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Full Length Article

A hybrid swarm algorithm based on ABC and AIS for 2L-HFCVRP

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ABSTRACT

This paper mainly addresses the heterogeneous fleet capacitated vehicle routing problem with two-dimensional loading constrains (2L-HFCVRP). The 2L-HFCVRP is a combination of two NP-hard problems and has a wide range of applications in transportation and logistics fields. In this paper, we propose a hybrid swarm algorithm, which is a combination of Artificial Bee Colony (ABC) algorithm and Artificial Immune System (AIS) algorithm, to solve the 2L-HFCVRP. The proposed algorithm is allowed to search infeasible solutions and several efficient strategies are developed to escape from local optima. The extensive computational results on several well-known benchmark data sets verify the effectiveness of the proposed algorithm. The proposed algorithm is shown to outperform the best algorithms in the literature for 2L-HFCVRP instances.

1. Introduction

With the rapid development of e-commerce technology, logistics plays a crucial role in the development of the local and global economy. Vehicle routing and loading problem is considered as one of the most important factors in the transportation and logistics fields. In the logistics industry, transportation account for over 50% of the major costs. One of the problematic issues is the loading constraints which limit the effective reduction of transport costs. Therefore, how to optimize the routing of vehicles has important practical and economic significance. In particular, it also plays a very important role in reducing emissions and saving energy consumption.

Vehicle routing and packing are two NP-Hard problems and most of the problems associated with them are very difficult to solve. Therefore, they have become a hot research topic in the field of combinatorial optimization. Vehicle routing problem (VRP) was first proposed by Dantzig et al. [1] when they studied the traveling salesman problem. Since then many scholars analyzed this issue and published a large number of relevant papers. VRP's research attracts great attentions within operations research, management science, computer sciences, and other fields since VRPs are of great practical significance. In recent years, several variants and algorithms of VRPs have been proposed to solve the real world problems. Although there are proposals about some exact algorithms [2,3], these algorithms are only suitable for solving small-scale problems. For solving complex problems, meta-heuristic algorithms were more favored [4]. For instance, several meta-heuristic algorithms based on swarm intelligence, such as ant colony algorithm [5] and particle swarm optimization [6], have been proposed to solve the VRPs.

Packing problem is one of the hot topics in the field of combinatorial optimization. Many variants and algorithms for this problem were developed. In [7], Lodi et al. gave a systematic classification of packing problems. A deterministic optimal algorithm for a small-scale two-dimensional cutting problem was proposed by Beasley [8], which cannot be used to solve large-scale real-world problems. The use of a heuristic algorithm to solve the two-dimensional packing problem was first proposed by Berkey [9]. In [10], Jakobs developed a hybrid genetic algorithm by combining several deterministic algorithms to solve the two-dimensional packing problem. Subsequently, some heuristic and meta-heuristics were proposed, for example, Leung and Zhang [11] proposed a heuristic algorithm based on the idea of layering for two-dimensional strip packing problem. Subsequently, a two-phase intelligent algorithm based on scoring rule and simulated annealing is developed by Leung et al. [12] for two-dimensional strip packing problem. However, swarm intelligence algorithms for packing problems are rarely reported in the literature.

Packing and vehicle routing have been studied separately for many years. With the development of the logistics industry, a more realistic vehicle routing problem with loading constraint (L-CVRP) attracts more attention. Vehicle routing problem with

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two-dimensional loading constraints (2L-CVRP) is first proposed by Iori et al. [13] and a branch and bound algorithm was developed to solve small 2L-CVRP. For large-scale problems, Gendreau et al. [14] developed a meta-heuristic algorithm based on tabu search for 2L-CVRP. Zachariadis et al. [15] studied a hybrid heuristic algorithm based on tabu search and guided local search. They also introduced a series of heuristic packing algorithms to check the feasibility of the loading. Later, Leung et al. [16,17] proposed an improved algorithm based on guided tabu search and a simulated annealing algorithm for solving 2L-CVRP. They also developed a new heuristic packing algorithm to deal with the loading constraint. Fuellerer et al. [18] proposed an ant colony algorithm based on swarm intelligence for 2L-CVRP. Duhamel et al. [19] proposed a GRASP × ELS algorithm by combining greedy adaptive random search algorithm with evolutionary local search. To solve 2L-CVRP, they transformed the loading constraint into a project scheduling problem. Recently Zachariadis et al. [20] proposed a novel heuristic algorithm called promise routing-memory packing (PRMP) based on compression idea, and obtained better experimental results. Tao and Wang [21] developed an effective tabu search approach with improved loading algorithms for the 3L-CVRP. Bortfeldt et al. [22] proposed a hybrid algorithm for the VRP with clustered backhauls and 3D loading constraints.

2L-CVRP is often assumed that each vehicle has the same size, while in the real-world problems, the size of vehicles can be different. Therefore, Leung et al. [23] extended 2L-CVRP for a more universal problem – vehicle routing problem with a two-dimensional heterogeneous loading constraints (2L-HFVRP), and developed a simulated annealing algorithm for it. More recently, Dominguez et al. [24] proposed a multi-start biased randomized algorithm for solving 2L-HFVRP. To the best of authors' knowledge, they are the only two papers that deal with 2L-HFVRP. In addition, there is one paper that developed an adaptive variable neighborhood search for 3L-HFVRP [25], another paper proposed an improved immigration memetic algorithm for solving the heterogeneous fixed fleet vehicle routing problem[26].

Artificial bee colony algorithm (ABC) is a kind of bionic algorithm inspired by nature which is based on the foraging behavior of bees with the characteristics of swarm intelligence. Karaboga [27] proposed a more systematic framework for artificial bee colony algorithm in [28] and successfully applied to the function numerical optimization problems. The algorithm is simple and practical, and has strong robustness. Subsequently, the artificial bee colony algorithm [28] has also been widely studied and successfully applied to a variety of problems [27]. Szeto et al. [29] used ABC for the capacitated vehicle routing problem. Wu et al. [30] used ABC with loading heuristics for solving 2L-CVRP and achieved good results. Davoodi et al. [31] used ABC to solve power system load flow problems. Fong et al. [32] used ABC for university timetabling. Xu et al. [33] used ABC for multi-objective optimization problems. Artificial immune system(AIS) inspired by biological immune system also provides a new method for solving complex problems, and it has been widely applied to intelligent optimization, pattern recognition, computer and network security, data mining, communication control, and many other engineering fields [34]. Shukla and Jharkharia[35] used AIS to solve vehicle routing problem with time window constraint for the delivery of agri-fresh produce. Recently, Aydin et al. [36] did research on the combination of ABC and AIS, and Wu [37] used ABC and AIS for unconstrained global optimization problems. Karaköse [38] used AIS for reinforcement learning. To the best of authors' knowledge, no AIS for 2L-CVRP is ever reported. These work mentioned above show that ABC has strong adaptive search capability and AIS has strong diversity search capability. In this paper, a novel hybrid swarm algorithm is developed by combining the characteristics of artificial bee colony and immune system to solve 2L-HFCVRP.

2. 2L-HFCVRP

2L-HFCVRP is a relatively new problem which consists of the capacitated vehicle routing problem and a two-dimensional packing problem. Therefore, the characteristics of CVRP and packing problem should be taken into consideration when the objectives and constraints for solving 2L-HFCVRP are considered.

2L-HFCVRP is defined as follows:Given a complete undirected graph $G = (V, E)$, where $V = \left\{0, 1, \cdots, n\right\}$ is a set of $n+1$ vertices, the vertex 0 denotes the depot, and the vertices 1, 2, $\cdots$, n corresponds to the positions of the customer1, 2, $\cdots$, n. $E = \left\{(i, j)\,|i, j \in V, i \neq j\right\}$is a set of undirected edges and each edge $(i, j) \in E$ is associated with a distance d_{ij} which denotes the distance of the customer i to j. There are K different types of available vehicles at the depot. For one vehicle type$k\,(k = 1, 2, \cdots, K)$, its maximal loading weight is Q_k, and there is a rectangle loading area $A_k$with length L_k and width W_k. For a vehicle with type k, it has a fixed cost$F_k$and variable costV_k. In general, a vehicle with larger capacity usually has higher fixed and variable cost. Assume that the driving distance of the vehicle k is R_k then its cost is $Fk + V_k \times R_k$. Each customer $i(i = 1, 2, ...n)$ needs a set of m_i rectangular items that is denoted by IT_i. Each item $I_{ir} \in IT_i$,$(r = 1, 2, ..., m_i)$has a size of length l_{ir} and width w_{ir}. Let $a_i = \sum_{r=1}^{m_i} l_{ir} w_{ir}$ denotes the area sum of the customer i' items, d_i denotes the total weight of items inIT_i.

For 2L-HFCVRP, a feasible solution must meet the following conditions:

(a) Each vehicle begins from the depot and eventually returns to the depot.
(b) Each customer can only be served once by one vehicle, and all items of each customer can only be packed into one vehicle.
(c) The total loading weight of each vehicle must not exceed its capacity.
(d) Each item has a fixed loading orientation, namely the length side of each item must be parallel to the long side of the vehicle. Overlapping of items is not allowed.

The objective of 2L-HFVRP is to find a set of routes satisfying all customers' demands and the constraints mentioned above so that the total cost is minimized. Fig. 1 shows a simple example of 2L-HFCVRP that has five customers, 11 items, and two vehicles.

In addition to the constraints mentioned above, in real situations, the customer may be required a visiting order to facilitate loading and unloading. For example, in last-in-first-out (LIFO) scheme, if the customer i is visited before the customer j, then items of the customer i are packed after the customer j. If we consider the sequence and orientation of loading, 2L-HFCVRP can be classified as follows:

a) 2|UO|L-HFCVRP: no loading sequence is required, and the orientation of items is fixed.
b) 2|UR|L-HFCVRP: no loading sequence is required, and the orientation of items is not fixed, namely, items are allowed to be rotated.
c) 2|SO|L-HFCVRP: the sequential loading is required, and the orientation of items is fixed.
d) 2|SR|L-HFCVRP: the sequential loading is required, and items are allowed to be rotated.

This paper mainly focuses on 2|UO|L-HFCVRP and 2|SO|L-HFCVRP and the solutions for these problems can be used for 2|UR|L-HFCVRP and 2|SR|L-HFCVRP respectively.