Integrated relief pre-positioning and procurement planning in humanitarian supply chains

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ABSTRACT

Humanitarian organizations typically pre-position relief items in strategic locations whose optimum levels are affected by the amounts of pre-disaster contractual agreements and post-disaster procurements. To account for these interrelationships, this paper proposes a novel two-stage scenario-based mixed fuzzy-stochastic programming model for integrated relief pre-positioning and procurement planning based on a quantity flexibility (QF) contract under a mixture of uncertain data. An effective multi-step solution method is also devised to solve the problem in real-sized instances. Applicability of the proposed model is examined through a real case study. Finally, a number of sensitivity analyses are conducted to provide helpful managerial insights.

1. Introduction

Natural disasters typically cause severe damages to urban infrastructures and drastically influence the affected people especially in densely populated regions (Pedraza-Martinez and Van Wassenhove, 2016). For instance, 22,000 natural and technological disasters have been occurred worldwide since the beginning of the twentieth century resulting in more than 8 million deaths (Kara and Savaşçı, 2017). Furthermore, the deadliest disasters have occurred in the last decades. One of the most recent and tragic earthquakes occurred in Nepal in 2015 with the magnitude of 7.8 and its aftershocks were observed over one month. This earthquake resulted in 8,569 deaths and 100,000 injuries along with 384 missing individuals (Bisri and Beniya, 2016). Also, 200,000 people were approximately killed during the Haiti earthquake in 2010 (Ergun et al., 2014) and 225,000 people were killed in the Indian Ocean tsunami in 2004 (Altay and Green, 2006).

Humanitarian logistics (HL) consists of several activities such as disaster planning and preparedness, procurement, transportation, and warehousing (Falasca and Zobel, 2011). According to McLoughlin (1985), these operations can be classified in four stages including preparedness, response, mitigation, and recovery. In general, preparedness and mitigation stages refer to those activities performed at the pre-disaster phase (e.g. pre-positioning of critical relief items) and the response and recovery stages are related to the post-disaster operations such as distribution of pre-positioned relief items and evacuating injured people (McLoughlin, 1985). Notably, preparedness aims to be prepared for possible future disasters while mitigation relates to those activities preventing from disaster occurrence (Kovács and Spens, 2007). Also, response phase aims to manage limited resources for emergency responses, but recovery phase tries to return the affected areas back to the normal conditions (Çelik et al., 2012). Particularly, the main domain of this paper includes the two phases of preparedness and response (i.e. the pre-disaster and the early post-disaster consisting of the first 72 h after striking a disaster).

Humanitarian organizations (HOs) typically purchase and stockpile the required relief items in strategic warehouses at pre-disaster and distribute them to affected areas in order to save lives immediately in the early post-disaster (Balcik and Ak, 2014).
Hence, configuring a relief pre-positioning and distribution network in an effective and efficient way can play an essential role in mitigating negative impacts of potential disasters. Nevertheless, the procurement and pre-positioning of relief items are so costly. Taupiac (2001) states that approximately 60% of the post-disaster phase costs pertains to the procurement process. Falasca and Zobel (2011) report that about 65% of HL expenditures are related to the procurement activities, 15 percent to transportation, 10% to personnel and 10% to administration. Also, sourcing and procurement related decisions in humanitarian relief chains (HRCs) can considerably affect the effectiveness of humanitarian operations in emergency responses. As a result, it is essential to integrate relief procurement planning while designing a relief pre-positioning and distribution network in HRC. However, there is a lack of research in this field especially those activities related to coordinating relief suppliers and HOs (Jahre, 2017; Shokr and Torabi, 2017). Therefore, it is vital to contribute substantially to relief supply planning in the context of HL aiming to increase the responsiveness of HOs in supplying required relief items in the right amount at the right time using different supply approaches simultaneously. In addition, HOs can enhance their HRCs’ cost-efficiency by supplying required relief items from suitable suppliers and avoiding extra costs because of improper procurement plans or even high level of inventory pre-positioning. Thus, not only cost-efficiency is important for HL network design, but also responsiveness plays a leading role in this context.

As mentioned before, HOs often proceed to pre-position relief items in a number of strategic locations dispersed around the identified disaster-prone areas at the pre-disaster phase. However, according to the more accurate demand data received at the early post-disaster, the required additional relief items must be purchased at post-disaster to fully meet the estimated demands. Therefore, it can be realized that because of importance of prompt and effective emergency response in the first 72 h to save affected people, relief supply management at both phases could play an important role in achieving this goal. For this purpose, both global and local suppliers in parallel can supply relief goods. Purchasing relief items from local suppliers has some advantages compared to purchasing from global suppliers, which may include: shorter lead times, lower transportation costs, and stimulating local economy. Nevertheless, purchasing from global suppliers may lead to longer delivery times, higher transportation costs, but at the same time access to larger quantities, more reasonable prices and qualities (Falasca and Zobel, 2011). Thus, it is invaluable for HOs to procure their required relief items from both local and global suppliers due to their advantages and disadvantages. For instance, HOs might purchase relief items for pre-positioning purposes from global suppliers because of their qualities and long lifetimes. On the other hand, HOs can provide extra required relief items in post-disaster from local suppliers because of their shorter delivery times.

As uncertainty is one of the main attributes of disastrous events, it should be captured to obtain robust solutions specially when designing HRCs (Tofighi et al., 2016). In practice, there is an inherent uncertainty in some input parameters such as demands of relief items, amount of public monetary, unit costs, and travel times (Galindo and Batta, 2013a). In addition, Galindo and Batta (2013a) stated that using scenario-based models would help researchers to deal with some uncertainties, but there is a need for considering some uncertainty within each scenario. Therefore, it is necessary to cope with uncertainties in the scenario-dependent parameters while developing mathematical models in order to find more realistic solutions.

Two well-known sources of uncertainty are fuzziness and randomness (Pishvaae and Torabi, 2010; Pishvaae et al., 2012; Mousazadeh et al., 2014). Randomness originates from the chance and random nature of phenomena. Random data are estimated through continuous or discrete probability distributions by utilizing sufficient historical and objective data. Stochastic programming (SP) is one of the favorite methods in the literature to cope with random data. However, in practice due to the nature of disasters (i.e. their unique characteristics), finding sufficient historical and objective data is typically impossible. Therefore, it is almost impossible to fit reliable probability distribution functions for all uncertain parameters in the real world. Notably, some historical data may be available for some input parameters, but they may not be enough to judge them as fully objective parameters. Therefore, we should rely on judgmental data received from field experts in the form of fuzzy (i.e. possibilistic) numbers to estimate such imprecise input parameters (Kabak and Ülengin, 2011). These kinds of data are chiefly based upon their experiences, but some partial objective data might be available (Tofighi et al., 2016). Therefore, these data have a mixed objective-subjective nature. To deal with such uncertain data, the possibility theory can be used instead of the probability theory by which triangular or trapezoidal fuzzy numbers are frequently adopted. Also, some input parameters may be fully subjective because there is no historical data for them. Possibilistic programming is the most adopted approach to deal with epistemic uncertainty in imprecise data (Torabi and Hassini, 2008). Thus, a possibilistic approach is utilized in this paper to formulate the problem under investigation. As Tofighi et al. (2016) state, we face both uncertainties in the HRC setting. In other words, we encounter random disaster scenarios at post-disaster for which discrete probability distributions are fitted. In addition, there is an inherent impreciseness in most of the scenario-dependent and scenario-independent data. Data such as relief items’ demands, and relief items’ flows from HRC’s facilities to demand points are tainted with epistemic uncertainty under each scenario (see Section 4.1 for the adopted approach). It is noteworthy to mention that, those imprecise parameters related to the post-disaster phase can be estimated at the early post-disaster by field experts who may visit the affected regions, based upon accessible objective evidences and their subjective experience (Tofighi et al., 2016). Such uncertainties in most of the parameters can affect the overall performance of the HRC and it is vital to incorporate them in the model formulation (see Section 5.3 for the value of uncertainty). In this regard, we develop a two-stage mixed possibilistic-stochastic model by which both random disaster scenarios and imprecise parameters are taken into account. As mentioned before, improving responsiveness and cost-efficiency of HRCs is one of the main challenges profoundly influenced by procurement operations directly and indirectly (Shokr and Torabi, 2017). In addition, a limited number of works exists in the literature addressing procurement management in HL and as quoted by Jahre (2017), it is still an open research field. In this regard, we also conducted some interviews with some logistics experts in Iranian Red Crescent Society (IRCS) and they approved that there is an urgent need to improve the responsiveness and cost-efficiency of the current HRC in IRCS. Keeping this in mind and considering the current literature motivated us to develop a novel procurement planning framework in the context of HL, which contributes to the literature as follows:
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