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Hybridized ant colony algorithm for the Multi Compartment Vehicle Routing Problem

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ABSTRACT

Multi Compartment Vehicle Routing Problem is an extension of the classical Capacitated Vehicle Routing Problem where different products are transported together in one vehicle with multiple compartments. Products are stored in different compartments because they cannot be mixed together due to differences in their individual characteristics. The problem is encountered in many industries such as delivery of food and grocery, garbage collection, marine vessels, etc. We propose a hybridized algorithm which combines local search with an existent ant colony algorithm to solve the problem. Computational experiments are performed on new generated benchmark problem instances. An existing ant colony algorithm and the proposed hybridized ant colony algorithm are compared. It was found that the proposed ant colony algorithm gives better results as compared to the existing ant colony algorithm.

1. Introduction

Q4 The Vehicle Routing Problem (VRP) is the class of problems in which the demands of customers are fulfilled with the products originating from depot and transported using a fleet of vehicles in such a way that the total traveling cost of all vehicles is minimized. The VRP was first considered as a generalized form of the famous Traveling Salesman Problem (TSP) formulated by Dantzig and Ramser [1]. They tried to find shortest route to deliver fuel using gasoline delivery trucks from central depot to gas stations. The most basic form of the problem is called Capacitated Vehicle Routing Problem (CVRP). In the CVRP a fleet of identical vehicles (initially settled in the depot) with constant capacity Q serves a number of customers, each has a constant known demand to be delivered or picked up. Each vehicle visits a group of the customers only once, such that the total demand of the customers assigned to any route does not exceed the capacity of the vehicle. The objective is to minimize the total distance traveled by all the vehicles. For recent research work in the area of the VRP and its variants see [2–6].

The Multi Compartment Vehicle Routing Problem (MCVRP) deals with satisfying the demand of customers with different products. The demand of each customer for each product is constant and known in advance. The products should be stored in different compartments of the same vehicle while being transported together. Vehicles are partitioned into a constant number of compartments with certain capacities. Customers are assigned to routes so that the total demand of customers assigned to any route for certain product does not exceed the capacity of the reserved compartment for this product. The objective is to minimize the total transportation cost.

There are many industries in which different products are handled separately using multi compartment vehicles. Compartment splitting is essential when products cannot be mixed while transported together as they have different individual characteristics. For example, in waste collection applications it was found that the total recycling cost can be reduced if the sorting process is eliminated. This can be achieved by classifying the disposal bins in the collection site. But this requires transporting the sorted waste to recycling facilities into different compartments. Nowadays, in most cities; the municipal cooperation provides separate garbage bins to individual household for garbage collection.

Another application of the MCVRP is the delivery of food and grocery where refrigerated and non-refrigerated grocery items are stored in two different compartments in the same vehicle. Chajakis and Guignard [7] presented two integer programming models for two different layout vehicles and presented Lagrangean Relaxations for the first model. They addressed the decisions involved in assigning customers to routes only and stated that sequencing

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of customers within trips can be solved by any traveling salesman algorithm. They stated that the customers' orders should be fulfilled completely by one vehicle.

Another application of the MCVRP is delivering different types of fuels using a fleet of vehicles or marine vessels with different capacity tanks. To solve this problem, Avella et al. [8] used set portioning to formulate a branch and bound algorithm. El Fallahi et al. [9] found an application in which animal foods is supplied to the farms separately. They proposed two algorithms to solve the problem: memetic algorithm and a Tabu Search algorithm.

Muyldermans and Pang [10] investigated the benefits of co-collection of sorted waste from different locations to central location by multi compartment vehicles over separate collection by regular vehicles. They introduced new local search procedure based on 2-opt, cross, exchange, and relocate moves to solve the problem and compared their results with El Fallahi et al. [9]. It was assumed in [8–10] that the demand of each customer for certain items cannot be splitted. However, they assumed that more than one vehicle can visit the customer to fulfill demands of different items. Reed et al. [11] proposed an Ant Colony System (ACS) with 2-opt local search improvement to solve the basic CVRP in recycling waste collection network. They extended their algorithm to solve the MCVRP in which the customers are visited only once by one vehicle. Our work is inspired from Reed et al. [11] algorithm extension for the MCVRP. We address the problem of garbage collection from certain locations where the garbage should be picked up and stored in different compartments on the same vehicle. We use a fleet of identical vehicles; each one of them visits a group of locations such that each customer is visited by only one vehicle and only once. The problem is to decide which customers are assigned together in one trip as well as the order of visiting them with the objective of minimizing the total traveling distance.

The ant colony (AC) algorithm is inspired by the behavior of ant colony in the search of food. They mark their trails by laying a substance called pheromone. The amount of laid pheromone on the path inspires other ants to know whether this path is promising or not. This observation inspired Dorigo et al. [12] to design a metaheuristic technique to solve combinatorial optimization problems. They presented the first AC in which agents called ants simulate the behavior of the real ants. The ants communicate with each other by the pheromone laid by the ants while traveling from one place to another. Higher amount of pheromone in a path increases the probability of ants to follow that path. Dorigo et al. [12] used the TSP to apply their algorithm and compare it with other approaches. Due to simplicity of the general procedures of the algorithm, it was applied in many different problems.

AC has been used in solving the VRP and its variants since Bullnheimer et al. [13] designed their AC trying to solve the basic VRP. Although they could not improve the best known solutions, their algorithm produced good results and showed competiveness with other metaheuristics. Montemanni et al. [14] used AC to solve the dynamic VRP. They introduced new benchmark problems and tested their algorithm which showed good results. Bin et al. [15] presented an improved AC by offering new pheromone updating strategy called ant-weight and by introducing mutation operator. Other than computation times, their algorithm was effective compared to other metaheuristics.

Gajpal and Abad [16] presented an AC to solve the VRP with simultaneous delivery and pickup. Balseiro et al. [17] tried to enhance the AC algorithm by hybridizing it with an insertion algorithm to solve a time dependent the VRP with time window constraints. De la Cruz et al. [18] proposed a sequential algorithm with AC and Tabu Search to solve the VRP with time window constrains in which heterogeneous vehicles deliver multiple products. All these papers presented new best known solution for the benchmark problems. This shows the effectiveness of ant colony algorithm in solving the VRP and its variants. One of the recent metaheuristic approaches is the Chemical Reaction Optimization. This approach has been successively used to solve many hard problems [19,20]. In future work, this approach can be tested to solve the MCVRP.

The aim of this paper is to improve the existing ant colony algorithm to solve the MCVRP. We improved the existing ant colony algorithm by hybridizing it with local search schemes. This paper also contributes on developing a mathematical formulation of the problem. In addition, new benchmark problem instances have been introduced. These benchmark problems can be used for comparing the results of new solution approaches in the future research work. We also illustrate the benefit of using the two-compartment vehicles instead of single-compartment vehicles.

The paper is organized as follows: in Section 2 main assumptions are identified, the problem is described, and a new formulation is derived. Section 3 describes the proposed hybridized ant colony algorithm HAC and the local search procedures. Extensive computational experiments are presented in Section 4. We also compare the proposed algorithm's performance with the existing ant colony algorithm. Section 5 concludes the paper.

2. Problem formulation

A list of notations related to the problem definition is presented below:

N	Set of customers
k	Set of vehicles
p	Set of compartments and products
q_{ip}	Quantity of product p to be picked up from customer i
Q_p	Vehicle capacity reserved for product p
L	The maximum length of any route
C_{ij}	The distance of traversing arc (ij)
Q_{ip}^k	The total carried quantity of product p by vehicle k after leaving vertex i

We provide a mathematical formulation for the problem to make the paper comprehensive. The mathematical formulation for the MCVRP considered in this paper is not available in the literature. However, a mathematical formulation for a variant of MCVRP is available in the literature [9]. In the variant of MCVRP, the customer is allowed to get served more than once. Our formulation is based on pickup of materials from customer locations. Let $G=(V, A)$ be an undirected graph with a set of vertices $V=\{0, 1, \ldots, n\}$, where 0 represents the depot node, and $N=\{1, 2, \ldots, n\}$ are the customers served by a number of identical vehicles k (initially located in the depot). Vehicles are divided into a number of compartments p equals to the number of products handled in the network. Each customer i has a known quantity q_{ip} to be picked up of each product p and each customer is visited exactly once by only one vehicle. Each vehicle visits a group of customers, such that the total load of this group of customers for certain type of products does not exceed the vehicle capacity of the compartment reserved for this product Q_p. The maximum length of each route cannot exceed L. Let C_{ij} be the distance of traversing arc (ij). Let X_{ij}^k be a binary variable equals to 1 if and only if vehicle k visits customer j just after customer i. Let Q_{ip}^k denote the total carried quantity of product p by vehicle k after leaving vertex i. Then, the MCVRP can be formulated as follows:

Minimize

$$Z = \sum_{k\in K}\sum_{i\in V}\sum_{j\in V} C_{ij}X_{ij}^k \quad (1)$$

Subject to:

$$\sum_{k\in K}\sum_{j\in N} X_{ij}^k = 1 \quad \forall i \in N \quad (2)$$