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A humanitarian logistics model for disaster relief operation considering network failure and standard relief time: A case study on San Francisco district

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ABSTRACT

We propose a multi-depot location-routing model considering network failure, multiple uses of vehicles, and standard relief time. The model determines the locations of local depots and routing for last mile distribution after an earthquake. The model is extended to a two-stage stochastic program with random travel time to ascertain the locations of distribution centers. Small instances have been solved to optimality in GAMS. A variable neighborhood search algorithm is devised to solve the deterministic model. Computational results of our case study show that the unsatisfied demands can be significantly reduced at the cost of higher number of local depots and vehicles.

1. Introduction

Disaster management involves a systematic approach to deal with natural and man-made disasters. The cycle of disaster management consists of four main phases: mitigation, preparation, response and recovery. The mitigation phase involves long-term efforts to prevent the occurrence of disasters or to reduce their effects. In the preparation phase, various strategic (long-term) decisions and procedures are devised before a disaster actually occurs, such as decisions about the number and locations of main distribution centers (DCs) to be established. The response phase includes operational decisions on vehicle routings, personnel and equipment, as well as last mile distribution of relief goods to affected areas after the occurrence of a disaster. In the recovery phase, restoring the previous states of the affected areas is the main activity of the government and non-governmental organizations involved in disaster management. Altay and Green (2006) stated some new approaches like multi-agency research, concentrating on some missing stages of the disaster management cycle for planning, infrastructure design and the impact of its failure, and management engineering issues as new trends which should be considered in disaster planning and operation.

Accordingly, humanitarian logistics has attracted a lot of attention in recent years. In particular, logistics planning is the core of every relief operation. To decrease human losses, a sufficient amount of supplies must be distributed after a catastrophe within some time limit. A severe problem that usually occurs after an earthquake is destruction of some parts of the transportation network. As a result, some roads and links in the city network may not be accessible. This will make it very difficult to dispatch and deliver relief goods from local depots to demand points. This issue must be addressed in a practical

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approach for disaster relief operation. Also, a geographical information system (GIS) can be used to acquire real-time data on transportation network failure before executing a relief operation in the response phase.

In humanitarian logistics, the initial response should be received in the first 72 h after the occurrence of an earthquake, as has been stated in Mitsotakis and Kassaras (2010). The first 12 h are critical and called the standard relief time (SRT). The government and non-governmental organizations should quickly assess the situation and begin to send relief goods from local depots to the demand points within this time limit. An effective humanitarian logistics system must minimize human losses by dispatching and delivering relief goods (food, water, medical supplies, etc.) to affected areas within the SRT. Besides, we must deliver a specific amount of relief goods needed for every person according to the standard given in Zutphen (2011). Any violation of the SRT constraint or lack of relief goods supply could cause suffering and loss for the affected people and must be highly penalized in a planning and decision making process.

In recent years, many studies have been carried out related to humanitarian or disaster relief logistics. The existing studies may be categorized based on their focus on the type of decisions involved in the preparation or response phase. Accordingly, the main distinction is between logistics planning problems at strategic and operational levels. At the strategic level, the main decisions are the number and locations of the main distribution centers (DCs) and pre-positioning of relief goods supplies. Such decisions are to be made before the occurrence of an earthquake. At the operational level, the key decisions are vehicles routing and last mile distribution of relief goods to the people affected in the aftermath of an earthquake.

Balcik and Beamon (2008) used a variant of the maximal covering location model to determine the number and locations of DCs and the amount of relief goods supplies to be stocked at each DC. Also, they applied their model to a case study to show the effects of pre- and post-disaster relief funding on the performance of the relief system. Mete and Zabinsky (2010) proposed a stochastic optimization approach to determine the storage locations of medical supplies and required inventory levels for each type of medical supply. In their two-stage stochastic programming model, warehouse selection and inventory levels are determined at the first stage and transportation decisions are made at the second stage. The resulting transportation plan is then converted to an optimal routing plan using a mixed integer programming (MIP) model. They also presented a case study considering various disaster scenarios in the Seattle area. Rawls and Turnquist (2010) developed a two-stage stochastic mixed integer program to determine the locations of warehouses and quantities of various types of emergency supplies to be pre-positioned. They assumed the existence of uncertainty regarding the demand and the availability of the transportation network after a catastrophic event.

Rennemo et al. (2014) developed an interesting three-stage mixed-integer stochastic programming model for distribution of relief goods in the response phase. The first stage deals with the decision on which LDCs are to be opened and the amount of goods to be sent from each main distribution center to each LDC. The second stage determines vehicle routing decisions made knowing the number of vehicles available at each LDC and the demand in each affected area. The uncertainty in network infrastructure is considered in the third stage. Their proposed model assumes the existence of uncertainty regarding the demand, the capacity of the vehicle fleet, and the state of the infrastructure. While our proposed model has similar features to the model in Rennemo et al. (2014), it differs from it in a number of ways. First of all, the model in Rennemo et al. (2014) does not consider vehicle routing in the first stage, where decisions on opening LDCs are made. Furthermore, the locations of the main distribution centers are fixed and thus location decisions do not affect routing decisions in their model. The proposed model in this paper is essentially a multi-depot LRP in which the location decisions greatly complicate the mathematical modeling of the problem. Since the decision on the locations of the main distribution centers is a strategic one, the proposed two-stage model can be used in the preparation phase. The model in Rennemo et al. (2014) is focused on humanitarian logistics at the operational level, while the model proposed in this paper can be used for both strategic and operational decisions. Another distinction between the proposed model and the one in Rennemo et al. (2014) is our consideration of the multiple usage of vehicles and the uncertainty in travel times. Our model includes standard relief time constraints to reach the affected areas within the golden time after the occurrence of an earthquake. Such a time constraint would potentially limit the number of demand points to be served by each tour. Thus, we may need more vehicles to serve all the affected areas within the SRT limit, which may not be available during a disaster relief operation. One way of dealing with this situation is to allow each vehicle to do multiple tours, as done in the proposed model. Furthermore, consideration of the uncertainty in travel times affects the SRT constraints and is handled by the proposed two-stage stochastic model.

Campbell and Jones (2011) examined the decision of where to pre-position supplies in preparation for a disaster and how much inventory should be stocked at each location. They evaluated the consequences of closed warehouse locations and considered both risk and inventory levels. Jia et al. (2007) addressed the uncertainty of demand and insufficiency of medical supplies to determine the facility location of medical supplies in response to large-scale emergencies. They developed three heuristics to solve such an allocation problem. They demonstrated that when the number of selected facilities is small, their genetic algorithm will generate better solutions than those obtained by the Locate-Allocate heuristic and the Lagrangian relaxation heuristic. However, by increasing the number of selected facilities, the performance of the genetic algorithm is reduced. In this study, the Lagrangian relaxation heuristic generated slightly better solutions than the Locate-Allocate heuristic.

Operational models also have a rich literature in disaster relief logistics. The types of decisions include vehicle routing and last mile distribution of relief items. De la Torre et al. (2012) surveyed the existing literature on disaster relief routing. They summarized the characteristics of the distribution models used in disaster relief operations. Also, they interviewed many organizations with different sizes, capabilities, and infrastructures operating in different regions worldwide to analyze operation research models for the transportation of relief items from the perspective of practitioners. Tzeng et al. (2007) devel-