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Multi-objective open location-routing model with split delivery for optimized relief distribution in post-earthquake

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The effective distribution of critical relief in post disaster plays a crucial role in post-earthquake rescue operations. The location of distribution centers and vehicle routing in the available transportation network are two of the most challenging issues in emergency logistics. This paper constructs a nonlinear integer open location-routing model for relief distribution problem considering travel time, the total cost, and reliability with split delivery. It proposes the non-dominated sorting genetic algorithm and non-dominated sorting differential evolution algorithm to solve the proposed model. A case study on the Great Sichuan Earthquake in China expounds the application of the proposed models and algorithms in practice.

1. Introduction

Earthquakes have been among major fatal natural disasters, causing a massive death toll. Examples in recent years include the Great Sichuan Earthquake killing nearly 70 thousand people in May 2008(Fawu et al., 2009), the Haiti Earthquake in January 2010 claiming approximately 230,000 lives (Patrick and Anna, 2012), the Chile Earthquake with at least 708 victims in February 2010 (BBC, February 28, 2010), and the Great East Japan Earthquake in March 2011 with 15,883 confirmed deaths (Christine, November 22, 2013). When an earthquake happens, immediate distribution of emergency supplies is pivotal in minimizing the damage and the fatality and therefore the main focus of post-earthquake relief operations. As the time and the resources are limited, emergency logistics decision-makers have to make optimal decisions in the allocation of limited time, funds and other resources.

In comparison with the traditional logistics, disaster relief distribution is more complicated and challenging in emergency logistics (Sheu, 2007). *The features of relief distribution in post-earthquake are critical for decision-making*. First, With "burstiness" of earthquake events, earthquakes cannot be predicted in advance with reasonable accuracy, which is different from hurricanes (Horner and Downs, 2007). Thus, decision makers need to establish temporary DCs where people can more effectively gain access to goods in post-earthquake stage, while for hurricane disaster the strategic location decision is made in preparedness planning stage (Horner and Downs, 2007, 2010; Rawls and Turnquist, 2010; Widener and Horner, 2011). Second, vehicles wait at their last node without returning to DCs until the next order is specified in post-earthquake, for that any given disaster areas receiving aids can be the new DC or the former DC may no longer provide service in the next mission. The open vehicle routing problem has been extensively discussed in traditional logistics (Schrange, 1981; Sariklis and Powell, 2000); however, few works have focused on OLRP in emergency logistics. Third, given the large demand of relief at the

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affected areas in post-earthquake, an affected area can be served more than one time once the demand of the disaster area is greater than the capacity of the serving vehicle. This is called split delivery in the relevant literature (Dror and Trudeau, 1989, 1990; Dror et al., 1994; Özdamar et al., 2004; Yi and Kumar, 2007; Yi and Özdamar, 2007). Allowing split deliveries can lead to substantial cost savings, which has been introduced and empirically shown by Dror and Trudeau (1989, 1990). The fourth is potential secondary disaster, such as after-shocks and debris flow following the main earthquake, posing threat to relief personnel. This potentially differentiates planning for earthquakes from other types of disasters, for example, terrorism attacks and hurricanes. *The connections between disaster areas become uncertainty with the influenced highway, bridge and railway etc. Reliability can be defined as the probability for vehicles travelling through the connections between disaster areas in time in post-earthquake.* Disaster relief distribution with enhanced reliability not only protects the rescue personnel but also ensures timely delivery of emergency supplies to those in needs. High reliability in distribution can be achieved through routing vehicles such that supplies on the vehicles could reach their intended destination for sure in a timely manner.

Based on above features, we study a relief distribution problem in post-earthquake with multiple conflicting objectives by considering travel time, the total cost, and reliability. The relief distribution involves the location of distribution centers (DCs) and vehicle routing and scheduling in post earthquake. The problem can be classified as multi-objectives open location-routing problem (OLRP) with split delivery.

In general, location of DCs and vehicle routing are addressed individually for emergency logistics (Haghani and Oh, 1996; Özdamar et al., 2004; Barbaroso and Arda, 2004). However they are highly correlated (Ballou and James, 1993). Studies on the design of mathematical models and solution algorithms for the integration of location and route problem are much fewer in a post-disaster situation. In Fiedrich et al. (2000), DCs are definite and fixed in the distribution network, and resources are directly sent from DCs to demand points. Single objective model is designed to minimize the total number of casualties. Tabu Search and Simulated Annealing are used with fictitious data to test the models. Yi and Özdamar (2007) describe an integrated location-distribution model for coordinating resource supply and wounded people evacuation operations in response activities. Vehicle routing and scheduling is not considered in the above. Sheu (2007) investigate a hybrid fuzzy clustering-optimization approach for multi-objective dynamic programming model. Weighting method is used to convert the two objectives of minimizing distribution cost and maximizing demand fill rate into one objective; however, the reliability of the infrastructure is neglected. Vitoriano et al. (2011) present an original multi-criteria optimization model based upon cost, time, priority etc. for humanitarian aid distribution. It helps to select vehicles and design routes; however, the location of DCs is not considered.

For multi-objective optimization models, classical optimization methods (Chanta et al., 2011; Dror and Trudeau, 1990; Sariklis and Powell, 2000; Tzeng et al., 2007) take multiple runs to find multiple optimal solutions by converting the multi-objectives into a single-objective. Over the past few years, some researchers have been engaged in the development of multi-objective evolutionary algorithms which can find multiple solutions in a single run due to their population-based approach. Strength Pareto evolution algorithm (SPEA) (Zitzler and Thiele, 1999), multi-objective scatter search (MOSS) algorithm (Beausoleil, 2006), non-dominating sorting genetic algorithm-II (NSGA-II) (Deb et al., 2002), etc., constitute the pioneering multi-objective methods. Non-dominated sorting differential algorithm (NSDE) is proposed by Rakesh and Babu in 2005 as an extension of differential algorithm (Storn, 1996; Storn and Price, 1997) to solve multi-objective problems. In this paper, NSGA-II and NSDE are used separately for the specific multi-objective OLRP, and some comparisons are made to verify the efficiencies of the two algorithms.

Within the scope of the study defined above, the proposed relief distribution models and approach in emergency logistics is unique with the following distinctive features:

(1) Multi-objective open location and routing scheduling problem with split delivery are considered to coordinate supplies and demands of relief. Heterogeneous vehicles with different capacities and velocities are used. Vehicles may wait at their last node without returning to starts until the next order is specified in OLRP. With split delivery, each disaster area can be served by more than one time once the volume of relief needed is bigger than vehicle's capacity. These distinct features make the problem closer to the real emergency situation.
(2) Two model approaches: the three-index method and flow variables and constraints method are used to model the proposed multi-objective OLRP with split delivery. The relationship among multi-objective OLRP with split delivery, location problem (*P*-median) and typical VRP are described. Research on multi-objective OLRP with split delivery is more limited compared with the extensive literature on pure location problems, VRPs and their variants.
(3) Reliability, as well as time and cost, is considered as an objective for relief distribution in the operation process. Reliability is one way to model high uncertainty in emergency logistics. The higher the reliability is, the safer the rescue workers are.
(4) Both NSGA-II and NSDE are used to solve the Multi-objective OLRP with split delivery. The natural number permutation encoding is used to represent solutions. Fast-non-dominated sorting and Crowding-distance Sorting operators are both used for the two algorithms in selection operation. The difference lies to the mutation operator and the crossover operator. We make comparisons using instances generated randomly.

The remainder of this paper is organized as follows: we describe the multi-objective OLRP in emergency logistics and the mixed integer programming mathematic models for the OLRP in Sections 2 and 3 respectively. In Section 4 we propose NSGA-II and NSDE to solve the multi-objective models. Finally, the models and algorithms are applied in *Great Sichuan*