Journal of Cleaner Production 154 (2017) 188–202

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Developing a robust multi-objective model for pre/post disaster times under uncertainty in demand and resource

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ARTICLE INFO

Article history:
Received 16 December 2016
Received in revised form
15 March 2017
Accepted 15 March 2017
Available online 22 March 2017

Keywords:
Humanitarian relief logistics
Robust stochastic optimization
$\varepsilon -$ constraint exact method
Non-dominant sorting genetic algorithm
Simulated annealing algorithm

ABSTRACT

Studies show that by the course of time, the number of natural disasters such as earthquakes is increasing. Therefore, developing a model for locating distribution centers and relief goods distribution systems in disaster times, along with appropriately locating health centers with the ease of access for transferring the casualties and saving their lives, is among the most essential concerns in relief logistics. Considering these two subjects, simultaneously, results in an increase in the quality of service in disaster zones. In this study, a multi-objective programming model is developed for locating relief goods distribution centers and health centers along with distributing relief goods and transferring the casualties to health centers, with pre/post-disaster budget constraints for goods and casualties logistics. For a better modelling of the reality, the uncertainties in demand, supply, and cost parameters are included in the model. Also, facility failure (e.g. relief distribution centers, health centers, hospitals and supply points failure) due to earthquakes is considered. The proposed model maximizes the response level to medical needs of the casualties, while targeting the justly distribution of relief goods and minimizing the total costs of preparedness and response phases. In order to handle the uncertainties, the robust optimization approach is utilized. The model is solved with $\varepsilon -$ constraint method. For the large sized form, the MOGASA algorithm is proposed, and the results are compared to those of the NSGAII algorithm. Then the validity and efficiency of the proposed algorithm is explored based on the results of both the proposed and exact methods.

1. Introduction

Nowadays, despite the advances in science and technologies, problems caused by natural disasters such as earthquakes, floods, hurricanes, lightning, avalanches, tornados, fires, volcanic eruptions, and etc. have affected different parts of the world imposing heavy casualties to nations and their assets. At the time of occurrence, demand for rescue efforts increases; and it definitely is unpredictable. On the other hand, quickly handling the casualties, sending relief goods, and transferring the casualties to health centers, in time, play a vital role in decreasing the casualties' pain and death (Balcik and Beamon, 2008). Therefore, designing a humanitarian relief logistics system which is able to harness the disaster and purge the aftermath through prioritization, planning, organizing, guiding, leading, and controlling the necessary actions, is crucial.

The unpredictable stochastic essence of natural disasters especially earthquakes, which is the topic of this study, requires a thorough plan for rescuing the casualties and responding to their demands after the occurrence. One of the important logistics strategies for enhancing the performance, decreasing the delay in emergency goods distribution, and transferring the casualties to health centers, is to pre-position relief distribution centers and health centers; and manage budgets near the vulnerable zones, if necessary. In order to deliver relief goods to the casualties within the least possible time, the optimum location and capacity of the distribution centers can be estimated in preparedness phase, so that the necessary goods could be stored beforehand. Also, transferring the casualties to health centers and hospitals, and distributing relief goods among them, are considered as important post-earthquake actions. Thus, based on the pre-disaster budget, disaster zones, and problem scenarios, new health centers can be opened for better handling the casualties, so that the number of

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http://dx.doi.org/10.1016/j.jclepro.2017.03.102
0959-6526/

loss and time to serve could be decreased to the lowest minimum; which, as a result, signifies the importance of estimating the optimal number and location of the warehouses and health centers -proportional to the budget. This study aims to develop a relief logistics network to locate distribution and health centers along with transferring the casualties; while demand, the number of casualties, resources, and distribution and transferring costs uncertainties are accounted for in a robust optimization approach.

In response to earthquakes, there are two important actions including evacuating and goods logistics. Evacuating, in response phase, consists of transferring the casualties from the affected areas and other logistics actions aiming to provide necessary relief goods and transferring the casualties to hospitals or health centers. To better understand the gap and the contribution of the paper, a concise literature review is presented in the following.

1.1. Literature review

One of the very first studies in locating the emergency facilities is led by Toregas et al. (1971), which utilizes linear programming approach to solve the set covering problem. Also, Tzeng et al. (2007) solves a deterministic multi-objective model consisting of minimization of total cost, minimization of total travel time, and maximization of the minimum satisfaction in planning period by a multi-objective fuzzy programming approach. Nolz et al. (2011) proposed a multi-objective model for post-disaster relief good distribution system, in which three objectives including minimization of the risk of the response, maximization of demand coverage, and minimization of total travel time, are considered. In addition, Lin et al. (2011) presented a multi-objective, multi-period, multi transportation means, multi-product model for delivering prioritized goods in disaster relief operations. They considered the minimization of uncovered demand and total travel time. Afshar and Haghani (2012) brought up a comprehensive model to explain the logistics operations in response to natural disasters. They presented a mathematical model for controlling the flow of relief goods in response network. Zhang et al. (2012) proposed an integer model for allocating available resources to demand points based on multiple resource constraints and the possibility of secondary disasters.

The other direction of the researches mainly focuses on transportation of the casualties, including Fiedrich et al. (2000), which presents a resource allocating model in the response phase of earthquakes for casualties' logistics control. Nothing about relief goods is mentioned. Although the majority of the articles have discussed only one of the logistics actions, some have explored both the casualties and relief goods logistics in earthquake response phase. Ozdamar (2011) presented a mathematical model for transporting the casualties and medical equipment to affected areas via helicopters. For this purpose, an integrated multi-objective model that aims to locate relief centers considering transportation and inventory level determination is presented by Najafi et al. (2013). The objectives of their model consist of minimization of costs and response risks, in which the latter is formulated in the form of minimization of the mean distance between established centers and the casualties. Camacho-Vallejo et al. (2015) proposed a bi-level mathematical model for humanitarian logistics that optimizes the decisions related to post-disaster international aids. This article studies these objectives in a non-linear mathematical model and solves the model in a mixed integer linear programming format.

On the other hand, because of the uncertainty in the received information including the number of casualties, demand level, network location, available goods, and hospital capacities, uncertainty is an inseparable part of the humanitarian relief network. Therefore, in a number of articles, the uncertainty is studied through stochastic optimization with different possible scenarios for natural disasters. Zhan and Liu (2011) studied demand, resource and road availability uncertainties in location-allocation problem and utilized scenario planning to control the uncertainty. They proposed a multi-objective stochastic model for handling demand, resource, and road availability uncertainties in emergency logistics network. Mete and Zabinsky (2010) developed a bi-level stochastic model for preparedness phase by determining warehouse locations and inventory levels. Their objectives comprised of transportation period and unsatisfied demand minimization. Duran et al. (2011) presented a mixed integer programming model that estimates the frequency, location and demand quantity based on historical data. The model optimizes warehouse locations and budget allocation, while, simultaneously, minimizes mean response time as the objective function.

Tofighi et al. (2016) presented a two stage stochastic fuzzy model for preparedness phase and emergency resource distribution in the humanitarian supply chain. In the first stage, the warehouse locations from a pool of candidate locations along with their inventory levels, are determined. In the second stage, a distribution policy in response to different possible disaster scenarios is developed. Rezaei-Malek and Tavakkoli-Moghaddam (2014) proposed a bi-objective mixed-integer programming model for the humanitarian relief logistics problem, in which the expected response time and total costs are minimized. They considered an objective that maximizes justice level. Bozorgi-Amiri et al. (2013) presented a robust multi-objective stochastic model for disaster relief logistics. They considered demand, resource, procurement costs and transportation costs to be uncertain. They also considered the minimization of the expected total costs of the relief chain and its variance along with minimization of the maximum shortage in affected areas. Their policy for handling the uncertainty is scenario-based.

In spite of the numerous researches in the field of response to the natural disasters, the complexity of the problem has made the consideration of the real world conditions difficult. The literature of relief logistics researches shows that models which combine the humanitarian and cost aspects have been explored far less than the single-objective models. Also, the majority of the researches in this field have either concentrated on the commodity and casualty planning, or made no distinctions in the transportation of the casualties and commodities while merging the pre and post disaster decisions. A significant number of researches have assumed that the demand and resource amounts are certain, which, with respect to the real world limitations, especially in the field of relief logistics in natural disasters, are uncertain. The justly distribution and response to the demands is also another important subject that has not been explored in the literature.

The contribution of this paper can be explained as expanding Bozorgi-Amiri's works by considering the uncertainty in the number of casualties, and the probability of hospitals and health centers to fail. Health centers are, also, a part of the humanitarian logistics which should be positioned before the earthquakes take place in preparedness phase; and in response phase the casualties' transfer to those health centers and hospitals are carried out. The major obstacle to achieving these humanitarian goals is the pre/post-disaster budget constraint which is included in the model in the form of two mathematical constraints. In order to solve the multi-objective model, the $\varepsilon-$constraint method is utilized and the MOGASA and NSGAII algorithms are proposed for the large-size instances.

In the following, a close-to-the-reality multi-objective robust stochastic model that helps to choose the best location policy for health centers and pre-storage of essential items is presented.