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A multiple ant colony optimization algorithm for the capacitated location routing problem

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ABSTRACT

The success of a logistics system may depend on the decisions of the depot locations and vehicle routings. The location routing problem (LRP) simultaneously tackles both location and routing decisions to minimize the total system cost. In this paper a multiple ant colony optimization algorithm (MACO) is developed to solve the LRP with capacity constraints (CLRP) on depots and routes. We decompose the CLRP into facility location problem (FLP) and multiple depot vehicle routing problem (MDVRP), where the latter one is treated as a sub problem within the first problem. The MACO algorithm applies a hierarchical ant colony structure that is designed to optimize different subproblems: location selection, customer assignment, and vehicle routing problem, in which the last two are the decisions for the MDVRP. Cooperation between colonies is performed by exchanging information through pheromone updating between the location selection and customer assignment. The proposed algorithm is evaluated on four different sets of benchmark instances and compared with other algorithms from the literature. The computational results indicate that MACO is competitive with other well-known algorithms, being able to obtain numerous new best solutions.

1. Introduction

The design of a logistics system is an important issue in today's competitive environment due to the significant contribution of the distribution cost to the total supply chain cost. This kind of problem is commonly solved in two phases: facility location for a long term policy and vehicle routing to satisfying customer demands for the operational decisions. These two components can be treated separately, but may lead to suboptimal solutions (Salhi and Rand, 1989). The location routing problem (LRP) integrates facility location problem (FLP), which determines the depot locations and allocates customers to each selected depot, and vehicle routing problem (VRP), which constructs the vehicle routes of the selected depot. Several real world applications can be found in the literature, for example, bill delivery (Lin et al., 2002), parcel delivery (Wasner and Zäpfel, 2004), and mobile network design (Billionnet et al., 2005). The LRP with capacities on both depots and routes is called capacitated LRP (CLRP) which is the focus of this paper.

The CLRP can be represented by a graph $G=(V, E)$, where $V=I\cup J$. $I=\{1, \ldots, n\}$ is the set of customer nodes and $J=\{1, \ldots, m\}$ denotes the set of candidate depot locations. Each customer $i\in I$ has a demand d_i. A capacity R_j and an opening cost f_j are associated with each candidate depot site $j\in J$. Associated to each edge $(i, j)\in E$ there is a routing cost c_{ij} which denotes the traveling distance or traveling cost between nodes i and j. A set K of homogeneous vehicles with capacity Q and cost C are available. Each customer must be served exactly once by only one vehicle. Each route must begin and end at the same depot and its total load cannot exceed vehicle capacity. The total load of the vehicles assigned to a depot cannot exceed the capacity of that depot. The objective is to find the optimal number and locations of the depots as well as the vehicle routes of each opened depot so as to minimize the sum of the fixed facility costs, transportation costs, and vehicle costs.

The CLRP is very difficult to solve since it encompasses two NP-hard problems: facility location problem and vehicle routing problem (Garey and Johnson, 1979). In CLRP, the location–allocation decision will influence the total cost of vehicle routes and the architecture of vehicle routes will affect the location of depots and allocation of customers. Consequently, how to deal with the interdependence between these decisions is an important issue. In this paper, we solve both location and routing problems simultaneously rather than independently with nested methods based on the ant colony optimization algorithm. We apply a hierarchical structure, with facility location as the main problem and vehicle routing as a subordinate one. To wit,

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we decompose the CLRP into facility location and multi-depot vehicle routing problem, while the latter problem is embedded into the first one. This concept of hierarchy is also emphasized by Balakrishnan et al. (1987) and Nagy and Salhi (1996). The proposed multiple ant colony optimization algorithm (MACO) is evaluated by four sets of CLRP benchmark instances from the literature and its computational results are compared with state-of-the-art algorithms.

The remainders of this paper are organized as follows. Section 2 provides an extensive review of LRP in the literature. The multiple ant colony optimization algorithm to tackle the CLRP is described in Section 3. In Section 4, the computational results of four groups of benchmark problems are reported. For each benchmark set we compare to the best available algorithms. Finally, conclusions are followed in Section 5.

2. Literature review

The LRP has been studied for decades, there are a few LRP surveys in the literature (Laporte, 1988; Min et al., 1998; Nagy and Salhi, 2007). Laporte (1988) reviewed early research on location routing problems and summarized different types of formulations, solution algorithms and computational results of research published prior to 1988. Min et al. (1998) synthesized the past evolution of location routing literature and explored promising research opportunities in incorporation of more realistic aspects, algorithmic design and model complexity. Recently, Nagy and Salhi (2007) surveyed the state of the art in location routing problem. They proposed a classification scheme and looked at a number of problem variants. They also investigated exact and heuristic algorithms and presented some suggestions for future research.

Most early work on LRP considers either capacitated routes or capacitated depots, but not both (Laporte et al., 1988; Chien, 1993; Srivastava, 1993; Tuzun and Burke, 1999). Recently, a number of studies have been devoted to the case with capacitated depots and routes (Wu et al., 2002; Prins et al., 2006a, 2006b; Bouhafs et al., 2006; Prins et al., 2007; Barreto et al., 2007; Duhamel et al., 2010; Yu et al., 2010). Our study also considers both depot and route capacities.

Several exact methods have been devoted to solve the LRP, but optimal solutions are only limited to medium-scale or to basic uncapacitated instances. Laporte and Norbert (1981) designed a branch-and-bound algorithm for an LRP with a single open depot, and solved instances with up to 50 customers. In Laporte et al. (1986), the solution to an LRP with vehicle capacity constraints is obtained by a branch-and-cut method. Subtour elimination constraints and chain-barring constraints guarantee that each route starts and ends at the same facility. Laporte et al. (1988) addressed an LRP with asymmetrical costs, in which vehicle capacity is replaced by a maximum route length. They elaborated a branch-and-bound algorithm that is able to solve instances with up to 40 customers, but the number of depots is small (2 or 3) and the number of routes per opened depot is limited to 2. Akca et al. (2009) presented a set-partitioning based formulation of the LRP and proposed a column generation approach to solve instances with up to 40 customers. Belenguer et al. (2011) proposed a branch-and-cut algorithm based on a zero-one linear model strengthened by new families of valid inequalities for solving the CLRP. They solved instances to optimality with up to 50 customers and five depots. Baldacci et al. (2011) proposed a branch-and-cut-and-price algorithm for solving the CLRP based on a set-partitioning-like formulation of the problem. The lower bounds produced based on dynamic programming and dual ascent methods, are used by an algorithm that decomposes the LRP into a limited set of MDVRP. The bounds provided by their model are very tight, being able to solve instances with up to 199 customers and 14 facilities.

As the LRP problem is NP-hard, most of the researches used heuristics to solve the LRP. Nagy and Salhi (2007) classified the heuristics into four different types as follows: sequential, clustering-based, iterative, and hierarchical. Sequential methods solve the location problem by minimizing the sum of facility to customer distance and the routing problem based on the selected depots sequentially. Clustering-based methods (Srivastava, 1993; Barreto et al., 2007) partition the customers into clusters and then find a depot for each cluster. The VRP is then solved for each cluster. Iterative methods (Hansen et al., 1994; Wu et al., 2002; Prins et al., 2007; Duhamel et al., 2010) decompose the LRP into two subproblems. Then, subproblems are solved iteratively by feeding information from one subproblem to the other. Hierarchical methods (Nagy and Salhi, 1996; Albareda-Sambola et al., 2005) consider the location problem as the main problem and the VRP as a subordinated problem. Nagy and Salhi (2007) believed that hierarchical methods may provide better solutions. Based on their observation, the proposed MACO in this paper is a hierarchical method.

Many heuristics that hybrid two different heuristic approaches are proposed in the literature. Tuzun and Burke (1999) proposed a two-phase tabu search (TS) approach for the LRP. One phase seeks a good facility configuration while the other one obtains a good routing for this configuration. Wu et al. (2002) presented a combined TS and simulated annealing (SA) decomposition approach to solve the multi-depot location routing problem with multiple fleet types and limited number of vehicles for each vehicle type. Lin et al. (2002) developed a meta-heuristic approach based on threshold accepting (TA) and SA to assist in making decisions of facility location, vehicle routing and loading decision for bill delivery services in Hong Kong.

Albareda-Sambola et al. (2005) proposed another two-phase TS heuristic for the LRP which incurs not capacity constraints on vehicles. Wang et al. (2005) proposed a two-phase hybrid heuristic which decomposes the LRP into location–allocation problem and vehicle routing problem. In the location phase, the TS was applied to obtain the configuration of facility locations. For each selected facility location, a vehicle routing problem was solved by ACO in the routing phase. Bouhafs et al. (2006) proposed a hybrid algorithm which combined the SA and ant colony system (ACS) to solve the CLRP. A good configuration of facilities was first found by the SA, and then the ACS was applied to construct the routings based on the configuration. These two ACO-related heuristics construct the routing problem and feed back the information for the facility selection phase.

Prins and his coworkers conducted different heuristic methods to the LRP. Prins et al. (2006a) combined greedy randomized adaptive search procedures (GRASP) and path relinking to develop a two phase algorithm for the capacitated location routing problem. In the first phase, the GRASP and a learning process were implemented to select depots. The second phase was to generate new solutions using a path relinking. Later, Prins et al. (2006b) presented a memetic algorithm with population management (MA|PM) to solve the same problem. Prins et al. (2007) proposed a cooperative approach, which combines the Lagrangean relaxation and granular tabu search (GTS), to solve the capacitated LRP. The algorithm alternates between a location subproblem, solved by Lagrangean relaxation, and a multi-depot VRP, solved by the GTS. Duhamel et al. (2010) presented a GRASP with evolutionary location search (GRASP $\times$ ELS) approach for the CLRP.

Barreto et al. (2007) integrated several hierarchical and non-hierarchical clustering techniques in a sequential heuristic