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Sustainable multi-depot emergency facilities location-routing problem with uncertain information

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ABSTRACT

Emergency facilities location and vehicle routing are two of the most challenging issues in emergency logistics. This paper presents an exploration of the sustainable multi-depot emergency facilities location-routing problem with uncertain information. An uncertain multi-objective location-routing programming model is constructed for emergency response with consideration of travel time, emergency relief costs and carbon dioxide emissions via uncertainty theory. By implementing the main-objective method, the uncertain multi-objective model can be rebuilt as an uncertain single-objective optimization model. The properties of the model are discussed in the framework of uncertainty theory. A hybrid intelligent algorithm that integrates uncertain simulation and a genetic algorithm is designed to solve the proposed model. Finally, numerical examples are presented to illustrate the optimization ideas and the robustness and effectiveness of the proposed algorithm.

1. Introduction

In recent years, the design of emergency logistics network systems has attracted significant attention from many researchers. Emergency logistics can briefly be defined as the process of planning, managing and controlling the efficient flows of resources from emergency sites to demand points to provide relief to the affected people under emergency conditions [41]. Compared to that in traditional logistics, the relief system in emergency logistics is complicated and challenging. The system consists of three major phases, i.e., a preparedness phase, response phase and recovery phase [6]. In this paper, we focus mainly on the first two phases of the emergency relief system. As two of the critical parts of the preparedness phase and the response phase, the emergency facilities location problem and vehicle routing problem have received considerable attention. For reviews on optimization models of emergency relief systems, we may consult Altay and Green [1], Caunhye et al. [5] and Zhang et al. [58]. The facility location problem concerns the choice of locations of facilities to serve a set of demand sites. The vehicle routing problem is concerned with finding efficient routes for a number of vehicles serving a set of customers.

The highly unpredictable nature of emergencies may lead to the real decisions are usually in the state of indeterminacy. Traditionally, probability theory is used to model indeterminacy, and many innovative studies on the facility location

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problem and vehicle routing problem have been conducted. In one of the earliest papers that considered a facility location problem with some random factors, Wesolowsky [48] studied a facility location problem with n demand points associated with probabilistic weights. After that, Drezner and Wesolowsky [10] extended the work of Wesolowsky [48] to a plane with p-norm distances by considering a similar problem. Zhou and Liu [61] proposed three mathematical models for a capacitated location-allocation problem with stochastic demands. Beraldi and Bruni [2] formulated a two-stage stochastic programming model for an emergency service vehicle location problem. With the objective of minimizing the expected maximum rectilinear distance from the facility to the demand points, Canbolat and Massow [4] considered an emergency facility location problem with random demands. For the case of Istanbul, Salman and Yücel [39] studied emergency facility location under random network damage. For the response phase, vehicle routing models were formulated in the emergency logistics in a random environment. Shen et al. [40] built a two-stage vehicle routing model with random demands and travel times for large-scale bioterrorism emergencies. Errico et al. [11] investigated a vehicle routing problem with hard time windows and stochastic service times. For good resources on stochastic vehicle routing problems, we refer readers to Bertsimas [3], Laporte et al. [23], and Fontem et al. [12].

The studies mentioned above all address either the facility location problem or vehicle routing problem but not both. For an effective response to an emergency, the planning for these two disaster phases (location and routing) must be coordinated, thus producing a location-routing problem that aims to determine the locations of depots while simultaneously determining dispatch routes. Location-routing models have been studied by many researchers since the late 1980s. Early location-routing problems were considered in deterministic environments [22,44,49]. Stochastic location-routing models were subsequently studied by scholars. Toro-Díaz et al. [43] developed a mathematical model for the location-routing problem of emergency medical services with the objective of minimizing the response time and maximizing coverage. Caunhye et al. [6] proposed a two-stage location-routing model with random demands. They solved the model by converting it into a single-stage counterpart. Gao et al. [13] introduced an ant colony algorithm to solve the location-routing problem in dynamic environments consisting of random and cyclic traffic factors. In past years, several other studies on the location-routing problem in random environments have been developed, such as Chan et al. [7], Zhu et al. [62], and Marinakis [30].

Although stochastic models are widely accepted and implemented, it is not suitable to regard every indeterminate phenomenon as a random phenomenon. Probability theory can be used to describe an indeterminate quantity only after we obtain sufficient historical data. However, we often lack the required observational data in many practical situations. In these cases, we have no choice but to take advantage of domain experts. Then, the travel distance may be expressed in human language such as “about four km”. Two mathematical systems exist to model subjective uncertainty. One is fuzzy set theory [53], which is based on fuzzy information. The other is uncertainty theory, which is based on experts' belief degree. In past decades, many scholars have applied fuzzy set theory to the location-routing problem, including Wen and Iwamura [46], Mehrjerdi and Nadizadeh [31], Nadizadeh and Nasab [33], Mousavi et al. [32], and Torfi et al. [42].

As a breakthrough to address indeterminate phenomenon, uncertainty theory offers a powerful alternative to consider the experts' belief degree. Uncertainty theory was founded by Liu [25] in 2007 and perfected by Liu [28] in 2010 based on normality, duality, subadditivity and product axioms. As a core concept of uncertainty theory, some mathematical properties of uncertain measure were studied by Liu [26], Gao [14], and Peng and Iwamura [35,36]. Nowadays, under the framework of the uncertainty theory, many researchers obtained useful results such as [8,29,51,52].

From a practical aspect, uncertain programming, which is a type of mathematical programming involving uncertain variables, was first proposed by Liu [27] in 2009. Uncertain programming has been widely applied in management science and engineering design. The shortest path problem [15], Chinese postman problem [54], assignment problem [55], and maximum flow problem [20] have been studied by some researchers on the basis of uncertain programming. In addition, Zhang and Chen [57] proposed an uncertain project scheduling model to minimize the expected duration under a total cost chance constraint. Qin and Kar [37] investigated a single-period inventory newsboy problem with uncertain demand of the product. Wu et al. [50] investigated the optimal contracts for agency problem with multiple uncertain information. Zhou et al. [59] studied the minimum spanning tree problem with uncertain edge weights and discussed the path optimality conditions for two types of uncertain minimum spanning tree. Zhang et al. [56] proposed three uncertain models for the fixed charge solid transportation problem and designed an algorithm based on a tabu search algorithm to solve the models.

In 2012, Gao [16] studied a single-facility location problem with uncertain demand. The author proposed two uncertain models based on vertex satisfaction degree and network satisfaction degree. Zhou et al. [60] proposed a multi-objective goal programming model by considering service quality, setup costs and operating costs under uncertainty. Wang and Yang [45] considered a hierarchical facility location for reverse logistics network design. Wen et al. [47] introduced an uncertain facility location-allocation model by means of chance constraints with uncertain demands and discussed the equivalent crisp model via α-optimistic criterion. Gao and Qin [17] investigated a p-hub center location problem with the objective of minimizing the maximum travel time.

Due to the increased pressure of environmental and social requirements, sustainability is currently a societal concern for development. Within this context, the design of a sustainable emergency logistic network is a challenge for decision makers. To respond to these challenges, the sustainability of emergency logistic network must consider not only economic aspects but also environment aspects [24,38]. To the best of our knowledge, there is currently no related research on emergency facilities location from the perspective of sustainability within the framework of uncertainty theory. With the observation of this point, this paper attempts to study the multi-depot emergency facilities location-routing problem by considering carbon dioxide (CO_2) emissions with uncertain information. To develop an effective model, two additional objective functions are