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A hybrid simulated annealing based heuristic for solving the location-routing problem with fuzzy demands

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Abstract The location-routing problem (LRP) is established as a new research area in the context of location analysis, which deals simultaneously with two problems of locating the facilities and designing the travel routes for vehicles among established facilities and existing demand points. In this paper, the location-routing problem with fuzzy demands (LRPFD) is considered which may arise in many real life situations in logistics management, and a fuzzy chance constrained program is designed to model it, based on the fuzzy credibility theory. A hybrid simulated annealing (SA) based heuristic incorporated with stochastic simulation is developed and proposed to solve the problem. The efficiency of the solution procedure is demonstrated via comparing its performance with those of some other existing solution procedures from literature using a standard benchmark set of test problems.

1. Introduction

One of the most important tasks of supply chain managers is to design an efficient and effective distribution network in order to deliver the produced goods to the customers with the lowest cost and in the shortest possible time frame. The efficient and effective movement of goods from raw material sites to processing facilities, component fabrication plants, finished goods assembly plants, distribution centers, retailers and customers is critical in today's competitive environment. Approximately 10% of the gross domestic product is devoted to supply-related activities [1]. Decisions to be made in the realm of supply chain management, like many other areas of management, are often categorized as strategic, tactical and operational decisions. A strategic or long-term decision does not take place on a regular basis and needs major capital investment. An example of a long-term decision is determination of facility location. Facility location selection (FLS) is a nonrecurring, cross-functional, and group decision-making (GDM) problem [2]. Tactical decision making is needed in a more frequent manner than a strategic one. An example of a tactical decision is the vehicle routing problem (VRP). Finally, the operational decisions such as scheduling are those decisions that take place regularly. Based on the above discussion, the location-routing problem (LRP) integrates the strategic (location) and tactical (routing) levels. Facility location and vehicle routing problems are two main streams of research in logistics and supply chain management which have been major research areas for both researchers and practitioners. Nowadays, most supply chain managers believe that the success of their supply chains highly depends on logistical decisions particularly location and routing decisions.

LRP is an NP-hard problem, as it is composed of two NP-hard problems; facility location and vehicle routing [3–5]. Moreover, it is generally accepted that solving the two sub-problems separately (either sequentially or iteratively) often leads to sub-optimal solutions. LRP has many real life applications, some of which are presented in literature such as: applications in newspaper distribution [6], food and drink distribution [7], blood bank location [8], and waste collection [9].

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There exist some review papers dedicated to the study of LRP literature. Laporte [10] reviewed early work on location-routing problems; he summarized the different types of formulations, solution algorithms and computational results of work published prior to 1988. More recently, Min et al. [11] developed a hierarchical taxonomy and classification scheme, which they used to review the existing location-routing literature. They categorized papers in terms of problem characteristics and solution methodology. One means of classification was the number of layers of facilities. Typically, two-layer problems focus on flows of commodities from distribution centers to customers, while three-layer problems include flows of commodities from plants to distribution centers to customers. Nagy and Salhi [12] conducted a comprehensive survey of location-routing papers up to 2006. They proposed a classification scheme and looked at a number of problem variants. Both exact and heuristic algorithms were investigated in their work. Interested readers are referred to these references in order to get more detailed knowledge of LRP models, extensions and solution methods.

Applications and numerous solution methods varying from Lagrangian relaxation to heuristic and metaheuristic approaches have been proposed in order to solve the LRP. Among many solution procedures, only a few of them are presented here, as follows. Prins et al. [13] presented a two-phased solution approach to solve the LRP with constraints on route and depot capacities. In the first phase, a greedy randomized adaptive search procedure (GRASP) is executed, based on an extended and randomized version of the Clarke and Wright algorithm. In the second phase, new solutions are generated by post-optimization using path relinking. Marinakis and Marinaki [14] considered a large scale real problem of location-routing within the food industry in Greece. To solve the problem, they proposed a new formulation of the LRP based on bi-level programming. According to the fact that in the LRP, decisions are made at strategic and operational levels they formulated the problem at such a way that in the first level, the decisions of the strategic level are made, namely, the top manager finds the optimal location of the facilities; while in the second level, the operational level decisions are made, namely, the operational manager finds the optimal routing of vehicles. Prins et al. [15] proposed a memetic algorithm with population management (MA|PM) to solve the LRP with capacitated routes and depots. MA|PM is a very recent form of memetic algorithm in which the diversity of a small population of solutions is controlled by accepting a new solution if its distance to the population exceeds a given threshold. Cappanera et al. [9] presented an obnoxious facility location-routing problem in which Lagrangian relaxation was used to decompose the problem into two subproblems of location and routing and two Lagrangian heuristics were presented. More recently, Prins et al. [16] combined the Lagrangian relaxation technique with a granular tabu search to develop another iterative two-phase approach (LRGTS) to solve the LRP and obtained promising results. The algorithm alternated between a depot location phase and a routing phase, exchanging information on the most promising edges. In the first phase, routes and their customers were combined to form supercustomers to transform the original LRP into a facility location problem. The Lagrangian relaxation of the assignment constraints were used to solve the resulting FLP. In the second phase, a granular tabu search was used to improve the multi-depot VRP solution obtained in the first phase.

Uncertainty in location-routing (or vehicle routing) problems arises in modeling a number of business situations that arise in the area of distribution. Laporte et al. [17] describes a family of stochastic location-routing problems in which the supplies of the customers are random variables. In the first stage decisions regarding depot location, fleet size, and planned routes have to be made without knowing the actual supplies. In the second stage a corrective recourse action is taken (when the total supply of the route turns out to exceed vehicle capacity) in which the vehicle returns to the depot and empties its load before resuming its journey. In their paper, two versions of the problem are studied: (P1) minimize the first stage cost so that the probability of the route failure does not exceed a preset threshold; (P2) minimize the first stage cost so that the expected penalty of any route does not exceed a fraction of its planned cost. Secomandi [18] considers a version of the vehicle routing problem where customer demand is of stochastic nature. His focus is on dynamically routing a single vehicle to serve the demands of a known set of geographically dispersed customers during real-time operations. The goal consists of minimizing the expected distance traveled in order to serve all customer demands. Fuzzy logic has been used to solve many applied problems so far. The need to use fuzzy logic in problems arises whenever there are some vague or uncertain parameters. In most cases, there is not sufficient data for fitting a probability distribution to customer demand. On the other hand, based on expert judgment, one can easily estimate these demands. Therefore, while using probability theory is difficult and costly, fuzzy logic is used to deal with uncertainty in these problems. The credibility theory has been used in many problems with fuzzy parameters so far, in parallel with some metaheuristics. Fazel Zarandi et al. [19] addressed multi-depot capacitated LRP (MDCLRP) in which travel time between two nodes is a fuzzy variable and proposed a simulation-embedded simulated annealing (SA) procedure in order to solve the problem. Erabo and Mingyong [20] considered the vehicle routing problem with fuzzy demands and proposed a fuzzy chance-constrained program model based on fuzzy credibility theory. They used stochastic simulation and an improved differential evolution algorithm to solve the problem. Considering the literature of the location-routing problem, our paper makes the following contribution to the literature. As far as the authors know, this is the first work in the literature of the LRP which considers fuzzy demands and the uses credibility theory to model and solve the problem. Moreover, a hybrid simulated annealing based heuristic has been proposed in which stochastic simulation is used to estimate the credibility of a solution.

In this paper, the LRP has two levels (depots and customers) and can be defined as follows: Let $G = (V, E)$ be an undirected network where V is a set of nodes comprised of a subset I of m potential depot sites and a subset $J = V \setminus I$ of n customers. E is a set of edges connecting each pair of nodes in V. Associated with each edge $(i, j) \in E$ is a traveling cost c_{ij}. Each depot site $i \in I$ has an opening cost O_i. Each customer $j \in J$ has a demand d_j of a single commodity which is assumed to be a fuzzy variable. Determination of the real values of customer demand prior to their realization is often too difficult or even impossible because of their uncertain nature. In this work we assume that there is not sufficient data for fitting a probability distribution to customer demand. It is assumed that these demands are estimated based on expert judgment. Therefore, fuzzy logic is used to deal with uncertainty in this paper. A set K of identical vehicles with capacity C is available. Each vehicle, when used by a depot i, incurs a depot dependent fixed cost F_i and performs a single route. Each route must start and terminate at the same depot. The objective is to determine which depots should