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Bi-criteria solid transportation problem with substitutable and damageable items in disaster response operations on fuzzy rough environment

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ABSTRACT

Successful planning and scheduling of relief operations play a key role in saving lives and reducing damage in disasters. These disaster operations involve a variety of challenging multi-objective optimization problems, for which soft computing methods are well suited. In this investigation, relief materials and human resources are transported from some distribution centers (DCs) to some delivery points (DPs) through conveyances. The objectives are to minimize both total cost and time for transportation. Some particular models for (a) substitutable items (b) damageable items and (c) safety Factor have been derived. To convert bi-criteria solid transportation problem into a single objective problem, three different techniques (i) Fuzzy interactive satisficing method, (ii) Global Criterion Method and (iii) Convex Combination Method are used. Then the reduced single objective problem is solved by a non-linear optimization technique – Generalized reduced gradient method using LINGO-14.0. The models are illustrated through some numerical examples and optimal results are presented in tabular forms.

1. Introduction

Although minor earthquakes occur nearly every day, the effects of a strong earthquake are devastating. Recent major earthquakes took place in Taiwan in September 1999, India in January 2001, Southeastern Iran in December 2003, Sumatra in December 2004, Pakistan in October 2005, Nepal in April 2015. Earthquakes have been one of human's kind major enemies in the battle against natural disasters. The United Nations, public and private sectors have established many disaster-prevention or disaster salvaging centers and programs. The difficulty with natural disasters like earthquakes is that even though thousands of networked seismograph stations are installed around the world with powerful computers continuously analyzing the data, we are still unable to predict when and where the earthquake will strike. Therefore, the most effective method to reduce the damage of a disaster is disaster-prevention through research, monitoring, dissemination of information, and education. Information coordination between related organizations is also valuable. According to Altay and Green [6], who reviewed OR/MS research in disaster operations management, there is increasing need for research in this area. Recently, Berkoune et al. [13] have developed a single objective transportation problem in disaster response operations. Recently Ozdamar et al. [1] have developed a model in coordinating debris cleanup operations in post disaster road networks and Sahin at al [2]. have presented a case for Turkey in debris removal during disaster response.

In recent years, research has moved to more sophisticated, realistic routing problems, such as dynamic problems [7], delivery problems with time windows [10] and fleet composition [9]. Among these new realistic problems, problems considering routing in emergency situations are beginning to emerge and lead to many new challenges, as pointed out by Sheu [8]. Haghani and Oh [11] studied a particular version of disaster relief operations as a multi-commodity, multi-modal network flow model with time windows. Balcik et al. [12] considered a heterogeneous limited fleet, multiple vehicle routes, and two product types. They solved a single depot problem having four demand nodes using two identical vehicles.

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The global increase in the number of natural disasters highlights the need for a better planning and operation of the responding agencies. During emergencies, various aid organizations often face significant problems of transporting large amounts of many different relief commodities from different distribution centers (DCs) to different delivery points (DP) in the disaster areas. The solid transportation of supplies and relief personnel must be done quickly and efficiently to maximize the survival rate of the affected population and to minimize both the cost and time of such operations. It is very difficult, if not impossible, to efficiently operate such a complex system without comprehensive mathematical models. We aimed at developing a system of computer algorithm and mathematical models to keep track of operational details of large-scale disaster response operations and find the optimal allocation of scarce resources to the most critical affected areas in order to minimize the loss of life and human sufferings.

The solid transportation problem (STP) was first introduced by Haley [28] in 1962, in which three kinds of constraints are taken into consideration, that is, source constraint, destination constraint and conveyance capacity constraint. The STP degenerates into the classical transportation problem as the number of conveyance is only one. In recent years, there have been numerous papers in this area. Some papers only minimize the total transportation cost. For example, Ojha et al. [23] considered a STP for an item with fixed charge, vehicle cost and price discounted varying charge. To solve the problem, genetic algorithm (GA), which is based on roulette wheel selection, arithmetic crossover and uniform mutation, was suitably developed and applied. However, in practical programming problems, the decision maker (DM) usually needs to optimize several objectives. Unfortunately, the objectives are often conflicting and incommensurable. Thus, the DM can not obtain the optimal values of all the objectives simultaneously. A growing body of literature on STP focuses on multiple objective problems, that is, multiple objective solid transportation problems (MOSTPs). Recently, many research papers have been developed in solid transportation in different imprecise environments (cf. Ojha et al. [4], Safi and Razmjoo [5], Berkounea et al. [33], Ozdamar et al. [1]). Qiang and Nagurney [3], Feng and Wen [36] have studied a fuzzy bi-level and multi-objective model to control traffic flow into the disaster area during post earthquake operations.

Here, we furnish some reviews on transportation problems in tabular form in Table 1.

In problems of decision making like transportation in disaster response operations, the available data/possible values of the system parameters cannot be always exactly determined and known. There are several reasons for that like lack of input information, multiple sources of data, fluctuating nature of parameter values, noise in data, bad statistical analysis, uncertainty in judgment, etc. For example, transportation cost depends upon the fuel price, labor charges, tax charges, etc., each of which fluctuates from time to time. So it is not easy to predict the exact transportation cost along a route for certain time period. Generally possible values of parameters are given by the experts in approximate rough intervals, linguistic terms, etc. For instance, unit transportation cost for a route is "about 10 $", say between 8$–10$, the supply of a source is "around 35–38 units", etc. Also each of the points in a given rough interval may not have the same importance or possibility. For a large data set of a certain parameter collected from previous experiments, generally all the points are not equally possible. Such type of linguistic information is approximated by fuzzy rough set. On the other hand, due to limited budget, weight, availability of goods and limited time, we have introduced bi-objective optimization problem during disaster response operations.

In this paper, we focus on one of the most important aspects of the response phase: the transportation of humanitarian aid (e.g., water, food, medical goods and survival equipment) to people at fixed distribution points. To this end, we propose a formal definition and a mathematical model for the Transportation Problem in Disaster Response Operations (TP-DRO) in Fuzzy rough environment. Some solution approaches are proposed to solve this problem.

The main contributions of this paper are summarized as follows:

- Bi-objective fuzzy rough solid transportation problem with fixed charge costs has been developed.
- Some particular models (substitute, damageable, safety factor) have been derived from the proposed model
- Multi-objective problems have been converted into single objective using three different methods.
- Reduced crisp problem has been solved by LINGO-14.0.
- The models are illustrated by some numerical examples and optimal results are presented.

The remainder of this paper is organized as follows: A short preliminaries and deductions of Fuzzy rough set are presented in Section 2. Section 3 provides an interactive fuzzy satisficing method, while Section 4 presents notations and assumptions. The formulation of proposed models in Section 5. Equivalent crisp model is presented in Section 6. The numerical experiment is done in Section 7. Finally, concludes this paper and outlines possible future research directions in Section 8.

Table 1
Summary of historical review.

Author(s) (year), Ref.	Nature of transport	Additional Funcion	Environments	Nature of Objective	Techniques
Yang & Liu (2007), [26]	STP	Fixed charge	Fuzzy-Cr.	Single	HIA
Yang & Feng (2007), [21]	STP	Fixed charge	Chance constraint	Single	Lingo
Ojha et al. (2009), [24]	STP	Entropy	Fuzzy	Multi	Lingo
Ojha et al. (2010), [23]	STP	Fixed charge, En	Fuzzy	Single	GA
Xie & Jia (2012), [25]	TP	Fixed charge	Crisp	Single	GA
Tao & Xu (2012), [22]	STP	–	Rough	Multi	Rough SGA
Kundu et al. (2013), [27]	STP	–	Fuzzy-tolerance	Multi-obj	GCM
Raj et al. (2012), [31]	TP	Fixed charge	Crisp	Two stage	GA
Molla et al.(2013), [29]	STP	Fixed charge	Fuzzy	Single	Metahuristic
Sun et al. (2013), [30]	SWM	–	Joint-Pr. CCP	Single-obj	Lingo
Mahapatra et al. (2013), [20]	TP	–	stochastic	Multi-choice	Lingo
Berkoune et al. (2012), [13]	TP	–	crisp	single	GA, CPLEX
Proposed model	STP	Time Fixed charge	Fuzzy-Rough	Multi-obj	Lingo (GRG)