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Enhanced intelligent water drops and cuckoo search algorithms for solving the capacitated vehicle routing problem

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ABSTRACT

The capacitated vehicle routing problem (CVRP) is investigated in this research. To tackle this problem, four state-of-the-art algorithms are employed: an improved intelligent water drops (IIWD) algorithm as a new swarm-based nature inspired optimization one; an advanced cuckoo search (ACS) algorithm; and two effective proposed hybrid meta-heuristics incorporating these methods, called local search hybrid algorithm (LSHA) and post-optimization hybrid algorithm (POHA). Both IIWD and ACS algorithms introduce new adjustments and features which improve the effectiveness of the proposed algorithms so as to optimize the CVRP. The hybrid methods, LSHA and POHA, take advantage of the merits of ACS and IIWD in exploring the solution space. These algorithms are enhanced to control the balance between diversification and intensification of the search process. Two well-known benchmark instances in the literature are solved so as to evaluate the proposed techniques. Experimental results are compared to the best obtained consequences previously reported in the literature. To present a comprehensive comparison between our proposed meta-heuristics and other state-of-the-art algorithms, some critical statistical test is employed; where the quality of our algorithms' performance in terms of average results is also determined. It is shown that the LSHA and POHA algorithms can effectively cope with such problems, where in most of instances LSHA can yield the best gained solutions in the literature. Specifically, in 92.9% of cases of Christofides benchmark and in 50% of cases of Golden benchmark, the best obtained solutions in the literature are achieved.

1. Introduction

After the seminal work of Dantzig and Ramser [15], Vehicle Routing Problem (VRP) has been extensively investigated. The basic vehicle routing problem is finding optimal routs for a fleet of vehicles to meet the demands of customers such that the cost of travels is minimized. All vehicles should start from one starting point, the depot, and have to come back to this point. Each customer should be visited one time only by one of the vehicles. One of the important variations of this problem which has been extensively investigated is capacitated VRP (CVRP) where the capacity of vehicles is limited. If the capacity of all vehicles is the same, then the problem is defined as homogenous CVRP, which is the interest of this paper. The formal statement of CVRP is

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as follows: Consider graph G = (V,A), where V = $\{v_0, v_1, \ldots, v_n\}$ represents the set of customers, with a non-negative demand and service time of d_i and st_i respectively, in which v_0 is the depot and A = $\{(v_i, v_j): v_i, v_j \in V, i \neq j\}$ is arcs (the connection or path between customers) and there is a cost associated with each arc, c_{ij}, for travelling from v_i to v_j which can be symmetric or asymmetric. Also, K identical vehicles with capacities of Q are located at the depot. The CVRP finds the optimal routes (with minimum associated cost) of each vehicle such that starting and ending point of each route is v_0, each customer is visited exactly one time only by one of the K vehicles, and the total demand of each route does not exceed the vehicle capacity, Q. Another possible limitation for maximum allowed tour length of each vehicle is imposed by L. Other variants of this problem are VRP with time window (VRPTW), VRP with backhauls, multiple depot, and so on. For a more detailed discussion see Toth and Vigo [55]. Luo et al. [33] presented a novel hybrid shuffled frog leaping algorithm (HSFLA) for VRPTW. They also proposed the adaptive soft time windows penalty measure so as to permit the existence of infeasible solutions in the evolution process.

The proposed methods to tackle VRP generally could be classified as exact, heuristic and meta-heuristic algorithms. The exact methods, such as Branch and Bound (B&B), Branch and Cut, Set Covering, Dynamic Programming (DP) and Integer Programming (IP) have already been proposed, and a detailed survey can be found in Toth and Vigo [55]. Since the problem is NP-hard, exact methods are inefficient and time-consuming even for small size instances; therefore, heuristic and meta-heuristic algorithms are attractive alternatives. The first heuristic algorithm was proposed by Clarke and Wright [11], and is based on the saving concept. Due to its simplicity it is widely accepted in practice [13]. The Sweep algorithm [23] is another heuristic algorithm which is a two-phase one where in the first phase customers are assigned to the vehicles and then 3-opt step is applied to improve the quality of the solution. Other heuristic algorithms have been presented by Fisher and Jaikumar [19], Bodin and Golden [6], and Altinkemer and Gavish [2].

The advantage of heuristic algorithms is that they are quite simple and effective; for instance, Gendreauet al. [22] investigated performance of some of the above heuristic algorithms and reported that their performances are within 2–10% above the best known (or optimal) solution. The main disadvantage of heuristic algorithm is that they cannot guarantee finding the optimal or near optimal solution of the problem. Therefore, meta-heuristic algorithms which are powerful tool to solve NP-hard problems have been considered. Several meta-heuristic algorithms including Simulated Annealing (SA), Tabu Search (TS), Variable Neighbourhood Search (VNS), and so on have been proposed for the addressed problem.

A lot of meta-heuristic algorithms have been suggested to solve the VRP problem. Of them, one can mention to Tabu Search (TS) which is employed in Osman [43], Gendreau et al. [21], Renaud et al. [48] and Barbarosoglu and Ozgur [4]. Simulated Annealing (SA) is utilized in Osman [43], Van Breedam [56] and Tavakkoli-Moghaddam et al. [53]. Genetic algorithm (GA) is used in Baker and Ayechew [3], Vidal et al. [58], Vidal et al. [57]. Ant Colony Optimization (ACO) as another classic meta-heuristic algorithm is employed in Bell and McMullen [5], Doerner et al. [17], Reimann et al. [47], Mazzeo and Loiseau [39], Bullnheimer et al. [9] and Doerner et al. [16]. Also, Variable Neighbourhood Search (VNS) is employed in Kytöjokiet et al. [31], Fleszar et al. [20] and Xiao et al. [59]. Most of these meta-heuristic algorithms are using simple heuristic techniques such as 2-opt and 3-opt to improve the quality of the solutions. Detailed review of the proposed algorithms can be found in Cordeau et al. [13] and [14], Gendreau et al. [22], Baldacci et al. (2012), Laporte et al. (2013) and Labadie and Prins (2012). Recently, Taha Yassen et al. [52] proposed a meta-harmony search algorithm (meta-HSA) which utilizes two HSA algorithms, an HSA-optimizer and HSA-solver. Their proposed meta-HSA was applied to Solomon's VRP with time windows benchmark so as to verify its effectiveness compared with standard HSA and the state-of-the art techniques. Also, Kourank Beheshti and Hejazi [30] investigated VRP with general soft time window involves designing a set of routes for a fleet of vehicles based at a central depot required to service a number of geographically dispersed customers. Their objective was to minimize the total travel distance and delivery time costs. Coelho et al. [12] investigated a VRP variant inspired on a real case of a large distribution company and designed a trajectory search heuristic called GILS-VND which combines three methods to solve this distribution problem, i.e., Greedy Randomized Adaptive Search Procedure (GRASP), Iterated Local Search (ILS) and Variable Neighborhood Descent (VND) methods.

Yu et al. [62] proposed ACO with new pheromone updating rule called "ant-weight strategy," and, based on experimental results, they concluded that the proposed algorithm is effective for the CVRP. Yurtkuran and Emel [63] proposed Electromagnetism-like Algorithm (EMA) in which iterated swap procedure (Ho and Ji, 2003) is incorporated. The proposed algorithm is compared to TS [43], SA (Osman et al., 2005), GA ([3]; Prins 2004), ACO [62], and PSO (Ai and Kachitvichyanukul, 2007). Results of their experiments based on Christofides et al.'s [10] benchmark problems showed that EMA is effective and competitive to the classical meta-heuristic algorithms, however, it outperformed almost all of the considered algorithms except GA (Prins 2004) and ACO [62]. Nagata and Bräysy [41] proposed memetic algorithm which uses edge assembly crossover. After applying the mentioned crossover, the solution may not be feasible; hence, they suggested a modification procedure. Also 2-opt, insertion, and swap as heuristic algorithms are then used in this algorithm. The proposed algorithm was effective, since they updated twenty problems already reported as best-known solutions in the literature. Mavrovouniotis and Yang [38] designed three immigrants methods specifically for the dynamic vehicle routing problem (DVRP) including random, elitism- and memory-based. The goal of random immigrants is to maintain the population diversity so as to avoid premature convergence. Also, elitism- and memory-based immigrants concurrently try to preserve the population diversity and transfer knowledge from previous environments in order to boost the adaptation capabilities.

Marinakis and Marinaki [36] proposed a hybrid GA in which the initial population is generated by applying multi-phase neighborhood search and GRASP algorithms. Furthermore, they applied PSO on individuals between each generation of GA to improve the quality of individuals. Later, Marinakis [35] applied multi-phase neighborhood search and GRASP algorithms and embedded a new local search algorithm called "Restricted Local Search". Sezto et al. [51] suggested Artificial Bee Colony (ABC) as a swarm-based heuristic for solving CVRP problem. They also proposed an enhanced version of their ABC techniques so as to improve the