

A NOVEL MODEL FOR QUICK RESPONSE TO DISASTER RELIEF DISTRIBUTION

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Abstract: This paper presents a hybrid fuzzy-optimization methodology to solve the large-scale disaster relief distribution problem with the main goal of minimizing the total number of fatalities. The proposed method mainly contains a three-stage operational algorithm. Here fuzzy clustering techniques are used in the first stage to classify the damaged areas based on respective relief demand attributes and priority, followed by the second and the third stage, where fuzzy linear programming is employed to deal with the situation when the demand for victims is greater than the available resources. Results of a numerical study are illustrated to demonstrate the applicability of the proposed method.

Keywords: Disaster-relief resource allocation; Rescue logistics management, Fuzzy linear programming, Fuzzy clustering

1. INTRODUCTION

Quick response (QR) to disaster relief right after the large-scale natural disasters, e.g., earthquakes, typhoons, floods, volcano eruptions, mudflows and landslides, is vital to saving human lives and alleviation of corresponding damage in disaster areas. Herein, the efficiency of rescue actions, including rescue resource allocation and relief distribution, in the first beginning phase of emergency rescue, determines the total number of fatalities.

Despite the importance of disaster relief distribution, previous studies aiming to solve related operational problems are rarely found. In contrast, most previous literature appears to aim to formulate the aforementioned problems in a planning level, e.g., rescue strategy planning and corresponding network configurations (Tseng and Chen, 1998 1999; Feng, 1999; Fiedrich et al, 2000; Barbarosoglu et al, 2002; Morris and Wodon, 2003; Cheng and Tseng, 2003).

This study investigates an integrated fuzzy linear programming model with the objective of minimizing the time spent in emergency rehabilitation and relief distribution to disaster areas. In the proposed approach, fuzzy linear programming and fuzzy clustering methodologies are utilized to formulate the corresponding disaster-relief resource allocation problem. Here, the proposed fuzzy clustering technique is employed to group damaged areas based on respective relief demand attributes and priority. The rescue vehicles are then assigned to execute corresponding relief distribution tasks using the proposed fuzzy linear programming model. In this paper a mathematical model allowing for calculation of an optimized resource schedule is present to help answer this question.

The rest of this paper is organized as follow. Section 2 presents the proposed fuzzy clustering and fuzzy linear programming models. In Second 3, a numerical study is illustrated to demonstrate the feasibility of the proposed method. Finally, the concluding remarks are summarized in Second 4.

2. METHODOLOGY DEVELOPMENT

In this study, a 3-stage operational algorithm is proposed to solve the aforementioned large-scale disaster relief distribution problem, where relief demands in disaster areas are assumed to follow fuzzy properties. The main operational procedures of the proposed algorithm are described as follows.

Stage 1: fuzzy clustering for disaster areas.

In this stage, the disaster areas are grouped by a proposed fuzzy clustering method with the following measures. First, the relative distance between each disaster area and relief distribution center, valued from 0 to 1, is fuzzified by the relation formula. This fuzzy distance represents the similarity of each disaster area, and is measured by the distance between disaster area and relief center.

The fuzzy relationship is defined as:

$$R(D_i, D_j) = 1 - \delta [(x_i - x_j)^2 + (y_i - y_j)^2]^{1/2} \quad (1)$$

Where D_i and D_j are elements of set D , representing the locations associated with a given relief center i and a given disaster area j , respectively; δ represents the maximal reciprocal of elements in a set D . Accordingly, the value of $R(D_i, D_j)$ is between 0 to 1.

Then the disaster areas are clustered by α -cut R , where $\alpha \in [0,1]$. The α value can be defined by the rescue commander to represent the appropriate similarity of disaster area group.

Stage 2: Fuzzy dispatching for disaster area group.

After clustering, the center-of-gravity position of each group is identified as the representation of the group. With the locations of damaged area groups, the proposed fuzzy dispatching model assigns one appropriate relief distribution center to each group under the objective of minimal rescuing time.

Here, the location of each group is represented by its center of gravity and the total demand is aggregated from the demands of the disaster areas in the same group. The location of center of gravity can be decided as follows:

$$\bar{X} = \frac{\sum_i X_i \cdot d_i}{\sum_i d_i} \quad (2)$$

where \bar{X} : the coordinates of the center of gravity at X axis.

$$\bar{Y} = \frac{\sum_i Y_i \cdot d_i}{\sum_i d_i} \quad (3)$$

where \bar{Y} : the coordinates of the center of gravity at Y axis.

After identifying the disaster areas with the aforementioned measures, the next step is to assign relief distribution centers for serving specific disaster area groups. To facilitate model formulation, three assumptions are postulated.

(1) Relief demands are assumed to follow fuzzy properties.

At the onset of a disaster, the demands and supplies in terms of rescuing goods are generally uncertain. Therefore, we propose the postulation that the fuzziness of demand and supply is represented by right- and left-skewed triangles membership functions as shown in Figure 1.

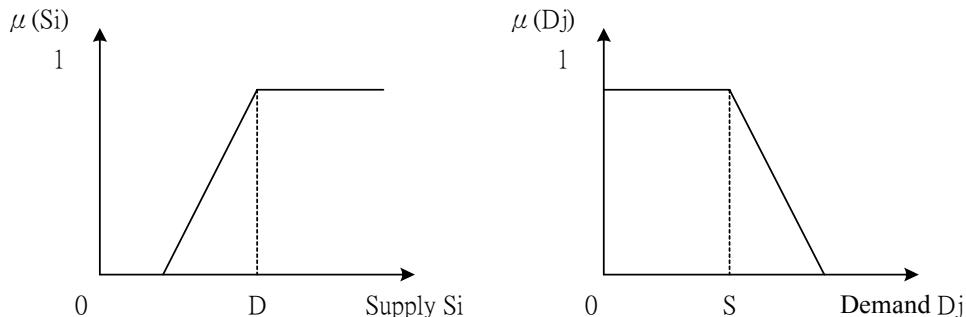


Figure 1 Fuzzy Membership Functions for The Measures of Relief Demands and Supplies

(2) Rescuing goods are assumed to be homogenous.

(3) Transportation cost is assumed to be linear in relation to the transportation distance.

In addition, the costs with respect to rescuing equipment, human resource, and services are neglected in this paper.

Accordingly, we have a fuzzy-based assignment model given by

$$\text{Min} \sum_{i=1}^m \sum_{j=1}^n c_{ij} x_{ij} \quad (4)$$

s.t.

$$\sum_{j=1}^n d_j x_{ij} \leq s_i \quad \forall i = 1, 2, \dots, m \quad (5)$$

$$\sum_{i=1}^n x_{ij} = 1 \quad \forall j = 1, 2, \dots, n \quad (6)$$

$$x_{ij} = 0 \text{ or } 1 \quad \forall i = 1, 2, \dots, m \quad \forall j = 1, 2, \dots, n$$

where:

i : number of relief centers, $i = 1, 2, \dots, m$

j : number of disaster group, $j = 1, 2, \dots, n$

c_{ij} : distance cost between node i and j

d_j : demand for disaster group j

s_i : supply for relief center i

x_{ij} : 1: relief center provides the demand for disaster group j ; 0: relief center does not provide the demand for disaster group j

The above model is formulated as a 0-1 integer programming and fuzzy linear programming model. Equation (1) represents the objective function to minimize the total distance cost. Equation (2) is the constraint specifying the maximum supply capability associated with each given relief distribution center. Equation (3) is specified to ensure that each disaster area group is served by only one relief center.

Accordingly, each disaster area group is served by one relief distribution center; however, one relief center may serve more than one disaster area groups at this stage.

Stage 3: fuzzy vehicle routing

At the third stage, a fuzzy-based vehicle routing model is proposed to determine the routing order and distributed relief quantity associated with each damaged area in the same group under the objective of minimum traveling time.

Similarly, to facilitate model formulation, the following assumptions are postulated.

- (1) The supply amount and location associated with each relief distribution center are given.
- (2) The relief demands are allowed to be satisfied partially.
- (3) Each disaster group is served by only one vehicle.
- (4) The time window limitation associated with each disaggregate disaster area is ignored.

The proposed fuzzy-based vehicle routing model is composed of the following two sequential steps.

Step1: deciding the distribution routes

$$\text{Min} \sum_{i=1}^n \sum_{j=1}^n c_{ij} x_{ij} \quad (7)$$

s.t.

$$\sum_{i=0}^n x_{ij} = 1 \quad \forall j = 1, 2, \dots, n \quad (8)$$

$$\sum_{j=0}^n x_{ij} = 1 \quad \forall i = 1, 2, \dots, n \quad (9)$$

$$y_i - y_j + (n+1)x_{ij} \leq n \quad \forall 1 < i \neq j < n \quad (10)$$

Step2: deciding the shipment for each disaster area group

$$\text{Min} \sum_{j=1}^n c_j^* d_j \quad (11)$$

s.t.

$$\sum_{j=1}^n d_j \leq S \quad (12)$$

$$d_j \geq d_j^* \quad \forall j = 1, 2, \dots, n \quad (13)$$

$$x_{ij} = 0 \text{ or } 1 \quad d_j \geq 0 \quad \forall i = 1, 2, \dots, n \quad \forall j = 1, 2, \dots, n$$

where

n : Summation of relief center and disaster area groups, where $i = 0$ represents the relief center and $i = 1 \sim n$ represents the disaster area groups.

c_{ij} : Distance cost between node i and node j .

c_j^* : Distance cost between relief center and node j .

d_j : Shipment for disaster area group j .

S : Total supply of relief center.

d_j^* : Demand of disaster area group j .

x_{ij} : 0-1 variable, where $x_{ij} = 1$ represents the link between node i and node j is utilized and

$x_{ij} = 0$ represents the link between node i and node j is not utilized.

y_i : Arbitrary real number.

Equation (7) and (11) represent the corresponding objective functions used to optimizing decisions for vehicle routing and relief distribution. Equations (8) and (9) represent the constraints which ensure that each disaster area group is served merely once by single relief distribution center. Equation (10) is specified to avoid the occasion of subtours. Equation (12) is the maximal limitation of demand and Eq. (13) permits the insufficient condition for damaged areas.

3. NUMERICAL STUDY

The numerical study randomly picks 50 points on the computer plane scope as the location of damaged areas. Demand for each disaster area is also assumed randomly valued from 1 to 10. The locations of 5 disaster relief centers, are decided using similar measures. The supply ability of each relief centers is elaborated as follows:

$$S_i = \frac{\sum_{j=1}^{50} d_j}{5} \times (1 + r) \quad (14)$$

where r is a random number between $[0,1]$.

The supply is designed to make some of the relief center having insufficient resource and some having enough resource. Moreover, the supply of each relief center should not differ too much. Table 1 summarizes the simulated locations associated with these relief distribution centers and corresponding supplies.

Table 1 The Locations of Disaster Relief Center and Relief Goods Supply Quantity

Disaster relief center	Location	Supply
1	(113,157)	50
2	(215,177)	59
3	(602,1)	58
4	(182,336)	51
5	(377,271)	57.5

At the first stage, the selected fifty damaged areas are clustered into six groups by $\alpha = 0.93$ as shown in Table 2. Then the fuzzy similarity relation matrix is estimated by the fuzzy relation equation $R(D_i, D_j) = 1 - \delta[(x_i - x_j)^2 + (y_i - y_j)^2]^{1/2}$ with the coordinates of each damaged area.

Table 2 The Result of Damaged Areas Clustering

Disaster Group Code	Number of damaged areas	Group Number
1	1,4,7,8,17,20,24,26,27,28,36,39,44,47,50	15
2	2,6,16,19,21,25,30,32,35,37,40,43,46	13
3	3,5,9,10,12,13,15,18,29,34,38,42,45,48	14
4	11,22,23	3
5	14,31,33,41	4
6	49	1

After clustering, the center-of-gravity position of each group is found. With the locations of damaged area groups, the fuzzy dispatching model assigns one appropriate relief center to each group. The numerical results indicate that relief center 2 distributes relief goods to damaged area group 1 ; relief center 4 distributes relief goods to damaged area group 2 ; relief center 5 distributes relief goods to damaged area group 3 ; relief center 1 distributes relief goods to damaged area groups 4 and 5 ; relief center 3 distributes relief goods to damaged area group 6 (See Table 3) .

Table 3 The Result of Damaged Areas Clustering

Disaster relief center	Supply	Disaster Group Code	Demand
1	50	4	10
		5	18
2	59	1	81
3	58	6	5
4	51	2	68
5	57.5	3	69

At the third stage, the aforementioned fuzzy vehicle routing is utilized to determine distributed order and quantity of each damaged area in the same group.

This fuzzy vehicle routing model is solved by LINDO. Taking the demand-supply relation for relief center 4 and damaged area group 2 as an example, The distributing route for damaged areas 2, 6, 16, 19, 21, 25, 30, 32, 35, 37, 40, 43, 46 are: relief center 4→damaged area 2→damaged area 16→damaged area 21→damaged area 25→damaged area 30→damaged area 35→damaged area 43→damaged area 46→damaged area 6→damaged area 19→damaged area 32→damaged area 37→damaged area 40→relief center 4.

And then the shipment for each damaged area is determined. Table 4 illustrates the corresponding shipment results for each damaged area of group 2.

Table 4 The Distribution of Relief Goods

order	number	quantity	order	number	quantity
1	2	5.25	8	46	5.25
2	16	3.75	9	6	2.25
3	21	0.75	10	19	2.25
4	25	5.25	11	32	4.50
5	30	6.00	12	37	1.50
6	35	2.25	13	40	4.50
7	43	4.50	Total		51

Although the shipments in the current time period are determined, the demand for each damaged area may not be completely satisfied. Using our proposed method, the remaining demands for each damaged area will be calculated and added into the distribution planning in the next time period (see Table 5).

Table 5 The Relief Goods Quantity of Unsatisfied Damaged Area

order	number	quantity	Unsatisfied demand	order	number	Quantity	Unsatisfied demand
1	2	5.25	-1.75	8	46	5.25	-1.75
2	16	3.75	-1.25	9	6	2.25	-0.75
3	21	0.75	-0.25	10	19	2.25	-1.75
4	25	5.25	-1.75	11	32	4.50	-1.50
5	30	6.00	-2.00	12	37	1.50	-0.50
6	35	2.25	-0.75	13	40	4.50	-1.50
7	43	4.50	-1.50	Total		-17	

Overall, the comparison results shown in Table 6 reveal that there are significant improvements in vehicle routing by implementing the proposed disaster areas classification strategy. Two observations from the analysis provided to elaborate on this generalization. First,

the improvements with respect to these distance cost are evenly. As depicted in Table 6, the measurement of average improvement is equal to 36%. Clearly, these measurements may also imply that there is an urgent necessity to improve the original relief strategy of without fuzzy clustering.

Using the proposed method, the decisions can be appropriately made in each time period in quick response to changes of relief demands given that new demand information is received by the proposed system. Note that our main purpose, as mentioned earlier, is to minimize the total number of fatalities under the condition that time-varying relief demand is greater than time-varying relief supply in the first beginning phase of emergency rescue. Apparently, the proposed algorithm cannot be terminated until the rescue mission is successfully completed.

Table 6 Distance Cost Comparison for Vehicle Routing With and Without Fuzzy Clustering

Vehicle routing without fuzzy clustering		Vehicle routing with fuzzy clustering	
Disaster relief center	Distance cost	Disaster relief center	Distance cost
1	199.2092	1	185.3780
2	1305.223	2	874.3933
3	34.7851	3	34.7851
4	655.2959	4	361.3621
5	997.8912	5	604.7005
Total	3192.4420	Total	2060.619

4. CONCLUSIONS

This paper utilizes fuzzy clustering and linear programming to solve the disaster-relief resource allocation problem. The situation of insufficient supply is considered to make the problem more realistic. Using fuzzy clustering method could decompose the complex problem into smaller scale to accelerate the searching of optimal solutions. The proposed 3-satge operational algorithm is summarized as follows.

In the first stage, the disaster areas are grouped by fuzzy clustering method. The relative distance between each disaster area and relief center, valued from 0 to 1, is fuzzified by the relation formula. The α value in using of α -cut method can be defined by the decision maker to match real conditions and get appropriate clustering results.

In the second stage, the center-of-gravity position of each group is found as the representation of the group. With the locations of damaged area groups, the fuzzy dispatching model assigns one appropriate relief center to each group under the objective of minimal rescuing time.

In the last stage, the fuzzy vehicle routing programming is utilized to determine distributed order and quantity of each damaged area in the same group under the objective of minimal traveling time.

Our numerical results have indicated the feasibility of the proposed method for

quick-response to disaster relief demands via appropriate disaster resource management and routing strategies. Nevertheless, cases studies mimicking various rescue scenarios under large-scale disaster conditions and model evaluation with delicate data warrant more research.

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