This later subclass is composed of problems that are simple to define but difficult to solve, especially when using large instances in which the number of nodes is huge. It is crucial to note that the routing problems belong to the NP-hard problems.

Regarding the restrictions on some resources such as time, energy, and vehicle capacities, sometimes visiting all the nodes is impossible. For example, we take the case of a rescue team that has to intervene after a disaster. Disaster relief is one of the cases where we expect to meet many restrictions: the team must rescue a maximum of people in a minimum of time. Moreover, we have the constraints of the capacitated vehicles, which limits the solution, for example, in the case of transportation networks or healthcare logistics. In order to reduce routing costs, multiple strategies have been proposed over the years, such as building new depots and facilities or using more vehicles with larger capacity. Unfortunately, these two strategies seem to be costly and difficult to implement. Consequently, the effect will be reversible and costs will increase. To deal with these problems, researchers introduced the concept of covering to reduce total costs as a new approach. This idea can be treated in different ways: sometimes the scientists divide the set of nodes into several sets beside others treat the problem by keeping the same set of nodes of the main problem.

1.1. Objectives of this paper

We noticed an absence of papers that review articles dealing with the covering concept applied in routing problems. In the literature, we can only find reviews on each problem by itself or with its variants. For example, in the case of the VRP the latest reviews are (Konstantakopoulos et al., 2022), (Asghari & Mirzapour Al-e-hashem, 2021), and (Kucukoglu et al., 2021). When studying the TSP, the more recent surveys are (Khoufi et al., 2019), (Pop et al., 2023) and (Cheikhrouhou & Khoufi, 2021). Finally, the researches on the LRP conduct to few reviews on this problem; the recent one are (Mara et al., 2021), (Schiffer et al., 2019) and (Tadaros & Migdalas, 2022). In order to fill the gap, we propose a survey that deals with this covering issue during a 10-year period from 2013 to 2023. The main objectives of this survey are:

- To review the articles that concern this topic and identify the main problems that have been handled.
- To classify and summarize the research.

- To show the development of the routing problem research over time.
- To derive principal recommendations and future work based on the literature survey.

1.2. Outline of this paper

The remainder of our survey is organized as follows: After introducing the general definition of the routing problems in Sect. 1, the research methodology and the studied problems are presented in Sect. 2. Whereas, the definition and literature review are provided in Sect. 3. Finally, Sect. 4 concludes this research and presents future research on this work.

2. Survey methodology

This section explains the survey methodology by outlining the main steps applied to select articles followed by a general definition of the problems studied.

2.1. Literature search procedure

Generally, to prepare a literature review on a specific subject some steps should be followed. In the first step a set of keywords should be selected depending on the studied problem. The second step is to determine the filter to apply using a set of inclusion and exclusion criteria. This step is crucial to identifying the papers that are most pertinent to our topic and removing the ones that aren't. In our work, in order to ensure that the appropriate papers have been covered we have to choose the most suitable set of keywords that explain the studied subject. Several propositions were made to express the nodes, the objective function and the studied variant which is in our case the coverage concept.

The topic areas are searched automatically to find articles. The following terms have been selected then used to restrict the search: “Nodes, Customers, minimum cost, minimum distance, best location, optimal tour, coverage distance, covering”. In order to ensure covering the recent works about the routing problems using the covering concept over the last 10 years (2013-2023), the combination of the mentioned keywords is applied to collect the publications from Google scholar database (www.scholar.google.com). consequently, a preliminary list of papers is generated. As previously stated, the next step is to select the most pertinent works related to our review basing on the type of paper, the date of publication, the language and the subject treated in this work. This survey covers only journal articles, conference proceedings and chapter book written in English. Other publication forms like unpublished working papers, master and doctoral dissertations, newspapers and books, etc. are not included.

2.2. Routing problems

The table1. below is a representation of the VRP, TSP, and LRP descriptions. In this work, we are interested to focus on the covering concept involved in these problems. For that we have to define each one of them to understand the differences better. Table 1 below presents the problems studied in this review and their abbreviations, the main description of each one of them, and finally the first formulation and the first application in the literature. First of all, we have to mention that all of them are proved to be NP-hard. There are some little differences between them, we can cite for example:

Given that the VRP is a generalization of the TSP where the capacity constraint is relaxed, the TSP do not necessarily need a depot. When talking about the depot; for the VRP and the TSP, it should be fixed in advance whereas for the LRP the choice of the depot is a part of the solution. The nodes for the TSP are connected each other since there is only one vehicle to pass through all of them. This is not necessarily the case for the VRP and the LRP since multiple vehicles are used, and the optimal solution can be represented by several tours. In the literature, we notice the importance of these problems in the resolution of several real cases such as: healthcare logistics (Veenstra et al., 2018) and (Ozdemir et al., 2022), covering the refugees (Buluc et al., 2022), disaster relief (Rath & Gutjahr, 2014) and (Barzinpour & Esmaeili, 2014) and many other examples. Table 1 provides a brief description in this regard.

Table 1. A brief description of the routing problems studied in this survey.

Problem	**Abbrev.**	**Description**	**First formulation**
Vehicle Routing Problem	VRP	consists of designing the best scheduling to visit the entire set of nodes starting from a central depot and finishing by returning to the same depot using a set of homogeneous vehicles such that all the customers are satisfied and the cost is minimized.	The first formulation was introduced by (Dantzig & Ramser, 1959) in which the delivery of gasoline to gas stations was modelled then solved.
Travelling Salesman Problem	TSP	A salesman is asked to make one and only one visit to each city in a set of n cities, beginning in any city and finishing at the starting point. The best tour is chosen while minimizing the total travel distance.	This problem was brought up by Hassler Whitney in a discussion at Princeton University in 1934. After that (Flood, 1956) tried to solve the school bus problem
Location Routing Problem	LRP	Two types of decisions are combined in this problem: the location of the depots and the routing of the vehicles. In addition to the set of customers and the fleet of vehicles, this problem requires a set of potential depots with opening costs. In order to minimize the total costs which includes the routing cost as well as the cost of open depots. In summary, the LRP's	Using a non-linear profit function (Watson-Gandy & Dohrn, 1973)were the first to introduce the LRP formulation which considers the location of the depots while visiting customers.

	objective is to choose which depots should be opened then assign clients to them, and plan vehicle routes.

3. Conducting literature review

As mentioned before, we are interested in studying the covering issue integrated in routing problems. This survey will be concentrated on 44 papers selected using the procedure explained in the previous section. We can notice that, few papers deal with this issue although the importance of applying it especially for resolution of several type of reel cases. Table 2 presents the studied articles, the problem treated in each paper, and the resolution approach used.

Table 2. Description and classification of the papers studied in this survey.

Paper	TSP	VRP	LRP	Real case	Resolution approach
(Shaelaie et al., 2014)	√				-CPLEX -GA hybridized with the LS and VNS
(Rath & Gutjahr, 2014)			√	√	-CPLEX -VNS
(Barzinpour & Esmaeili, 2014)			√	√	LINGO
(Shaelaiea et al., 2015)	√				-CPLEX -VNS
(Salari et al., 2015)	√				-CPLEX -A hybrid heuristic by combining ACO and DP
(Allahyari et al., 2015a)		√			A hybrid metaheuristic combining GRASP, ILS and SA
(Ozbaygin et al., 2016)	√				Branch-and-cut
(Grinde, 2017)	√				-CPLEX -Excel/VBA
(tripathy et al., 2017)	√				MGA with Global Parent Crossover operator
(Mukherjee et al., 2017)	√				A RID and an IGA
(Nedjati et al., 2017)			√		-CPLEX -NSGA-II, then NSGAII-2NI and NSGAII-FFI
(Zhang & Xu, 2018)	√				The Cover Tree Traversal algorithm
(Veenstra et al., 2018)		√	√	√	-Branch-and bound -A hybrid VNS
(Raziei et al., 2018)			√		-CPLEX -GA
(Kammoun et al., 2019)		√			VNS with VND
(Amiri & Salari, 2019)	√				-CPLEX -Heuristic algorithm consists of three major procedures initialization, local search and shaking
(Venkatesh et al., 2019)	√				-CPLEX -MS-ILS
(Mukherjee et al., 2019)	√				RID-MGA

Paper	TSP	VRP	LRP	Real case	Resolution approach
(A Mukherjee et al., 2019)	√				RS-MGA
(Cherkesly, M. È. Rancourt, et al., 2019)			√	√	-CPLEX -A generalized heuristic
(Huang et al., 2019)			√		-CPLEX -MCWSA-TS
(Pandiri et al., 2020)	√				-ABC algorithm and an approach based on the GA
(Lu et al., 2021)	√				-HEA
(Tripathy et al., 2021)	√				-NSGA-II
(Maziero et al., 2023)	√				-Branch-and-cut -A heuristic
(Singh et al., 2021)	√				-Gurobi -ACO and GRASP
(Eydi et al., 2021)		√			-CPLEX -NSGA-II
(Arslan, 2021)			√		Branch-and-price
(L Jiang et al., 2022)	√				-CPLEX -A two-phase heuristic based on VNS
(Kundu et al., 2022)	√				-Heuristic
(Dutta et al., 2022)	√				-ACO
(Ouelmokhtar et al., 2022)	√			√	-OPL within CPLEX -PAES
(Biswas et al., 2022)	√				-NSGA-II
(Li Jiang et al., 2022)	√				-HBBO
(Hashimoto et al., 2022)		√			-ILS
(Chiussi et al., 2022)		√		√	-CPLEX -TSMheu
(Buluc et al., 2022)		√		√	Three heuristics
(Ozdemir et al., 2022)		√		√	-CPLEX -Four heuristics: Random, Node Potential, Set Covering, and Co EC Node Potential
(Vu et al., 2022)		√			-CPLEX -GRASP
(Wang et al., 2022)			√		Branch-and-price
(Yang et al., 2023)		√		√	-A two-stage algorithm based on the improved k-means clustering algorithm and GA
(Khan et al., 2023)	√				-MOEA/D-GWO
(Kaushal & Devi, 2023)			√	√	-MICA
(Santa González et al., 2023)			√	√	-CPLEX
(Tirkolaee et al., 2024)	√				-CPLEX

Table 3 describes the resolution approach used to solve the routing problems studied in the selected papers. These problems are an important part of combinatorial optimization problems. Several methods of solutions are used to solve these problems. These methods are classified into two types: exact and approximate.

Table 3. Solution method descriptions.

GA: Genetic Algorithm meta	IGA: Improved Genetic Algorithm
LS: local Search meta	NSGAII-2NI: 2N Improvement (2NI) Procedure
VNS: Variable Neighborhood Search	NSGAII-FFI: First Front Improvement (FFI) procedure
ACO: Ant Colony Optimization	VND: Variable Neighborhood Descent
DP: Dynamic Programming	MS-ILS: Multi-Start Iterated Local Search
GRASP: Greedy Randomized Adaptive Search Procedure	NSGA-II: First Nondominated Sorting Genetic Algorithm II
ILS: Iterated Local Search	RS-MGA: A Random Search and Modified Genetic Algorithm
SA: Simulated Annealing	ABC: Artificial bee colony algorithm
MGA: Metameric Genetic Algorithm	HEA: A hybrid evolutionary algorithm
RID: Random Insertion-Deletion	OPL: Optimization Programming Language
RID-MGA: A Random Insertion Deletion (RID) and Modified Genetic Algorithm (MGA)	MCWSA-TS: A hybrid heuristic algorithm combined with a tabu search and a modified Clarke Wright saving algorithm
PAES: Pareto archived evolution strategy	HBBO: Hybrid biogeography-based optimization
TSMheu: Tour-Splitting Metaheuristic	MOEA/D-GWO: Multi-objective evolutionary algorithm using Grey Wolf optimization
MICA: A multi-objective imperialist competitive algorithm	

3.1. Exact methods

The exact methods ensure that the obtained solutions are optimal. The essential idea of an exact method is the implicit enumeration of all solutions of the search space. Such a method has specific techniques that allow for the reduction of the search space, hence reducing the number of solutions to enumerate while assuring that the global optimal solution is unquestionably inside the reduced search area. The Exact algorithm is supposed to solve continuous linear programming models which is not always the case, the majority of the problems treats discrete variables then we talk about Integer Programming (IP) or are both continuous and discrete in this case we talk about Mixed Integer Programming (MIP). Since the most treated problems are classified as MIP models, multiple advanced optimization techniques are applied to solve them. Among the exact methods researchers use, we can cite dynamic programming, the branch and bound, the branch and cut, and the branch and price. If we consider the works studied in this review, we can enumerate the following papers which have applied only an exact method to solve their problem: (Barzinpour & Esmaeili, 2014), (Ozbaygin et al., 2016), (Arslan, 2021), (Wang et al., 2022) and (Santa González et al., 2023).

Unfortunately, such algorithms take a long to find an optimal solution, especially for solving big-size instances. Consequently, it is very hard to solve many NP-hard problems to optimality using this algorithm. Therefore, it justifies the recourse to the approximate methods which provide near-optimal solutions in a reasonable time.

3.2. Approximate methods

The approximate approaches produce satisfactory results in a reasonable amount of time, but there is no guarantee that the solutions are optimal. These methods contain three classes: Heuristic algorithms, Metaheuristics and Hybrid algorithms.

- Heuristic algorithms: are designed to treat a specific problem to obtain a satisfactory solution in polynomial time. These algorithms must focus on and study the treated problem's characteristics because it must consider its unique particularities. Among the treated papers, the ones that applied these algorithms to study the routing problems are: (Amiri & Salari, 2019), (Cherkesly et al., 2019), (Maziero et al., 2023), (L Jiang et al., 2022), (Kundu et al., 2022), (Buluc et al., 2022), (Ozdemir et al., 2022).
- Metaheuristics: in contrast to heuristics based on the analysis of the characteristics of the investigated problem, metaheuristics are resolution concepts that may be applied to a variety of optimization problems. These algorithms are easily adapted to many problems, and their application proves their efficiency in solving complex problems in a reasonable time. In this review, several papers have applied different types of Metaheuristics some of them are: (Rath & Gutjahr, 2014), (Nedjati et al., 2017), (Raziei et al., 2018), (Chiussi et al., 2022), (Vu et al., 2022)
- Hybrid algorithms: The most difficult algorithms are hybrid ones since they use a combination of different techniques and metaheuristics to produce effective results. Usually, this is done to integrate each algorithm's desired properties, making the whole algorithm superior to its individual parts. This combination can improve the performance of the algorithm and consequently guarantee a better solution. We can cite some authors who has used a hybrid algorithm among the studied papers in this work: (Shaelaie et al., 2014), (Salari et al., 2015),(Allahyari et al., 2015b), (Veenstra et al., 2018), (Kammoun et al., 2019), (Venkatesh et al., 2019), (Singh et al., 2021).

Based on the study of the papers that were shown in the preceding table, we found that the research on the covering concept is continuously growing. This affirmation can be proved using Figure 1. which presents the number of papers that appeared in the last decade. We can notice that the idea is becoming more and more significant and attracting more researchers. As described in previous sections, this work is interested in the VRP, TSP and LRP. Figure 2 is used to show the distribution of the studied papers in this study according to the selected problems.

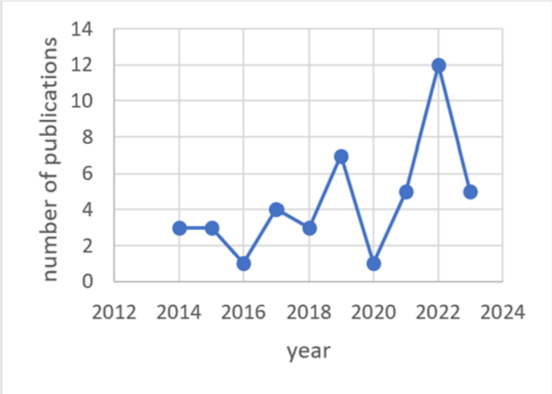

Fig. 1. A chronological repartition of the number of publications.

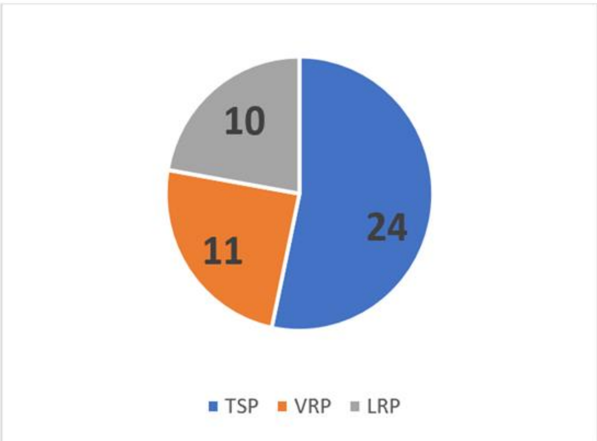

Fig. 2. The distribution of the number of publications according to the problem.

4. Conclusion

The routing problems are among the most interesting and challenging combinatorial optimization issues since they can potentially solve several real-life situations. This paper aims to review and analyze recent research published in the last decade on the covering concept applied in the following routing problem: VRP, TSP and LRP. Researchers exploring this issue will find this study to be a helpful tool. Our study has limitations, such as the fact that we do not address every potential paper because we do not search through several databases or because we have excluded some sorts of publications. While selecting the relevant publications, we encountered several works considering the coverage concept, but they were excluded and considered as related problems. Due to the importance of this concept, our future work will be elaborated without concentrating only on the routing problem.

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