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Discrete Optimization

Solving the dynamic capacitated location-routing problem with fuzzy demands by hybrid heuristic algorithm

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ABSTRACT

In this paper, the dynamic capacitated location-routing problem with fuzzy demands (DCLRP-FD) is considered. In the DCLRP-FD, facility location problem and vehicle routing problem are solved on a time horizon. Decisions concerning facility locations are permitted to be made only in the first time period of the planning horizon but, the routing decisions may be changed in each time period. Furthermore, the vehicles and depots have a predefined capacity to serve the customers with altering demands during the time horizon. It is assumed that the demands of customers are fuzzy variables. To model the DCLRP-FD, a fuzzy chance-constrained programming is designed based upon the fuzzy credibility theory. To solve this problem, a hybrid heuristic algorithm (HHA) with four phases including the stochastic simulation and a local search method are proposed. To achieve the best value of two parameters of the model, the dispatcher preference index (*DPI*) and the assignment preference index (*API*), and to analyze their influences on the final solution, numerical experiments are carried out. Moreover, the efficiency of the HHA is demonstrated via comparing with the lower bound of solutions and by using a standard benchmark set of test problems. The numerical examples show that the proposed algorithm is robust and could be used in real world problems.

1. Introduction

Due to the fact that customers' demand is showing an upward trend with competitive prices and a lesser waiting time is desired for receiving the goods, it makes logistics the main issue in supply chain management (Zare Mehrjerdi & Nadizadeh, 2013). In recent years, the efficient, reliable, and flexible decisions on location of depots and the distribution routings are of vital importance for managers (Karaoglan, Altiparmak, Kara, & Dengiz, 2012; Nadizadeh, Sahraeian, Sabzevari Zadeh, & Homayouni, 2011). Many researchers indicated that if the routes are ignored while locating the depots, the costs of distribution systems might be immoderate (Karaoglan, Altiparmak, Kara, & Dengiz, 2011; Martínez-Salazar, Molina, Ángel-Bello, Gómez, & Caballero, 2014). Salhi and Rand (1989) first showed that the solving of the location problem without route consideration may lead to a sub-optimal solution. The location-routing problem (LRP) overcomes this drawback by simultaneously considering the location and routing decisions (Guerrero, Prodhon, Velasco, & Amaya, 2013; Hashemi Doulabi & Seifi, 2013; Jarboui, Derbel, Hanafi, & Mladenović, 2013).

The LRP can be defined as a combination of two problems of facility location problem (FLP) and vehicle routing problem (VRP) Escobar, Linfati, and Toth (2013), Lopes, Plastria, Ferreira, and Beatriz Sousa (2014), Stenger, Schneider, Schwind, and Vigo (2012). Since both problems belong to the class of NP-hard problem, the LRP is also an NP-hard problem (Barreto, Ferreira, Paixao, & Sousa Santos, 2007; Belenguer, Benavent, Prins, Prodhon, & Wolfler-Calvo, 2011; Samanlioglu, 2013). In the LRP, customer demands must be satisfied, vehicle capacities should not be exceeded, and the minimization of facility fixed and operating costs, as well as of routing costs have to be realized (Rieck, Ehrenberg, & Zimmermann, 2014). Laporte (1988) was the first researcher who discussed and classified the LRP models. Min, Jayaraman, and Srivastava (1998) reviewed the LRP literature using a hierarchical classification based on the problem characteristics such as the number of depots, the capacity of depots and vehicles, and the form of the objective function. Nagy and Salhi (2007) also performed a comprehensive literature review on the LRP models, solution approaches, application areas and some future works.

Recently, Prodhon and Prins (2014) analyzed the new literature on the standard LRP and new extensions such as several

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distribution echelons, multiple objectives or uncertain data. They also compared the results of state-of-the-art meta-heuristics on standard sets of instances for the classical LRP, the two-echelon LRP and the truck and trailer problem.

The LRP is applicable to a wide variety of fields such as food and drink distribution, newspapers delivery, waste collection, drug distribution, bill delivery, military applications, parcel delivery, relief goods distribution in natural disaster, and various consumer goods distribution (Ceselli, Righini, & Tresoldi, 2014; Manzour-al-Ajdad, Torabi, & Salhi, 2012; Rath & Gutjahr, 2014; Ting & Chen, 2013). In capacitated location-routing problem (CLRP), the problem is constrained with the vehicles and the depots capacities. The objectives in CLRP are to determine the location of depots and a set of customers to be assigned by each depot as well as the distribution routes (Baldacci, Mingozzi, & Wolfler Calvo, 2011; Contardo, Cordeau, & Gendron, 2013; Contardo, Hemmelmayr, & Crainic, 2012). Since CLRP is an NP-hard problem, most of papers in the field of CLRP are focused on only new solution methods that are often based on heuristic or meta-heuristic approaches (Nguyen, Prins, & Prodhon, 2012; Yu, Lin, Lee, & Ting, 2010). Some reviews on solution approaches of CLRP exist in the literature that can be found in Duhamel, Lacomme, Prins, and Prodhon (2010) and Derbel, Jarboui, Hanafi, and Chabchoub (2012).

The dynamic location-routing problem is a very important area of the LRP which has not been addressed much in the literature. The static (single-period) LRP is very much prone to the criticism that the planning horizons of the location and routing do not match. In other words, the LRP integrates the strategic (location) and tactical (routing) levels. Locational decisions are usually quite stable in time, because of implementation costs and set-up times. On the other hand, routing decisions (even master tour decisions at a tactical level) are more often changed than location decisions, especially when they refer to the transportation of goods to customers with varying demands (Albareda-Sambola, Fernández, & Nickel, 2012). Therefore, by considering a planning horizon for facility location that contain shorter planning intervals for route planning, dynamic LRPs are a much better model of real-life location problems with routing aspects and provide an important means of refuting the above criticism (Nagy & Salhi, 2007).

In this paper, the dynamic capacitated location-routing problem with fuzzy demands (DCLRP-FD) is considered. In the DCLRP-FD, depots can only be opened at the beginning of the planning horizon and remain unchanged throughout the planning horizon. On the other hand, the routing of vehicles can be changed at each period due to fluctuations of demands. The vehicles and depots have a limited capacity to serve the customers that their demands change in each time period. Moreover, it is assumed that the demands of customers are fuzzy variables. A fuzzy chance-constrained programming is designed based upon the fuzzy credibility theory to model the DCLRP-FD. The high complexity of this problem makes it impossible to be solved in practice with commercial software. For this reason, a hybrid heuristic algorithm (HHA) with four phases including the stochastic simulation and a local search method are proposed to solve the problem. To the best of our knowledge, this paper is the first work in the field of LRP that consider both the planning horizon and uncertainty for the customers' demand.

The remainder of this paper is organized as follows: In the next section, the literature review of the work is presented. In Section 3, some basic concepts of fuzzy theory are given. Section 4 defines the DCLRP-FD in more details and presents a fuzzy chance-constrained programming model using the credibility theory. Details of the hybrid heuristic algorithm to solve the DCLRP-FD are presented in Section 5. In Section 6, different numerical experiments are given to reveal the performance of the proposed algorithm. In the final section, the conclusion remarks of the paper are presented.

2. Literature review

The first effort on dynamic LRP dates back to the research of Laporte and Dejax (1989). They considered multiple planning periods for the LRP, whereby in each period both the locations and the routes may be changed. They presented an ingenuous network representation of the problem. The resulting network optimization problem was solved by exact and heuristic approaches. Salhi and Nagy (1999) assumed that the depots were fixed throughout the planning horizon but the vehicle routes changed following changes in customers' demand. It was also assumed that the customer set did not change. In their work, a number of solution approaches were investigated. Ambrosino and Scutella (2005) considered a multi-level LRP with static and dynamic planning horizons and applied commercial software to solve the integer linear programming (ILP) formulation of the problem. Prodhon (2011) considered the periodic location-routing problem. The objective of the problem was to determine the set of depots to be opened, the combination of service days to be assigned to customers and the routes originating from each depot for each period of the horizon, in order to minimize the total cost. To solve large size instances of the periodic location-routing problem, a hybrid evolutionary algorithm was proposed. The algorithm was hybridized with a heuristic based on the randomized extended Clarke and Wright algorithm to create feasible solutions. Finally, the proposed method was evaluated over three sets of instances and the results showed that it outperforms the previous methods. Albareda-Sambola et al. (2012) presented the multiperiod location-routing problem with decoupled time scales. Their problem was defined over a finite time horizon, in which location and routing decisions were made at different time scales. They also assumed that locations could be opened or modified only in some selected time periods of the planning horizon and then they remain unchanged during the time periods between them. Due to the complexity of the model, they proposed an approximation based on replacing vehicle routes by spanning trees, and its capability for providing good quality solutions was assessed in a series of computational experiments.

Dynamic problems divide the planning horizon into multiple periods. Normally within the planning horizon there is some uncertainty about some of the parameters (typically the customers' demand). In this paper, it is assumed that the demands of customers in each time period are not known and they are considered as fuzzy variables. This means that the information about demand at each customer is often not precise enough. For example, based on experience, it can be concluded that demand of a customer is "around 50 units", "between 20 and 60 units", etc. A problem under uncertainty may be modeled using various approaches such as using fuzzy variables. Whether to use fuzzy or stochastic variables in a model directly depends on the semantic of the problem and also the availability of reliable data. Although many problems can be modeled using stochastic variables, there are some reasons in which it becomes almost impossible or irrational to use stochastic variables, such as: there are not enough data to be used to model the problem and, the available data is not reliable and error-prone (Fazel Zarandi, Hemmati, Davari, & Turksen, 2013). Therefore, while the use of probability theory is cumbersome and costly, fuzzy logic can be worthwhile in these cases.

Recently fuzzy logic has been used to solve many different problems. The need to use fuzzy logic in problems arises whenever there are some vague or uncertain parameters. Credibility theory has been used in many problems with fuzzy parameters so far, in parallel with some meta-heuristics (see Zare Mehrjerdi & Nadizadeh, 2013). There are some works on the CLRP with fuzzy variables in the literature of CLRP. The work of Zarandi, Hemmati, and Davari (2011) is the first attempt to model the CLRP using fuzzy variables