Computers & Operations Research 62 (2015) 184–196

Contents lists available at ScienceDirect

Computers & Operations Research

journal homepage: www.elsevier.com/locate/caor

A simulated annealing heuristic for the open location-routing problem

Vincent F. Yu*, Shin-Yu Lin

Department of Industrial Management, National Taiwan University of Science and Technology, No. 43, Section 4, Keelung Road, Taipei 10607, Taiwan

ARTICLE INFO

Available online 27 October 2014

Keywords:
Capacitated location-routing problem
Open location-routing problem
Simulated annealing
Third-party logistics

ABSTRACT

This paper introduces the open location-routing problem (OLRP) that is a variant of the capacitated location-routing problem (CLRP). OLRP is motivated from the rise in contracting with third-party logistic (TPL) companies and is different from CLRP in that vehicles do not return to the distribution center after servicing all customers. The goal of OLRP is to minimize the total cost, consisting of facility operation costs, vehicle fixed costs, and traveling costs. We propose a simulated annealing (SA)-based heuristic for solving OLRP, which is tested on OLRP instances that have been adopted from three sets of well-known CLRP benchmark instances with up to 318 customers and 4 potential depots. The computational results indicate that the proposed heuristic efficiently solves OLRP.

1. Introduction

Determining facility locations and planning vehicle routes are two critical issues in the design of a supply chain network, both of which significantly impact the operation and profitability of companies. Therefore, many studies have been devoted to the facility location problem (FLP) and the vehicle routing problem (VRP). The capacitated location-routing problem (CLRP) simultaneously considers these two important components of a logistic system. Since companies nowadays are putting more focus on their core capabilities to gain competitive advantages, logistics activities are often outsourced to third-party logistics (TPL) providers. When a company contracts its distribution activities to a TPL company, the service vehicles are owned by the TPL company. Therefore, after servicing its customers, these vehicles return to the TPL company, instead of the distribution centers or depots of the hiring company. In this case, CLRP no longer applies. Therefore, we propose the open location routing problem (OLRP) to deal with this situation.

OLRP usually happens in a company that either does not have its own fleet of vehicles or its fleet is not large enough to service its customers. Thus, the company contracts with a TPL company to acquire sufficient capacity. From the contractee's point of view, there is no cost associated with the starting trip from the TPL company to its depot as well as the returning trip from a vehicle's last customer to the TPL company. In other words, the contractee is only concerned about the cost associated with the trip between its depot and the last customer that the vehicle services. Therefore, when the contractee is planning the vehicle routes, it can assume that a vehicle does not return to the depot after finishing its deliveries to customers. If the vehicle does return to the depot, then it must visit the same customers in the reverse order as in the open vehicle routing problem (OVRP) [1]. OLRP integrates the concepts of CLRP and OVRP because it simultaneously determines facility locations and plans open vehicle routes that start from a depot and end at a customer in order to satisfy all customers' demands.

OLRP has many applications in practice. For example, newspaper companies and advertising companies must determine the optimal locations of their printing plants so as to cover their service areas at a minimum cost. Since these companies usually do not have their own fleet of vehicles to distribute newspapers or print advertisements, hiring a 3PL company to distribute their products from their printing plants is a cost-saving and efficient option. Another application of OLRP is for air mail/cargo systems. Due to cost constraints, courier service companies cannot have facilities all around the world, and hence they need to choose some strategic locations as their distribution centers. Furthermore, they tend not to have their own air transportation and thus cooperate with airline companies to deliver their shipments. In both applications, the expenses of hiring a TPL company are usually affected by the number of units of a particular kind of transportation that they are hiring and how far the hired fleet travels. The objective of OLRP is therefore to minimize the total costs of the distribution system, including depot opening cost, vehicle fixed cost (hiring a vehicle from a contractor), and vehicle traveling cost. Because TPL service is gaining popularity worldwide, OLRP has become an important research problem for many organizations.

The differences between the solution values of CLRP and those of OLRP can be a good reference for a company that is considering whether or not it should outsource its logistics activities to TPL companies. Since these differences represent potential savings

* Corresponding author. Tel.: +886 2 2737 6333.
E-mail address: vincent@mail.ntust.edu.tw (V.F. Yu).

http://dx.doi.org/10.1016/j.cor.2014.10.009
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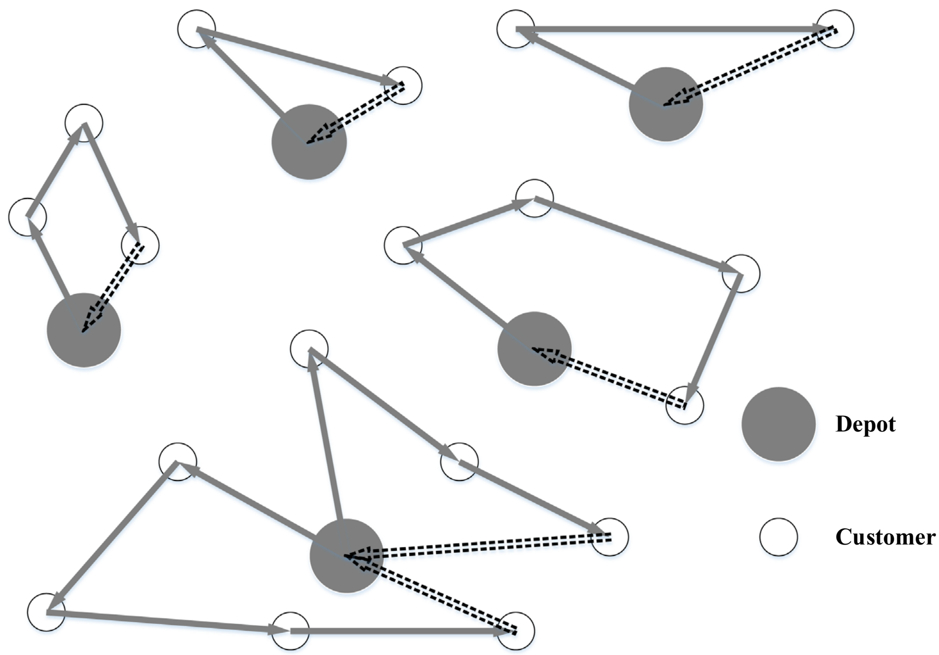

Fig. 1. Illustration of the difference between an OLRP solution and its corresponding CLRP solution.

resulting from logistics outsoucing, they can also facilitate price negotiations between the company and TPL service providers.

Fig. 1 illustrates the difference between an OLRP solution and its corresponding CLRP solution. The solid arcs in the figure represent an example of an OLRP solution, while the solid arcs together with dotted arcs give the corresponding CLRP solution. We can see that each vehicle route in the OLRP solution is a Hamilton path, while the CLRP solution comprises a set of Hamilton cycles.

Since OVRP is NP-hard [2] and is a special case of OLRP, OLRP is also NP-hard. Therefore, heuristic solution approaches are efficient and effective alternatives for solving medium- and large-scale OLRP instances. In this paper we propose a simulated annealing (SA)-based heuristic to solve OLRP, because it performs well in solving CLRP [3].

The remainder of this paper is organized as follows: Section 2 summarizes the related literature. Section 3 introduces a mathematical model for OLRP. Section 4 presents the proposed SA heuristic for solving OLRP. Section 5 discusses the computational study. Section 6 concludes this study and suggests directions for future research.

2. Literature review

Due to its complexity, many heuristic algorithms have been developed for CLRP. Tuzun and Burke [4] proposed a two-phase tabu search (TS) for solving CLRP. The first phase applies TS to seek out a good facility configuration. The second phase performs another TS to search for a good routing that corresponds to the configuration. Prins et al. [5] proposed a two-phase heuristic for CLRP. Their first phase executes a greedy randomized adaptive search procedure (GRASP) based on an extended and randomized version of the Clarke and Wright savings algorithm. This phase implements a learning process for the choice of depots. The second phase generates new solutions using a path relinking mechanism.

Barreto et al. [6] employed a cluster analysis-based sequential heuristic and several proposed measures for solving CLRP, concluding that their cluster method has great potential for finding better CLRP solutions. Prins et al. [7] solved CLRP by separating it into the facility-location problem (FLP) and the vehicle routing problem. First, they applied a Lagrangean relaxation to solve FLP and then used a granular tabu search heuristic to improve vehicle routes. Derbel et al. [8] hybridized the genetic algorithm (GA) with iterated local search (ILS) for solving CLRP. Since GA might fail to converge to the global optimum and ILS could fall too quickly into local optimum, they imbedded ILS into GA so as to refine the search through successive iterations and to maximize the chance of convergence to the optimal solution. Duhamel et al. [9] solved CLRP with a greedy randomized adaptive search procedure (GRASP), calling an evolutionary local search (ELS) with two solution searching spaces: giant tours without trip delimiters and true CLRP solutions.

Yu et al. [3] proposed an efficient SA heuristic for solving CLRP, by utilizing a special solution representation that diversifies the search and improves the performance of their SA heuristic. More recently, Ting and Chen [10] developed a multiple ant colony optimization algorithm (MACO) to solve CLRP. The algorithm separates CLRP into three decision sub-problems: a single-source capacitated facility location problem, a customer-to-depot assignment problem, and a CVRP problem for each depot. Each sub-problem is solved with an ant colony method and conjoins by exchanging information through pheromone updates. Readers can refer to Lopes et al. [11] for a more comprehensive review of the CLRP literature, as they proposed a taxonomy for location-routing problems from both the problem structure and the solution methodology perspectives.

Similar to CLRP, many heuristic solution approaches have been proposed for solving OVRP in the literature. Sariklis and Powell [12] proposed a two-phase heuristic consisting of a clustering phase and a routing phase to solve OVRP. The clustering phase determines the minimum number of clusters based on the capacity of vehicles, sequentially assigns customers to the clusters, and then makes adjustments to the assignments to improve the quality of the clusters. The routing phase searches for an optimal chain in each cluster by solving a minimum spanning tree problem for each cluster. If the minimum spanning tree is not a chain, then the solution is infeasible and will be converted into a feasible solution by adding penalties to the solution. If the resulting solution is still infeasible, then a special method converts the infeasible solution into a feasible one.