European Journal of Operational Research 250 (2016) 239–250

Contents lists available at ScienceDirect

European Journal of Operational Research

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

Innovative Applications of O.R.

# Humanitarian logistics network design under mixed uncertainty

S. Tofighi[a], S. A. Torabi[a,*], S. A. Mansouri[b]

[a] School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran
[b] Brunel Business School, Brunel University, London, UK

ARTICLE INFO

*Article history:*
Received 11 October 2014
Accepted 31 August 2015
Available online 8 September 2015

*Keywords:*
Humanitarian logistics
Integrated stock prepositioning and relief distribution
Mixed possibilistic-stochastic programming
Differential evolution

ABSTRACT

In this paper, we address a two-echelon humanitarian logistics network design problem involving multiple central warehouses (CWs) and local distribution centers (LDCs) and develop a novel two-stage scenario-based possibilistic-stochastic programming (SBPSP) approach. The research is motivated by the urgent need for designing a relief network in Tehran in preparation for potential earthquakes to cope with the main logistical problems in pre- and post-disaster phases. During the first stage, the locations for CWs and LDCs are determined along with the prepositioned inventory levels for the relief supplies. In this stage, inherent uncertainties in both supply and demand data as well as the availability level of the transportation network's routes after an earthquake are taken into account. In the second stage, a relief distribution plan is developed based on various disaster scenarios aiming to minimize: total distribution time, the maximum weighted distribution time for the critical items, total cost of unused inventories and weighted shortage cost of unmet demands. A tailored differential evolution (DE) algorithm is developed to find good enough feasible solutions within a reasonable CPU time. Computational results using real data reveal promising performance of the proposed SBPSP model in comparison with the existing relief network in Tehran. The paper contributes to the literature on optimization based design of relief networks under mixed possibilistic-stochastic uncertainty and supports informed decision making by local authorities in increasing resilience of urban areas to natural disasters.



## 1. Introduction

The rate and impact of natural disasters have increased dramatically in the past decades due to population growth, global trend in urbanism, land use and stressing of ecosystems. According to Natural Disaster Database, earthquakes alone have killed more than 700,000 people since 1990 (EM-DAT, 2015). Lack of adequate preparedness in major urban areas has raised likelihood of the deadly and calamitous earthquakes. Destructive effects of disasters, although inevitable, could be mitigated by a proactive approach and the development of appropriate preparedness plans. Responding to a natural disaster within the first 72 hours after its occurrence plays a vital role since communities are not expected to stand on their own for much more than that time (Salmerón & Apte, 2010).

Generally speaking, humanitarian relief chains (HRCs) aim at rapidly providing the emergency supplies for the affected people in order to minimize human suffering and death via efficient and effective allocation of the restricted resources. HRCs are typically configured to address the main humanitarian logistics issues in the preparedness phase of the so-called 'disaster management life cycle'. These issues involve inventory prepositioning network design at pre-disaster phase and relief distribution planning problem at pre-disaster phase, which are addressed in this paper. Interested readers are referred to Balcik and Beamon (2008) for more details about these logistical issues in HRCs.

Coordination of HRCs is complicated and challenging (Balcik, Beamon, Krejci, Muramatsu, & Ramirez, 2010) mainly due to demand uncertainty and the risks associated with trying to deliver relief items efficiently and on time, which are normally exacerbated by the destruction of local infrastructure and resource limitations (Balcik & Beamon, 2008). Dominating characteristics of HRCs including the unpredictability of demand in terms of timing, location, type, and size, and complex coordination due to damages to communication network and other infrastructures differentiate the humanitarian logistics from business logistics. This enforces additional complexity and unique challenges to the management of HRCs (Balcik & Beamon, 2008; Kovacs & Spens, 2007). Nevertheless, despite major *contextual differences* between commercial and humanitarian supply chains, supply chain management (SCM) concepts are at the center of any humanitarian logistical operation (Van Wassenhove, 2006). Hence, designing a HRC needs a SCM approach to coordinate the involved

* Corresponding author. Tel.: +98 21 88021067; fax: +98 21 88013102.
*E-mail addresses:* stofighi@ut.ac.ir (S. Tofighi), satorabi@ut.ac.ir (S.A. Torabi), Afshin.Mansouri@brunel.ac.uk (S.A. Mansouri).

http://dx.doi.org/10.1016/j.ejor.2015.08.059
0377-2217/

parties, eliminate redundancies, and maximize performances in terms of costs and speed (Tomasini & Van Wassenhove, 2009).

Profit maximization (or cost minimization), which is the main objective in commercial supply chains is replaced by timely and fair provision of aid to beneficiaries in humanitarian operations. In other words, two attitudes (i.e. the egalitarian and utilitarian approaches) should be jointly considered when designing HRCs (De La Torre, Dolinskaya, & Smilowitz, 2012). Egalitarian policies tend to maximize the delivery quantity or speed by considering an equal weight for meeting needs of different target populations. Minimizing the time to deliver goods to beneficiaries is the well-applied egalitarian objective (Duran, Gutierrez, & Keskinocak, 2011). On the other hand, utilitarian objectives tend to focus on needs of the most vulnerable populations and targeting the people with the higher priorities. Minimizing the weighted unmet demand while considering different weights for unmet demands of different demand points, is an example of utilitarian objectives (Salmerón & Apte, 2010).

Uncertainty in the required data is one of the main issues when designing a HRC via optimization models. Particularly, in large-scale emergencies, data may not be available or easy to communicate. As commented by Galindo and Batta (2013, p. 19), “several factors involved in a typical disaster setting introduce uncertainty into parameters such as demands, costs, and travel times. Therefore, it is important to model the uncertainty of such parameters. The use of scenarios might help, but some uncertainty might need to be considered within each scenario, as well”.

Generally speaking, randomness and fuzziness are two main sources of uncertainty (Pishvaee & Torabi, 2010; Pishvaee, Torabi, & Razmi, 2012). Randomness stems from the random (chance) nature of data for which, discrete or continuous probability distributions are estimated based on available but sufficient objective/historical data. Stochastic (or robust) programming approaches are usually used to deal with this sort of uncertainty whenever random distributional information is (or is not) available for such input data. Also, using stochastic programming is meaningful only when a certain action can be repeated several times. However, due to special characteristics of disasters, in most cases there is not enough historical/objective data to model uncertain parameters within each scenario as random data. Moreover, there is no repetition in the occurrence of disasters. As such, it is hard or even impossible/meaningless to estimate probabilistic distributions for uncertain parameters in this context. Consequently, in such situations, we are faced with imprecise parameters whose impreciseness arises from the lack of knowledge regarding their exact values, i.e., facing with *epistemic uncertainty* about these data (Kabak & Ülengin, 2011; Pishvaee & Torabi, 2010).

In practice, we often have to rely on judgmental data from decision makers (i.e. field experts) in order to provide reasonable estimations for imprecise parameters. Naturally, these judgmental data are mainly based upon the experts’ past experiences and their professional opinions and feelings for which, there might be some (yet insufficient) relevant objective data as well. Accordingly, these parameters have a mixed objective–subjective nature and could be formulated through the possibility theory as a complement to probability theory. Suitable possibility distributions could be adopted for each of these possibilistic data typically in the form of triangular or trapezoidal fuzzy numbers. Moreover, possibilistic programming approaches are usually applied to cope with epistemic uncertainty of imprecise data. It should also be noted that some data might have a fully subjective nature in the form of judgmental data, which are explained by experts. In this case, a fully subjective possibility distribution is adopted for each fully judgmental data based upon the expert’s subjective knowledge and feelings. However, in both cases, fuzzy numbers are generally used to formulate the possibility distribution of these imprecise and/or fully subjective data (Torabi & Hassini, 2008).

In the context of HRC design problem, there is an *inherent randomness* about the realized scenario in the post-disaster, which arises from the discrete occurrence probabilities of earthquake scenarios. Also, there is an *inherent impreciseness* (i.e. epistemic uncertainty) in the scenario independent and scenario dependent data. This type of uncertainty includes those data such as demand of each relief item and usable ratio of prepositioned relief items and transportation links in the post-disaster (due to possible damages to storage facilities and transportation routes) under each disaster scenario. For a more detailed description of such parameters, see Section 3. Furthermore, there exists such *impreciseness* about the data at post-disaster, for instance in terms of transportation times in the network’s routes under the realized disaster scenario. These data are mainly estimated through a “*needs assessment process*” in the early post-disaster by humanitarian experts who have visited the affected areas based on both available objective evidences and their subjective data according to their past experiences.

Existence of such inherent uncertainties in most of the critical parameters can significantly influence the overall performance of the designed HRC. As such, since we are dealing with a mixture of uncertain data, i.e., imprecise (possibilistic) data within each random disaster scenario in our problem setting, we enhance the classical two-stage stochastic programming framework to cope with the mixture of random and possibilistic data simultaneously. In this way, our methodological contribution can be considered as developing a new method combining traditional stochastic programming with fuzzy numbers to represent different uncertainties involved in the problem (as highlighted by Galindo and Batta (2013)). For this, uncertain disastrous events at post-disaster phase are modeled as stochastic scenarios. The occurrence of each disaster scenario follows a stochastic process where each scenario has its own likelihood. Notably, using stochastic scenarios for modeling probable post-disaster situations is common in HRC design problem (Mete & Zabinsky, 2010; Rawls & Turnquist, 2010). Furthermore, the scenario dependent parameters within each scenario along with scenario independent parameters are formulated as possibilistic distributions in the form of triangular or trapezoidal fuzzy numbers to reflect their impreciseness. The reason for this assumption is that each disaster scenario has its specific conditions and consequences, which are not repetitive. As a result, historical data for such parameters cannot be accumulated. Nevertheless, dealing with such mixed uncertainties will lead to robust solutions by taking into account a portfolio of both random and possibilistic events regarding the various realizations of uncertain data.

This research is motivated by the complex problem of designing a humanitarian relief chain in Tehran. The city is located in an earthquake prone area with three faults running through its populated districts. Therefore, increasing the Tehran’s resilience to earthquake is one of the main priorities of local authorities and relief organizations. This involves designing a humanitarian relief network which is addressed in this paper.

In this paper, we propose a hybrid uncertainty programming approach to cope with a range of uncertainties when designing a HRC by incorporating a credibility measure-based possibilistic programming into a scenario-based stochastic programming framework. The proposed approach accounts for imprecise/possibilistic and random data simultaneously by a novel mixed possibilistic-stochastic optimization-based approach. We apply the proposed approach for designing the relief network in Tehran and compare its performance with the pre-planned network. In this way, this research contributes to the literature of optimization-based approaches of HRCs and provides empirical evidence to demonstrate applicability of the proposed approach based on real data for earthquake preparedness in Tehran.

It should be noted that our proposed hybrid uncertainty programming approach is a novel case of the scenario-based