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Decision-Making Support in Vehicle Routing Problems: A Review of Recent Literature

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ABSTRACT

The Vehicle Routing Problem (VRP) involves a set of customers with known locations, each having a certain demand for goods or services. There is also a fleet of vehicles available, each with limited capacity and often a fixed starting point. With the aid of mathematical programming tools, this paper offers an overview of the most recent VRP research. This study also examines the algorithms for solving VRP models and categorizes them in terms of their application areas. For these reasons, related publications that appeared in the international journal have been compiled and studied. According to the literature review, multi-criteria decision-making (MCDM) techniques have yet to constitute the most mathematical programming methods used to solve the VRP problem.

1. Introduction

The Vehicle Routing Problem (VRP) has many applications in real life and VRP models are used in many different types of distribution and transportation. Particularly in developed countries, the models are significant economically. Therefore, businesses and researchers always looking for the best solution to address and boost transportation efficiency while at the same time, the economic component in cost savings is a major driving force by Mohammed *et al.,* [1]. The previous study [2-4], summarized the concept of VRP as the obstacles to designing the shortest paths between one location to another dispersed locations such as citizens, cities, universities, warehouses, schools, stores, and others. Hence, making the right choice in vehicle routing plays a significant role in enhancing economic benefits and the suitability of logistics planning [5].

Due to the numerous applications of VRP, researchers have focused on developing solution strategies for these issues. The VRP has changed and been thoroughly researched [6-9] which showed

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many useful and essential methods for the general VRP. However, based on mathematical programming, the first VRP model has been proposed by Dantzig and Ramser [10] to solve the problems of delivering petrol to service stations.

VRP is classified as an NP-hard problem. Thus, heuristics or meta-heuristic algorithms are typically used to find the best or optimal solution. Because of its superior performance, this type of algorithm is the best approach for dealing with VRP in real-life problems even though the optimal solution is not guaranteed. Nowadays, the problem normally has multiple criteria which are conflicting with one another.

In recent years, the rapid advances in computer and information technology have risen to new mathematical programming techniques in operations research and management science including modelling the VRP problem. Numerous mathematical models such as statistical models, forecasting and simulation, mathematical programming models, and heuristics or meta-heuristics algorithms have been developed to help the Decision Maker (DM) in determining the optimum answer. As a result, the optimal solution is not guaranteed. Thus, the goal of this study is to provide an in-depth analysis of the existing literature in order to investigate the present state of research in VRP using mathematical programming approaches. This study also examines the literature-presented solution techniques for VRP that take the DM’s preferences into account. As an outcome, some potential approaches for more research in VRP are further suggested based on the literature assessment. The papers are analysed from the past literature from 2018 to 2023. The papers are journal and proceeding papers that resulted from keyword searching “VRP” and “MCDM” through Google Scholar.

The rest of the paper is organized as follows: The next section briefly explains the definition of the VRP models and their variants. Then, the MCDM techniques are presented. Later, the solution approaches used to solve the VRP models by using MCDM methods are discussed. Next, the objectives and constraints of VRP are described. Lastly, the study’s conclusions and potential paths are reviewed.

2. Definitions and Applications of Vehicle Routing Problems

Utilizing mathematical programming techniques involves transforming the scheduling issue into an optimization problem. The objective is to minimize (or maximize) a certain parameter, such as total duration while adhering to a range of constraints that are usually expressed through a combination of equalities and inequalities. These constraints, as well as the objective function, might encompass variables that are either binary (zero-to-one) or possess non-linear relationships. The ensuing mixed integer linear or nonlinear programming (MILP/MINLP) problem is then solved using a suitable solver. This approach guarantees a theoretically optimal solution, given its existence. Nonetheless, a drawback of this approach is that the solver algorithm could demand a large amount of time to converge. Méndez *et al.,* [11] state that to mitigate this, practitioners might introduce simplifications tailored to the problem, allowing for faster solutions without compromising essential elements of the scheduling model. Another approach akin to this is constraint programming, where the problem is solely framed as a series of constraints. The primary objective is to swiftly determine a feasible solution, and this method can yield multiple potential solutions are taken from the previous study [12,13].

A recent study by Konstantakopoulos [14] defines routing as the act of choosing the most cost-effective, efficient, and/or time-saving path among various options for goods/messages to reach their designated destinations. The primary aim of routing problems is typically to minimize the overall cost of providing the service. Other objectives can also come into play, especially in the public sector. For instance, in the case of emergency services like ambulance, police, and fire departments, the utmost priority is often given to minimizing the response time to incidents. Huang *et al*., [15] define vehicle routing as the process of choosing a route for traffic within, between, or across networks. Path selection involves applying a routing measure to numerous routes in order to choose (or anticipate) the optimal one by Susanty *et al.,* [16].

The majority of systems employ a deterministic dynamic routing algorithm, where a device consistently opts for the same route to a specific final destination unless it receives information suggesting a superior alternative path by Effendy *et al.,* [17]. However, there are a few routing algorithms that diverge from this deterministic approach. These algorithms employ a randomized technique to establish the best route for a good to traverse from its original source to its ultimate destination [18]. In certain networks, the complexity of routing is heightened by the absence of a single entity responsible for path selection. Instead, multiple entities participate in choosing paths or even segments of a single path. Inefficiencies can arise if these entities opt for paths that primarily align with their own objectives, potentially conflicting with the goals of other members [19]. A classic example involves traffic in a road system, where each driver picks a path that minimizes travel time. However, this type of routing can lead to equilibrium routes that are suboptimal for all drivers. Specifically, Braess' paradox serves as an illustration, demonstrating that the addition of a new road can paradoxically increase travel times for all drivers [20].

3. Classification and Applications of the Multi-Criteria Decision-Making

In the decision-making area, MCDM provides the best alternatives especially when choosing a complex domain. Ghannadpour and Zandiyeh [21] presented a model for the problem of minimization of risk and travel time in order to maximize the security of the transportation of money and valuable goods. This problem was formulated by a multi-objective intelligent genetic algorithm (MOIGA) to recognize and wisely choose the most effective heuristic. The computational findings showed that the proposed model and the proposed technique for the solution are appropriate.

Another MCDM technique for the industrial robot was presented by Chodha *et al.,* [22]. In this study, the problem lies in prioritizing industrial arc welding robots. In order to evaluate to select the proposed problem, the authors apply the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) and the Entropy weight method to determine the importance weights based on the objective preferences. According to their results, TOPSIS-Entropy MCDM methods are a good solution. Another similar study carried out in this area implemented fuzzy multiple criteria decision-making (FMCDM) analysis by considering both subjective and objective elements [23].

The MCDM techniques in automotive have been studied by Sivalingam *et al.,* [24]. The author proposed the additive ratio assessment (ARAS) method and the combinative distance-based assessment (CODAS) to estimate vehicle radiator performance with multi-walled carbon-based nanofluids. The model results showed those substantial input factors give a positive correlation to automobile radiators. In a different effort, Artificial Neural Networks (ANN) were presented by Ahmadi *et al.,* [25] to predict the friction factor of CuO-based nanofluids in a car radiator. By using ANN software, the finding was found that the proposed method had better precision. Likewise, the ANN technique was also recommended by Tian *et al.,* [26] for forecasting the thermal conductivity of oil based on hybrid Al2O3-MWCNTs.

A very recent study by Bhaskar and Khan [27] investigated the material selection for dental applications. The authors employed the Analytical Hierarchy Process (AHP) in the first stage. The approach model was hybrid into AHP-VIKOR, AHP-TOPSIS, AHP-MOORA, AHP-ELECTRE, and AHP-PROMTHEE to rank the material and compare among these models. The result of this study showed that AHP-VIKOR, AHP-TOPSIS, and AHP-PROMETHEE have a greater correlation compared to AHP-MOORA and AHP-ELECTRE. Rani and Kaushal [28] agreed to apply AHP-TOPSIS for location-sensitive disaster event detection. Cihan *et al.,* [29] used AHP and TOPSIS methods to solve the planned echocardiography device selection problem. While Ilham *et al.,* [30] use the AHP methods to find suitable renewable energy resources.

The study of Ng *et al.,* [31] proposed the solution of the Microarray Leukemia classification between genes and diseases. Both multi-population particle swarm optimization (MPSO) and Support Vector Machine (SVM) methods were used for selection. Based on the solution obtained, the MPSO method is more accurate because of the higher average accuracy with less result variance. Hamurcu and Eren [32] made the selection of the best electric buses for public transportation to improve urban air quality with MOORA and TOPSIS methods. The authors reported that the MOORA method could provide an ideal answer under the 6 criteria.

Table 1
Classification of the applications studied with the MCDM methods used in solving the problem

Applications	MCDM Methods	References
Security	MOIGA	[21]
Arc welding robot	TOPSIS	[22]
	FMCDM	[23]
Automotive	ARAS & CODAS	[24]
	ANN	[25,26]
Dental material selection	FUZZY AHP	[27]
Disaster event detection	AHP & TOPSIS	[28]
Echocardiography	AHP & TOPSIS	[29]
Energy Resources	AHP	[30]
Health	MPSO	[31]
Transportation	MOORA	[32]

4. Solutions Approaches to Vehicle Routing Problems

Numerous methods have been proposed to solve the VRP problems. Ghoseiri and Ghannadpour [33] employed a modified, effective genetic algorithm to tackle the problem and goal programming to formulate it. Abundant research studies apply metaheuristic techniques to address the issue of vehicle routing. One of the studies carried out by Balaji *et al.,* [34] applied metaheuristic techniques based on AHP by giving priority to the customer in determining the best route. The effectiveness of the proposed method was demonstrated by a significant reduction in travel distance from 1518 km to 1306 km. In the same problem, Du *et al.,* [35] proposed the Attention Route Planning Network Pickup and Delivery Traveling Salesman problem. The results indicated that the suggested models perform better than other stochastic optimization methods. In Akbar and Aurachmana [36], the authors used a capacitated vehicle routing problem with time windows (CVRPTW), with pick-up and delivery by using the Genetic Tabu Search Algorithm for mineral water company distributors. Another study was carried out by Sitek *et al.,* [37] with alternative delivery, pick-up, and time window and they solved by using a hybrid of mathematical programming, genetic algorithms, and constraint programming.

Eren and Tuzkaya [38] investigated the problem of medical waste collection by integrated safety and distance elements. The authors implemented the Traveling Sales Problem (TSP) and Membership Function by using AHP, PROMETHEE, and TOPSIS. Although this study's findings were highly encouraging, they were limited by a few considerations including a multi-vehicle, single collection area, and as well as many other hospitals. Tirkolaee *et al.,* [39] developed a sustainable solution to the multi-trip location-routing problem with time windows (MTLRP-TW) to manage medical wastage during the COVID-19 pandemic by formulating a novel mixed-integer linear programming (MILP) model. In order to solve the instability and uncertainty demands, the authors applied fuzzy chance-constrained programming. A weighted goal programming (WGP) that solves the model consists of multi-objective has also been proposed. Haitam *et al.,* [40] also agreed to apply the MILP technique for the collection of medical samples at home. Faizal *et al.,* [41] used Particle Swarm Optimization Algorithm (PSO) to shorten the time spent on the collection of BMC. From their results, the time delay is mostly eliminated by 42%.

Park *et al.,* [42] introduced a heuristic approach Genetic Algorithm (GA)-based on solving the waiting approach for the synchronous pickup and delivery VRP. The effectiveness and applicability of the technique were demonstrated via computational experiments. Euchi and Sadok [43] extended GA with a sweep technique as a local search (GAxSweepLS) to locate a tour of vehicles and drones. The effectiveness of the suggested method was evaluated using target data with up to 1,500 generations, and the findings showed that it could produce effective solutions in appropriate amounts of time. Mohammed *et al.,* [44] also agreed and applied GA to find the best routes in UNITEN. The authors reported the suggested method provides effective outcomes with the time factor has been slightly reduced. Ahkamiraad and Wang [45] developed a hybrid genetic algorithm and particle swarm optimization (PSO) in cross-docked distribution networks. The authors carried out for small up to large scale problems and compared the approach with PSO and CPLEX. The finding suggested that heuristics were useful and quite effective in the allocated time compared to the exact method. Zhen *et al.,* [46] combined particle swarm optimization with a genetic algorithm to plan a series of journeys for the vehicle fleet distributed by several depots.

Land and Doig [47] proposed the Branch and Bound method for the first time in 1960. The algorithm was implemented to resolve issues that emerged in the Netherlands' healthcare logistics. Considering the increasing importance of efficiency in distribution and logistics systems, Auliani *et al.,* [48] presented the Branch and Bound method in finding the routes with the lowest delivery costs. A similar study by Ferreira *et al.,* [49], proposed the branch-and-cut approach and considered three variants in the model. The results showed that the proposed models successfully outperform previous results. Casazza *et al.,* [50] suggested a branch and price algorithm for single commodity split pickup and split delivery.

Ju *et al.,* [51], the authors formulated a VRP considering reconnaissance and transportation (VRPCRT) for horde movements during the war as a mixed-integer programming model. Considering that, these models were compared with their approach with the ant colony optimization (ACO) algorithm to test the performance. The computational results revealed that the ACO algorithm yields better outcomes even in large-scale problems. Ng *et al.,* [52] suggested using an artificial colony algorithm with numerous colonies to increase the routing flexibility under time-dependent traffic congestion.

Table 2
Methods applied to solve Vehicle Routing Problems

References	GP	GA	AHP	SOP	GTS	P	TOPSIS	MILP	PSO	BB	BC	BP	ACO
[33]		•											
[34]			•										
[35]				•									
[36]					•								
[37]		•											
[38]			•			•	•						
[39]	•												
[40]								•					
[41]									•				
[42]		•											
[43]		•											
[44]		•											
[45]		•							•				
[46]		•							•				
[47]										•			
[48]										•			
[49]											•		
[50]												•	
[51]													•
[52]													•

Note: GP-Goal Programming, GA-Genetic Algorithm, AHP-Analytic Hierarchy Process, SOP-Stochastic Optimization, GTS-Genetic Tabu Search, P-PROMETHEE, TOPSIS-Technique for Order Preference by Similarity to Ideal Solutions, MILP- Mixed-Integer Linear Programming, PSO-Particle Swarm Optimization Algorithm, BB-Branch and Bound, BC-Branch and Cut, BP- Branch and Price, ACO-Ant Colony Algorithm.

5. Objectives and Constraints Involved in Vehicle Routing Problems

The objective of VRP is to determine the most efficient routes for a fleet of vehicles to supply goods or services to customers while satisfying certain constraints. The main objective is to minimize the total cost, distance, or time required to serve all customers. The minimization directly impacts fuel consumption, vehicle wear and tear, and overall operational costs.

Constraints in VRP include vehicle capacity constraints, time window constraints, precedence constraints, depot constraints, non-split delivery constraints, routing time constraints, and network connectivity constraints. Vehicle capacity ensures that the total demand of all customers allocated to a vehicle does not exceed its capacity. In time window constraint, it requires that each customer should be visited within their specified time window, ensuring that the service is provided within the desired time frame. Precedence constraint ensures that the order of service is maintained according to customer dependencies. For example, a customer may require a certain service to be performed before they can be served. For depot constraint, each vehicle must start and end its route at a central depot or base. This constraint ensures that the vehicles return to their starting point and do not exceed their operational boundaries. Some goods or services cannot be divided or split among multiple vehicles. Thus, the non-split delivery constraint ensures that a single vehicle must be responsible for delivering the entire load to a certain customer. The total time taken to complete the routes must be within certain limits. In that case, the routing time constraint accounts for factors such as driver working hours, legal restrictions, or other operational limitations. In network connectivity constraints, the routes must respect the connectivity of the road network. Vehicles cannot traverse roads that are restricted or inaccessible.

The objectives and constraints can vary depending on the specific VRP variant, such as capacitated VRP, time-constrained VRP, or VRP with multiple depots. Table 3 depicts the objectives and constraints involved in VRP of a few research papers. The most common objective is to minimize the cost while fulfilling the customer's demand.

Table 3
Objectives and constraints involved in Vehicle Routing Problems

References	Travel time (courier to customer)	Distance	Vehicle Capacity	Travel time (supplier to courier)	Cost	Number of collected goods	Customer demand
[35]					•		•
[42]		•	•				
[48]		•			•		
[53]	•					•	
[54]					•		•
[55]					•		•
[56]	•					•	
[57]		•			•		
[58]			•		•		
[59]	•			•			
[60]					•	•	
[61]					•		•
[62]		•				•	
[63]					•		•
[64]		•					•
[65]	•	•					
[66]					•		•

6. Conclusions

The review has demonstrated that throughout the last five years, mathematical programming has been successfully used in VRP. Many of the research studies used heuristics or metaheuristics to solve VRP under real-life constraints. However, little study has been done in VRP testing the MCDM method. Thus, future research can explore the MCDM method other than TOPSIS and AHP in solving VRP. The review also showed that many studies implied at most 2 criteria (objective and constraint) in solving VRP. Future research can also tackle other variants in VRP that include more than 2 criteria at once. There exists the need to modify the criteria or constraints to achieve results meeting practical requirements.

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