A Study on Bio-Inspired Metaheuristics for Solving Vehicle Routing Problem

R. Yesodha* and T. Amudha

Department of Computer Applications, Bharathiar University, Coimbatore - 641 046, Tamil Nadu, India; yesodharaj@gmail.com, amudhaswamynathan@buc.edu.in

Abstract

This paper aims to present a brief survey on Vehicle Routing Problem (VRP) and its variants with different Bio-inspired metaheuristics. Metaheuristics is a high-level technique that coordinates simple heuristics and rules to find good approximate solutions and Bio-inspired metaheuristics which helps to solve challenging combinatorial optimization problems in an adaptable and distributed fashion. Vehicle routing problem is one of the Nondeterministic Polynomial Hard combinatorial optimization problem which aims to optimize the routes and reduce the overall cost of the routes with minimum distance. Recent years, combinatorial optimization problems are gaining more awareness of the researchers both in scientific as well as industrial world. Biologically-inspired methods are becoming more progressively important in the face of complexity in today’s demanding applications. The significant attention towards VRP is due to its real-world importance and also it is very difficult to solve it and still it is foremost important problem in the area of Operations Research.

Keywords: Bio-Inspired Metaheuristics, Combinatorial Optimization, Vehicle Routing, VRP Applications, VRP Variants

1. Introduction

Combinatorial Optimization problem is used to find the finest object from a given set of objects to satisfy the desired objectives. Metaheuristics is one the most desired solution approaches for resolving combinatorial optimization problems and they have been applied to large variety of applications. Bio-Inspired Computing (BIC) is a part of Nature-Inspired Computing (NIC) that focus on social performance and occurrence of biological species and it is inspired from behavior of nature and this field is far closely interrelated to the field of Artificial Intelligence. In the last two spans, the researchers are progressively fascinated in natural sciences, particularly biology as a basis of demonstrating examples. Exploring the Bio inspired algorithms is the vast effort to solve optimization problems which have the capability to define and decide difficult dealings from nature by using simple rules. BIC usage is a very encouraging approach in several fields extending from computer science, electronics, mechanical engineering, chemical engineering, molecular biology, wireless sensor networks, computer security and robotics, biomedical engineering, control systems, parallel processing and power systems, data mining, production engineering and image processing etc. Bio-Inspired Computation methods have been applied to various Combinatorial Optimization Problems like Vehicle Routing problem, Knapsack problem, Assignment problem, Bin packing problems, Scheduling problems, Protein folding problems etc. Transportation plays an essential part in our daily life. The delivery of products from depots to customers is one of the key activities that play a significant part in the effectiveness of business. Vehicle routing problem is a Nondeterministic Polynomial Hard combinatorial optimization problem to serve the consumers from central depots and returned back to the originated depots with given vehicles. In the last twenty years the meta-heuristics has arisen as the most promising path of research for the VRP variants. One of the earliest and also the simplest routing problem is the Traveling Salesman Problem (TSP), in which the shortest

* Author for correspondence
trip to visit a number of cities must be determined for a salesman who starts from and terminates at the same city. The VRP was introduced by Dantzig and Ramser in the year 1959\(^2\). Main objective of the VRP is to optimize the routes and decrease the total cost of the routes by reducing travel period with minimum distance along with capacity constraints and vehicle used\(^5\). The shortest distance travelled by all the vehicles without violating any rules is considered as feasible solution. The classic type of the VRP is Capacitated VRP (CVRP), later other variants like VRP with Time Windows (VRPTW), Multiple Depot VRP (MDVRP), Periodic VRP (PVRP), Split Delivery VRP (SDVRP), Stochastic VRP (SVRP), VRP with Backhauls (VRPB), VRP with Pick-Up and Delivery (VRPPD), VRP with Satellite Facilities (VRPSF), Open Vehicle Routing Problem (OVRP) and many other vehicle routing problems were also\(^24,34,57,63,64\). The basic rules for the VRP is (a) Every customer is visited exactly once (b) Every vehicles will starts and ends its routes in the same depot (c) Capacity exceeding is not allowed (d) the service to the customer must be within the time factor\(^28,47,58\).

Applications of VRP are as follows: Transportation, courier services, Bank deliveries, freight distribution and collection, postal deliveries, garbage collection, newspaper delivery, industrial refuse collection, school bus routing, security patrol services, airline & railway routing, grocery distribution and national franchise restaurant deliveries etc\(^64\). The formation of the paper is as follows: In subdivision 2, VRP variants were explained, in subdivision 3, Bio-Inspired Metaheuristics for VRP were explained and in subdivision 4, Research Challenges for VRP were discussed and in subdivision 5, conclusion and future work are expressed.

### 2. Variants

In this section vehicle routing variants are explained.

#### 2.1 Capacitated VRP

In CVRP, the vehicles have capacity limitation where the goods must be distributed to the customer from a common depot at lowest travel cost and every vehicle must have equal capacity for a single product. CVRP aim is to reduce the vehicle fleet, sum of travel period and the overall demand of commodities for each route that may not exceed the capacity of the vehicle, which serves that route\(^19,23,24,28,47,58,63\). The solution is achievable if the overall quantity assigned to each route should not go beyond the vehicle capacity\(^47,111\).

#### 2.2 VRP with Time Windows

In VRP using Time Windows, for every consumer goods must be distributed in certain time window with known demands along with least cost and distance. The vehicles cannot arrive earlier or later than the time\(^34,57,64\). In case if the vehicle arrives earlier then the earliest arrival time and waiting time will occur. Each customer should also consider the service period for loading or unloading the goods for each route\(^64\). VRP using Time Windows aims to reduce the vehicle fleet, overall travel period and waiting time\(^23,57\).

#### 2.3 Multiple Depot VRP

In Multi-Depots Vehicle routing problem, first it entails the assignment of customers to the depots. Customers are serviced by several depots, each depot having their own fleet of vehicles. Each vehicle departs from a depot and finally turns back to the original depot with respective constraints (capacity, distance travelled along with time window). The routes of all vehicles are intended before they depart from the original depots\(^57,97\). MDVRP goal is to reduce the vehicle fleet, travel period, and overall demand of commodities that must be distributed from various depots. The solution is achievable if each route fulfils the standard VRP conditions\(^64\).

#### 2.4 Periodic VRP

In Periodic vehicle routing problem variant customers must be served many times for a given designed period\(^77,78\) and the set of dates in which a vehicle serves a customer is not fixed earlier, but instead a list of possible set of dates is related through every customer. Whenever the customer is served and its duty period or vehicle capacity is over, the vehicles can turn backs to the original depots\(^66,88\). The objective is to reduce the vehicle fleet and the overall travel period needed to supply all customers while satisfying operational constraints. The results are obtained if VRP constraints are fulfilled. Moreover, vehicles will not turn back to the depot on the similar day it leaves\(^21,65\).

#### 2.5 Split Delivery VRP

In the Split Delivery Vehicle Routing Problem visiting each customer only once rule is removed, instead
deliveries can be splitted and served many times and the demands can be larger than the vehicle capacity and number of vehicle constraints is also excluded. The main intention of SDVRP is to distributing the customers goods and in each tour it does not exceed the capacity of the vehicles and the overall distance travelled is reduced. A solution is possible by satisfying the VRP rules including that the customers may be delivered by using more number of vehicle.

2.6 Stochastic VRP
In Stochastic vehicle routing problem where some information is random, it is not necessary to satisfy all the rules. The goal of this variant is to reduce the vehicle fleet and stochastic or service period along with the customer demands. A feasible policy for the vehicle is any strategy of visiting locations such that all demands are satisfied.

2.7 VRP with Backhauls
The Vehicle Routing Problem with Backhauls incorporates customers to whom the goods are to be distributed and a set of sellers whose goods need to be shift back to the depots. In VRPB, distributions for each path must be accomplished earlier any pickups are made, this is to avoid the rescheduling the loads on the vehicle. The goal of VRPB is to minimize the overall distance toured. In VRPB routes which have only pickup is not acceptable and deliveries should be made before pickups without omitting the constraints.

2.8 VRP with Pick-Up and Delivery
In VRPPD customers can resend some goods and it must fit into the vehicle and this constraint faces challenging problems like planning, bad consumption of the vehicle volumes, enlarge travel distances and number of vehicles also increases. Due to this issues cost is increases to face the consumer needs. The solution is achievable if each route fulfils overall quantity allotted without violating capacity rule and also vehicle should have sufficient capacity for picking-up the products at the customers.

2.9 VRP with Satellite Facilities
In Satellite Facilities there are no restrictions for the vehicles to return back to the depot, it can continuously deliver the goods to the customer until the duty period of the driver is over. Distribution of fuels and certain retail items are the main application for this variant. Satellite facility is an intermediary facility with unlimited supply used for the replenishment by a vehicle. Extra cost arises to optimize the routes when the customer needs is random and this variant helps to safeguard against unpredicted demands.

2.10 Open Vehicle Routing Problem
In OVRP variant, vehicles not necessary to return back to the distribution centre if it requires, similar route in the reverse order is used. The OVRP describes well-organized paths with least overall distance and cost for the vehicles that distribute the goods to the consumers. Each consumer must visit once by unique vehicle, along with capacity and time constraints. The foremost variance among Open Vehicle Routing Problem and Vehicle Routing Problem is that the paths in the Open Vehicle Routing Problem contains Hamiltonian paths starts at the depot and ends with customer, while the paths in the Vehicle Routing Problem remains Hamiltonian cycles. OVRP aims to reduce the total vehicles used and minimize the overall distance covered and the issue faced by this variant is cost for the extra vehicle but it reduces the distance with extra paths.

3. Bio Inspired Metaheuristic for VRP
Bio-inspired algorithms like Ant Colony Optimization (ACO), Bat algorithm, Genetic algorithm, Shuffled frog leaping algorithm, Genetic, evolutionary, Bacterial foraging optimization, particle swarm optimization, Cuckoo search, memetic etc., were used to resolve VRP and their effects have exposed the ability of Bio-inspired metaheuristics in VRP problematic solving. Table 1 describes the Bio-inspired metaheuristics applied to vehicle routing domains.

4. Research Challenges for VRP
During the past decades, significant research on vehicle routing problems has been carried out. Distributing huge goods in a limited period to the customer is the
| Problem                          | Variants                        | Algorithms used                                                                 | Applications                                                                 | References               |
|---------------------------------|---------------------------------|--------------------------------------------------------------------------------|------------------------------------------------------------------------------|--------------------------|
| Vehicle Routing Problem         | Capacitated VRP (CVRP)          | ACO, Artificial Bee Colony, Hybrid ABC, Honey Bees Mating Optimization, Bumble Bees Mating Optimization, Hybrid Bat, Hybrid Genetic, Golden Ball, Particle Swarm Optimization, Hybrid Quantum-Inspired Evolutionary Algorithm, Hybrid Cuckoo Search, Fruit Fly Min-Max, Firefly | Logistics, railway, river, and rural road networks, supply chain management, Ambulance Routing, emergency management situations, Defense and computer networking, Truck and Trailer Routing Problem, Mail collection, Airport baggage handling | [83,41,14, 92,93,95, 96,91,28, 39,11,99, 40,29,20, 19,35,7, 105,106, 26,76,36] |
|                                 | VRP with Time Windows (VRPTW)   | ACO, Hybrid Genetic, Intelligent water drops, Memetic, ANT, Genetic, Immune Genetic, bee evolutionary genetic (BEGA), Transgenic, Shuffled frog leaping algorithm, PSO with Genetic, Bacterial foraging optimization | Bank deliveries, Mail collection, postal deliveries, Airport baggage handling industrial refuse collection, airline and railway routing, national franchise restaurant deliveries, school bus routing and security patrol services, fast-food delivery, Truck and Trailer Routing Problem | [84,57,9, 102,10,43, 32,90,31, 71,59,33, 25,46,36] |
| Multiple Depot VRP (MDVRP)      |                                 | Shuffled frog leaping algorithm, Genetic, particle swarm optimization, ACO, Memetic, Artificial immune | Logistics and Transport of Biomass for Electricity Production, bus fleet scheduling, supply chain management, fast-food delivery, waste collection, Milk Collection and Distribution | [33,8,119, 60,42, 80,104] |
| Periodic VRP (PVRP)             |                                 | Genetic, evolutionary, particle swarm optimization, memetic, ACO                  | Courier services, grocery distribution, waste collection, ATM cash replenishment, Supermarket Chain | [44,13,114, 66,48,101, 88] |
| Split Delivery VRP (SD-VRP)     |                                 | Evolutionary Local Search, memetic, ACO, Genetic                                | Distribution of medical supplies during natural disasters or terrorist attacks, cattle feed distribution problem, helicopter crew-scheduling problem | [37,109,55, 38] |
| Stochastic VRP (SVRP)           |                                 | Particle swarm optimization, Memetic Differential Evolution algorithm, Evolutionary algorithm, Genetic, Artificial Bee Colony, ANT | Gas stations, Automatic Teller Machines, Taxi cab services, vending machines, delivering medical supplies, delivering post to large customers, recycling and waste management, Emergency services, logistics, home heating oil delivery, and forklift routing. | [95, 97,113,118, 2,56] |
| VRP with Backhauls (VRPB)       |                                 | Multi-ant colony system, Memetic, Genetic, Differential Evolution algorithm,     | Catering firm, distribution of groceries, retail distribution, supermarket, airline scheduling, handling of returnable bottles, railway fleet routing and scheduling | [100,67,79, 30,27,115, 69,75] |
| VRP with Pick-Up and Delivery (VRPPD) |                           | Genetic, memetic, Differential Evolution algorithm,                              | Department stores, Mail collection, Airport baggage handling                   | [70,22,36] |
| VRP with Satellite Facilities (VRPSF) |                           | Genetic                                                                          | Home heating oil, propane, automotive parts, delivery of goods to groceries     | [49,87,36] |
| Open Vehicle Routing Problem (OVRP) |                           | Genetic, ACO, Evolutionary                                                       | Seafood Product Delivery Routing Problem                                        | [45,6,61] |
challenging aspect in the vehicle routing problem. The emerging emphasis on dealing with uncertainty and the dynamics in VRP is the biggest task to achieve. Research in VRP must focus more on effective, simpler and faster solution methods capable of performing an extensive and also intelligent routing, since the solutions for the VRP have not yet been fully exploited. Real world needs solution methods that are fast, flexible, accurate and robust in terms of consistent performance across. In Dynamic routing problems, planning the routes is the toughest task and it is very difficult to face the fleet controlling jobs and it is necessary to improve the decision support systems for dynamic routing. No standard instances are available for dynamic routing. Recent years researchers are showing more progress in optimization, dynamic and uncertainty problems.

5. Conclusion and Future Work

Several methods have been proposed to solve and optimize the difficult combinatorial optimization problems but algorithms inspired from the natural behavior yields special attention for its performance. This paper, discusses the combinational optimization and VRP, express the variants of VRP and its objective functions, describes the bio-inspired metaheuristics for VRP and their applications and also highlighted the research challenges for VRP. Researchers are continuously applying their best efforts to design new techniques to provide better solution as related to previously existing procedures. As a future research work, it is intended to apply some of the best performing bio-inspired metaheuristics for VRP and to analyze their problem solving effectiveness. Bio-Inspired algorithmic techniques can be suitably used to incorporate hybridization that can perform better results as very few researches have been carried under hybrid methods. Comparison and performance measures of each variant can be made. It is frequently required to find more effective algorithms for the larger scale vehicle routing problem and it is often necessary to exploit some adaptive mechanisms and also, it was identified that Bioinspired computing algorithms has high scope for solving VRP and its variants in both static and dynamic aspects.

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