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An integrated relief network design model under uncertainty: A case of Iran

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ABSTRACT

In this study, a scenario-based robust approach is suggested for a multi-objective mixed-integer linear programming model in designing the relief network. A new approach to humanitarian inventory grouping problem based on the relief management objectives is proposed. The proposed model simultaneously optimizes inventory groups' number and corresponding service levels, assignment of relief commodities to groups, relief facility location, and relief service assignment. The proposed model aims to minimize the risk and the total cost of network management and simultaneously maximize the network population coverage. The fault tree analysis technique is used for vulnerability assessment of each demand point. To tackle the proposed optimization model, a hybrid Taguchi-based non-dominated sorting genetic algorithm-II is developed that incorporates an enhanced variable decomposition neighborhood search algorithm with fitness landscape analysis as its local search heuristic. The results illustrate the efficiency of the proposed model and solution algorithm in dealing with the considered disaster management issues.

1. Introduction

In recent years, the incidence of natural disasters and their costs of damages have steadily increased while the governments spend lots of money on disaster prevention and relief each year. Therefore, academic studies on disaster operations management and humanitarian logistics deserve particular attention. Disaster management aims to control the potential damages from hazards, guarantee prompt, appropriate support to victims of disasters, and achieve quick and effective recovery. The disaster management cycle demonstrates the ongoing process with the purpose of a strategy for lessening the impacts of disasters, responding through and directly after a disaster, and starting to recover after a disaster happened. Proper planning and actions at all stages of the disaster management cycle lead to more readiness, better warnings, vulnerability reduction or the prevention of disasters during the next implementation of the cycle. The complete disaster management cycle includes the determination of public strategies and tactics that either amends the origins of disasters or moderate their effects on the beneficiaries such as people, properties, and infrastructures (Wisner and Adams, 2002). There are four phases of disaster management include mitigation, preparedness, response, and recovery (McLoughlin, 1985). The mitigation involves steps to reduce the vulnerability to disaster impacts. The preparedness focuses on understanding how a disaster might impact the situation and how suitable preparation can build capacity to respond to needs and recover from a disaster. Immediate threats presented by the disaster and start of resources distribution are addressed by the response phase. Finally, the recovery phase is the restoration of all aspects of the disaster's impact on a community and the return of the condition to some sense of normalcy. An efficient design of relief chain networks plays an important role in disaster operation management. The proper relief network could be considered as an efficient connection between the preparedness and response phases (Bashiri and Hassanzadeh, 2016). In this paper, a comprehensive mathematical model for multi-objective strategic relief network design based on the concept of demand covering and hub location problem is proposed. The vulnerability of demand points under disaster is handled via using a fault tree analysis (FTA) method. An efficient hybrid meta-heuristic is proposed, which is based on a combination of the Taguchi-based non-dominated sorting genetic algorithm (NSGA)-II and particle swarm optimization. In addition, a fitness landscape analysis method is adopted to improve the systematic procedure of neighborhood structure selection in the proposed variable decomposition neighborhood search (VNDS) algorithm.

2. Literature review

Nowadays, disaster management is to prepare and plan for hazards in a proactive manner rather than waiting for them and reacting later.

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Therefore, many researchers have engaged in the disaster management (Galindo and Batta, 2013). A relief facility location problem is one of the most important issues in the disaster management (Caunhye et al., 2012a, 2012b). The facility location problem with reliability issue consideration has been well studied in the literature (Akgun et al., 2015). Various models based on mathematical programming for selection of facility location under disaster are proposed such as p-median (Aydin, 2016; Widener and Horner, 2011; Yushimito et al., 2012), p-center (Lu and Sheu, 2013; Lu, 2013), maximal covering problem (Jia et al., 2007; Balcik and Beamon, 2008; Doerner et al., 2009), and covering tour problem (Nolz et al., 2011). Various optimization models for disaster management such as a facility location, relief distribution, and casualty transportation have been studied in the previous studies (Akgun et al., 2015; Hasani and Mokhtari, 2018; Hasani and Zegordi, 2015b). KıLCı et al. (2015) proposed a mixed integer linear programming model for temporary shelter sites selection under earthquake occurrence in the Istanbul. Celik et al. (2016) proposed a two-stage stochastic mixed integer programming model for the decisions on facility location and pre-stocking levels for emergency supplies, and allocation of distribution centers. In addition, various proposed maximal covering location models with multiple coverage and facility location requirements combine the process of facility location with stock-prepositioning, evacuation, relief distribution, and vehicle routing model to perform relief distribution (Jia et al., 2007; Caunhye et al., 2012a). A joint location-inventory model is developed which tries to locate relief facilities, where they can cover and response the most demands of the vulnerable points (Belardo et al., 1984). Additional decision-making requirements such as a budget limitation and demand response time are considered by Balcik and Beamon (2008). Because of the importance of an inventory management in responding to demands of vulnerable points under disaster, relief distribution, and stock prepositioning mainly for a cost minimization issue are considered in some studies (Caunhye et al., 2012a). In another study, a priori planning instead of a post-disaster management is considered to acquire the more efficient emergency response in the event that it is needed via considering ordering costs, holding costs, and the possibility of post-disaster damage to stock (Rawls and Turnquist, 2010). Duran et al. (2011) propose a mathematical model for minimizing total response time to customers' demands under disaster. In another study, failures of supply facilities and linkage between facilities such as roadways damaged or destroyed in the relief distribution network are considered by using a scenario-based approach (Rawls and Turnquist, 2010). Ukkusuri and Yushimito (2008) proposed a location routing approach for the humanitarian prepositioning problem via considering the failures of facility capacity and linkage between facilities as well as a budget constraint. Campbell and Jones (2011b) developed a joint risk-based location-inventory mathematical model for prepositioning supplies in preparation for a disaster and determining an optimal stocking quantity at each relief facility.

As mentioned before, most of the conducted studies on the relief pre-positioning problem focused on determining the relief facility location and relief inventory management simultaneously with the aim of improving the quality of the relief operations (Caunhye et al., 2012a, 2012b). Relief inventory management is one of the key operations, which has an important impact on the relief management effectiveness. Beamon clarifies the general concept of stock repositioning in the humanitarian logistics, which is affected by various limitations such as budget, number of relief facilities, relief capacity, and uncertainty of relief demand. Akkihal (2004) proposed a mixed-integer mathematical programming model for simultaneously relief facility location and inventory pre-positioning for humanitarian operation with the aim of minimizing the total distance from the relief facilities to demand points. Hale and Moberg suggested that relief resources should be established in a manner as to not be exposed to risk. However, these facilities need to be closer to the disaster areas to which they are allocated to serve. Ozbay and Ozguven proposed a humanitarian inventory management model which can calculate the amount of the appropriate safety stock at a total minimum cost of relief inventory management. Balcik and Beamon (2008) develop a maximal covering location model for relief facility location and multi-commodity inventory management under budget and relief capacity constraints. Gatignon et al. assess the performance of the decentralized humanitarian supply chain of the international federation of the Red Cross operations under 2006 Yogyakarta earthquake in Indonesia. Lin et al. developed a mathematical model for disaster relief operations with the aim of minimization of total penalty cost of unsatisfied demand under natural disaster occurrence. Opit and Kim proposed a model for relief operation planning which determines the decision of relief facilities and amount of relief commodities should be kept at each relief facility. Tofighi et al. (2011) developed a relief network model based on the two-stage scenario-based stochastic programming approach for designing relief network under the disaster to determine an inventory pre-positioned level of relief commodities. Campbell and Jones (2011a) developed a risk-based mathematical model for determining the relief facility location and relief commodity inventory level at each relief facility. Ozguven and Ozbay proposed a multi-product stochastic humanitarian inventory management model for humanitarian emergency service providing to determine the optimal emergency inventory levels at the minimal cost. The interested readers are referred to Caunhye et al. (2012b) and Hoyos et al. (2015) for further information on the proposed optimization models for the location with relief distribution and stock pre-positioning problem in the literature.

In this study, a comprehensive scenario-based robust multi-objective mathematical model for relief network design subject to disruption is presented. While there are few studies on relief network design in literature, this study differs from the similar studies in terms of simultaneously considering triple objectives include minimizing demands serving risk; maximizing demand covering, and minimizing total relief network cost. Assessment of potential risk of relief network is handled via using the FTA method. To enhance the efficiency of inventory management decisions, a new approach for inventory grouping is incorporated with the decision of relief network management. Finally, an efficient solution algorithm based on the hybrid metaheuristic algorithm is proposed to obtain a list of Pareto optimal solutions. The proposed local search algorithm differs from the previous studies by using the customized neighborhood search structures via considering the fitness landscape analysis to improve the procedure of neighborhood structure selection. In addition, extensive computational experiments are conducted to investigate the performance of the proposed model as well as solution algorithm to solve considered instances.

3. Problem definition and formulation

In this paper, minimizing the maximum risk of deficiency in serving demand points by relief centers under disaster is studied. Locating the relief facilities near the disaster areas has an important impact on minimizing a response time. However, this decision would be risky because the established facilities near the vulnerable points could be disrupted. Therefore, the established relief facility may not support the demand points properly as a consequence of the severity of disaster impact on the infrastructure. In the domain of the risk analysis, three main components of risk are considered in this study based on the alleged real-life experiences include threat, vulnerability, and consequence (Willis et al., 2005). The threat is the probability of disaster occurs during a specified period. The vulnerability is defined as the probability that the damages occur. Compensations take place at a demand point because it is not served on time by the located facilities during a specified period. In our case, the vulnerability is calculated via using the FTA method. A consequence, as an outcome of the damage, has a specific effect on the targets such as the number of population living in a disaster zone. Finally, the expected risk is computed as the product of threat, vulnerability, and consequence.