

Emergency relief routing and temporary depots location problem considering roads restoration

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Abstract

Natural disasters often damage parts of relief distribution infrastructure (e.g., bridges, roads) and leave immense amounts of debris in affected areas. This paper proposes a novel multi-objective possibilistic model for coordinating relief distribution and road restoration. An illustrative example is also provided.

Keywords: Humanitarian Logistics, Emergency Relief Routing, Roads Restoration.

Introduction

Every year natural disasters, such as earthquakes, typhoons, and floods kill or mutilate a large number of people and cause economical damages around the world. Timely delivery of basic living needs like shelter, food, water and medicine to the affected people is one of the most important challenges at post-disaster. The process of planning, managing, and controlling the efficient, cost-effective flow and storage of goods and materials to provide relief to affected people is called emergency logistics (Sheu 2007).

Although at the first glance, emergency relief distribution problems could be seen the same as commercial routing problems, but disaster relief presents many unique logistics challenges. Some of these challenges extracted from past experiences are as follows:

- There are several sources of uncertainty in the post-disaster environment,
- despite of commercial routing problems, in emergency relief distribution minimization of total arrival time, unsatisfied demand and risk and also maximizing the travel reliability and safety are more important than minimizing total transportation cost,
- limited resources that often are not enough for fulfilling all of demands,
- natural disasters often damage parts of the distribution infrastructure (e.g., bridges, roads) and leave immense amounts of debris in affected areas. The damaged roads not only hinder the providing of rescue, health and medical assistance, water, food, shelter and long term recovery efforts, but also are a treat for drivers' safety and can be cause of not arriving vehicles to the demand points.

In order to coordinate emergency relief routing and emergency roads restoration operations, a novel possibilistic multi objective, multi-period, multi-commodity model is proposed in this paper that accounts for locating temporary depots near the affected areas for better relief distribution as well.

The rest of the paper is organized as follows. The relevant literature is reviewed in the next section. Problem description and proposed model are elaborated in third and fourth sections. Section 5 provides solution procedure and an illustrative example is provided in sixth section. Finally, conclusions are presented in Section 7.

Literature review

In recent years, humanitarian logistics has received increasing attention from academic researchers. There are several reviews related to humanitarian logistics in the literature (see for example: Altay and Green 2006; Kovács and Spens 2007; Simpson and Hancock 2009; Anaya-Arenas et al. 2012; Caunhye et al. 2012; de la Torre et al. 2012). At below, we briefly review the most relevant published works to ours at post-disaster emergency logistics literature.

Despite of commercial setting in which cost efficiency measures are of most important, in disaster relief routing problems other responsiveness-oriented performance measures such as total arrival time, unsatisfied demand, risk, travel reliability and safety are more important. Several papers (e.g., Hsueh et al. 2008) take into account a measure of quick delivery such as minimizing the latest or average arrival time when dealing with a disaster relief routing situation. Also, in order to enhance drivers' safety and probability of arriving vehicles to the demand points, some papers account for reliability of routes as an objective function of developed model. For example, (Vitoriano et al. 2009) propose a decision support system focusing on distribution of humanitarian relief goods with three objectives: cost, ransom probability, and reliability.

Removal and disposal of debris are two initial and most important aspects of disaster response and recovery operations (Fetter and Rakes 2012). Debris removal activities are commonly organized into two phases named initial response and recovery. At the initial response phase, because of limitation on required resources like facilities, manpower and time, repairing and debris cleaning of all destroyed roads is often impossible. Thus, decision makers (DMs) should select the most important roads whose refurbishment has the more impact in emergency relief distribution. (Viswanath and Peeta 2003) formulate a multi-commodity maximal covering network design problem in order to identify the most critical routes for earthquake response and to seismically retrofit bridges. Their model seeks those routes that minimize the total routing costs over the selected routes and maximizes the total demand covered. (Yan and Shih 2009) introduce a model to simultaneously plan emergency roadway repair and subsequent relief distribution on a roadway network. They employ network flow techniques to develop a model aiming to minimize the length of time required for both emergency repair and relief distribution. The authors also develop an ant colony system based hybrid algorithm for solving the emergency roadway repair time-space network flow problem (Yan and Shih 2012). (Liberatore et al. 2012) propose a hierarchical multi-objective model for the joint optimization of recovery operations of damaged elements of the distribution network and distribution of emergency goods and apply the developed model (called RecHADS) to a case study based on the 2010 Haiti earthquake.

In the pre-disaster phase, locating central depots for pre-positioning emergency relief is a critical and mostly applied task. However, experiences show that establishing such central depots have some drawbacks. These central depots usually are located at areas where the probability of being affected by disaster is very low. Therefore, central depots are located far from the affected areas. As discussed by (Lin et al. 2012), due to distant location, the centralized-supply delivery strategy suffers from the major drawback that vehicles must spend a significant amount of time traveling back and forth from the central depots to the affected areas. As such, establishing temporary depots near the affected areas with respect to roads conditions and repairing activities can result

in a better relief distribution and more accessibility to the demand points.

The main purpose of this paper is to propose a practical post-disaster relief logistics model coordinating relief distribution and road restoration operations while accounting for the impreciseness of critical input data through possibilistic programming enabling the DMs to make efficient, effective and safe decisions. Based on our literature review, it is the first time that a multi-objective, multi-period location-routing problem is proposed in the context of humanitarian operations in order to coordinate the relief distribution and road restoration operations at post-disaster under fuzziness.

Problem formulation

Suppose that there are a pre-specified central depot and some potentially candidate locations for establishing temporary depots for facilitating relief distribution after a disaster. The candidate locations for setting up temporary depots are pre-determined and reasonably near to the demand points. Each demand point faces a different demand for each relief item per time period. It is assumed that roads in affected areas are partially damaged and according to the prior predictions, there are a number of work teams equipped with bulldozers, excavators, trucks, and other equipments to restore the most important roads as quickly as possible. The other assumptions are as follows:

- Each road has an amount of reliability at post-disaster based on its damage percentage. Reliability of a route is used as a measure for maximizing safety of drivers and number of loads that really arrive at demand points,
- The number of periods required for repairing each road is given. It is based on road damage percentage and taking 4 hours required to remove 1000 m³ earthwork by each work team into account (adopted from Yan and Shih 2009),
- The temporary depots are replenished from central depot by air transportation (e.g., helicopters). However, replenishment issue is beyond the scope of our model,
- Each time period can be a few hours up to a day,
- A road under repair cannot be used for relief distribution during the respective period(s),
- A road after restoration will be perfectly safe and reliable,
- The available vehicles are limited and have different capacities.
- Each temporary location can have some limited vehicles and when a vehicle is assigned to a temporary location, the vehicle can only travel from its temporary location,
- Due to incompleteness and/or unavailability of required data in such a chaotic environment after a disaster, critical parameters (such as damage percentages and demands) are assumed to be imprecise (fuzzy) in nature. Furthermore, it is assumed that a suitable possibility distribution based upon both available objective data and subjective opinions of DMs has been estimated for each imprecise parameter in the form of a triangular fuzzy number, same as $\tilde{n} = (n^p, n^m, n^o)$, where n^p , n^m and n^o denote the most pessimistic value, the most possible value, and the most optimistic value of $\tilde{n}$,
- Three objectives are considered in this paper: minimizing the total cost (an efficiency measure), minimizing the sum of arrival times at demand points (an efficacy measure) and maximizing the reliability of selected routes (a measure of safety).

The notations used for model formulation are as follow:

Notation

Sets

V	set of all nodes
I	set of potential temporary depots that is a subset of V
J	set of demand points that is a subset of V
K	set of vehicles
S	set of supply items
T	set of time periods

Parameters

$\tilde{c}_{ijk}$	travel cost between nodes i and j for vehicle k ($i, j \in V$)
$\tilde{p}_{ij}$	travel time between nodes i and j ($i, j \in V$)
$\tilde{F}_i$	fixed cost of opening temporary location i ($i \in I$)
$\tilde{w}$	cost of each repairing work teams in each period
$\tilde{d}_{jst}$	demand of item type s at demand point j and period t ($s \in S, j \in J, t \in T$)
Q_k	volume capacity of vehicle k ($k \in K$)
b_s	unit volume of item s
$\tilde{h}_{ij}$	road damage percentage between nodes i and j ($i, j \in V$)
e_{ij}	number of time periods needed for repairing road between nodes i and j ($i, j \in V$)
F	maximum number of temporary depots
H	operating hours at each time period
G	number of available work teams
M	a big number

Decision variables

x_{ijkt}	1, if vehicle k travels from node i to j at period t , 0 otherwise
y_{ijt}	1, if a work team starts repairing road between nodes i and j at period t , 0 otherwise
f_i	1, if the temporary location i is opened, 0 otherwise
a_{jt}	arrival time at demand point j in period t
RE_{kt}	reliability of the route traversing by vehicle k in period t
r_{ijt}	reliability of road between nodes i and j in period t
z_{ki}	1, if vehicle k is assigned to temporary location i , 0 otherwise.

According to the above notations and assumptions, a possibilistic multi-objective mixed integer linear programming (PMOMILP) formulation has been developed for the problem.

$$\text{Min } \tilde{Z}_1 = \sum_{i \in V} \sum_{j \in V, j \neq i} \sum_{k \in K} \sum_{t \in T} \tilde{c}_{ijk} x_{ijkt} + \sum_{i \in I} \tilde{F}_i f_i + \sum_{i \in V} \sum_{j \in V, j \neq i} \sum_{t \in T - e_{ij}} \tilde{w} e_{ij} y_{ijt} \quad (1)$$

$$\text{Min } Z_2 = \sum_{j \in J} \sum_{t \in T} a_{jt} \quad (2)$$

$$\text{Max } Z_3 = \sum_{k \in K} \sum_{t \in T} RE_{kt} \quad (3)$$

$$\tilde{p}_{ij} + a_{it} \leq a_{jt} + M(1 - \sum_{k \in K} x_{ijkt}) \quad \forall t \in T, i, j \in J \quad (4)$$

$$a_{jt} \geq \sum_{i \in I} \sum_{k \in K} \tilde{p}_{ij} x_{ijkt} \quad \forall j \in J, t \in T \quad (5)$$

$$RE_{kt} \leq r_{ijt} + M(1 - x_{ijkt}) \quad \forall t \in T, k \in K, i, j \in J \quad (6)$$

$$RE_{kt} \leq \sum_{i \in I} \sum_{j \in J} x_{ijkt} \quad \forall t \in T, k \in K \quad (7)$$

$$r_{ijt} = 1 - \tilde{h}_{ij} (1 - \sum_{t'=1}^{t-e_{ij}} y_{ijt'}) \quad \forall i, j \in V, t \in T \quad (8)$$

$$x_{ijkt} \leq 1 - \sum_{t'=t-e_{ij}+1}^t y_{ijt'} \quad \forall t \in T, k \in K, i, j \in J \quad (9)$$

$$\sum_{i \in V} \sum_{j \in V, j \neq i} y_{ijt} + \sum_{j \in V, j \neq i} \sum_{j' \in V, j' \neq i} \sum_{t'=\min\{t-e_{ij}+1, 1\}}^{t-1} y_{ijt'} \leq G \quad \forall t \in T \quad (10)$$

$$\sum_{i \in V} \sum_{j \in V, j \neq i} \tilde{p}_{ij} x_{ijkt} \leq H \quad \forall k \in K, t \in T \quad (11)$$

$$x_{ijkt} \leq f_i \quad \forall i \in I, j \in J, k \in K, t \in T \quad (12)$$

$$\sum_{i \in I} f_i \leq F \quad (13)$$

$$\sum_{i \in V} \sum_{j \in J, j \neq i} \sum_{s \in S} b_s \tilde{d}_{js} x_{ijkt} \leq Q_k \quad \forall k \in K, t \in T \quad (14)$$

$$x_{ijkt} \leq z_{ki} \quad \forall i \in I, j \in J, k \in K, t \in T \quad (15)$$

$$\sum_{k \in K} \sum_{i \in V, i \neq j} x_{ijkt} = 1 \quad \forall j \in J, t \in T \quad (16)$$

$$\sum_{j \in V, j \neq i} x_{ijkt} - \sum_{j \in V, j \neq i} x_{jikt} = 0 \quad \forall i \in V, k \in K, t \in T \quad (17)$$

$$x_{ijkt} = 0 \quad \forall i, j \in I, k \in K, t \in T \quad (18)$$

$$\sum_{i \in I} z_{ki} \leq 1 \quad \forall k \quad (19)$$

$$f_i, z_{ki} \in \{0, 1\} \quad \forall i \in I, k \in K \quad (20)$$

$$x_{ijkt}, y_{ijt} \in \{0, 1\} \quad \forall i, j \in V, j \neq i, k \in K, t \in T \quad (21)$$

Objective function (1) aims to minimum the total costs consisting of: transportation cost, cost of opening temporary locations, and the roads repairing cost. Objective function (2) minimizes sum of arriving time at the demand points in order to achieve quick response to beneficiaries. Also, maximizing reliability of used routes is pursuit by objective function (3).

Constraints (4) and (5) ensure that the variables a_{jt} represent the appropriate arrival times. Furthermore, constraints (4) ensure there are no subtours that do not pass through temporary locations. Notably, reliability of each route is equal to minimum reliability of the arcs (roads) along the route. Constraints (6) and (7) show the reliability of used routes. Reliability of each road should be calculated based on its damaged percentage in each period and after repairing a road, the road will be reliable (i.e. its reliability will be equal to 1). Accordingly, formula (8) calculates reliability of roads in each period according to the respective assumptions. Constraints

(9) ensures the damaged roads should not be used for relief distribution during their restoration and constraints (10) limit number of damaged roads that can be repaired in each period based on the number of available work teams. Constraints (11) guarantee that travel time required to complete assigned tour for each vehicle do not exceed the operational hours in any time period. Constraints (12) guarantee that only opened temporary depots serve the demand points and constraint (13) ensures that total number of opened temporary depots does not exceed its maximum allowable number. Constraints (14) ensure that assigned load to each vehicle does not exceed its respective capacity. Constraints (15) demonstrate that each vehicle can only travel from its assigned temporary location. Constraints (16) ensure that each demand point must be visited exactly once in each period. Constraints (17) guarantee that the number of vehicles leaving a demand point or a temporary depot is equal to the number of arriving ones. Constraints (18) show that travel between temporary depots is not allowed. Constraint2 (19) guarantee that each vehicle will be assigned at most to a temporary depot and finally, constraints (20) and (21) show the type of variables.

Solution procedure

To transform a possibilistic model to an equivalent crisp one, several methods relying on the possibility theory have been developed in the literature. In this paper, (Jiménez et al. 2007) method is used to defuzzify the original possibilistic model because of its computational efficiency and easy implementation in practice (Pishvae and Torabi 2010). According to (Jiménez et al. 2007), the equivalent crisp α -parametric counterpart of the following possibilistic model can be written as follows:

$$\begin{array}{ll} \min & z = \tilde{c}^t x \\ \text{s.t.} & \tilde{a}_i x \geq \tilde{b}_i, \\ & \tilde{a}_j x = \tilde{b}_j, \\ & x \geq 0 \end{array} \xrightarrow[\alpha\text{-parametric model}]{\text{equivalent crisp}} \begin{cases} \min & z = EV(\tilde{c})x \\ \text{s.t.} & \left[(1-\alpha)E_2^{a_i} + \alpha E_1^{a_i} \right] x \geq \alpha E_2^{b_i} + (1-\alpha)E_1^{b_i} \\ & \left[(1-\alpha/2)E_2^{a_j} + \alpha/2 E_1^{a_j} \right] x \geq \alpha/2 E_2^{b_j} + (1-\alpha/2)E_1^{b_j} \\ & \left[\alpha/2 E_2^{a_j} + (1-\alpha/2)E_1^{a_j} \right] x \leq (1-\alpha/2)E_2^{b_j} + \alpha/2 E_1^{b_j} \\ & x \geq 0 \end{cases} \quad (22)$$

Where α denotes the possibility level of imprecise data. Moreover, we would have:

$$EI(\tilde{n}) = [E_1^n, E_2^n] = \left[\frac{1}{2}(n^p + n^m), \frac{1}{2}(n^m + n^o) \right] \text{ and } EV(\tilde{n}) = \frac{E_1^n + E_2^n}{2} = \frac{n^p + 2n^m + n^o}{4}.$$

Accordingly, a similar approach is applied to develop the crisp counterpart of the original multi-objective possibilistic model. In this way, we will face with a crisp multi-objective linear programming (MOLP) model. Several methods have been developed in the literature to solve a crisp MOLP model. In this paper, an interactive fuzzy approach i.e. TH method (Torabi and Hassini 2008) is used to solve the resulting MOLP model because of its capability in measuring the satisfaction level of each objective function explicitly and producing both balanced and unbalanced efficient solutions. The steps of the solution approach which is actually a mixture of (Jiménez et al. 2007) and TH method, can be summarized as follows:

Step 1: Determine an appropriate triangular possibility distribution for each imprecise parameter and formulate the PMOMILP model for the problem,

Step 2: Convert the possibilistic objective functions into their crisp counterparts by using the expected value of corresponding imprecise parameters,

Step 3: Convert the possibilistic constraints into their crisp α -parametric counterparts,

Step 4: Determine the α -positive ideal solution (α -PIS) and α -negative ideal solution (α -NIS) for each objective function by solving the corresponding α -parametric MILP model (see Pishvae and Torabi 2010),

Step 5: Specify a linear membership function for each objective function,

Step 6: Convert the resulting MOMILP model into an equivalent single-objective MILP using the TH aggregation function as follows:

$$\begin{aligned} \max \quad & \lambda(v) = \gamma\lambda_0 + (1-\gamma)\sum_h \theta_h \mu_h(v) \\ \text{s.t.} \quad & \lambda_0 \leq \mu_h(v), \quad h = 1, \dots, 3 \\ & v \in F(v), \lambda_0 \quad \text{and} \quad \gamma \in [0, 1] \end{aligned} \quad (23)$$

where $\mu_h(v)$ and $\lambda_0 = \min_h \{\mu(v)\}$ respectively show the satisfaction degree of h th objective function and the minimum satisfaction degree of objectives. Also, θ_h and γ indicate the relative importance of the h th objective function and the coefficient of compensation.

Step 7: Solve the crisp model (23) with the given coefficient of compensation γ and relative importance of the fuzzy goals (θ vector). If the decision maker is satisfied with the current efficient compromise solution, stop. Otherwise, provide another efficient solution by changing the value of some controllable parameters same as α and γ , and then go back to Step 3.

Computational experiment

Numerical example

In this section, an illustrative example is provided to show the applicability and usefulness of the proposed model and solution method. The example size is kept small so that the problem can be solved by a commercial solver in a reasonable amount of time. To generate required data, we have adopted an earthquake scenario for Tehran provided by (JICA 2000).

Tehran, capital of Iran, is surrounded by three main faults: Mosha, North-Tehran and North-Ray fault. Among these main faults, North-Ray fault has the potential to generate earthquake with a seismic intensity of 9 in the southern area of the city and 7 to 8 in the northern area.

In this numerical example, five demand points in the southern area of the city with more heavily damages are considered for which four potential temporary locations have been identified. Each imprecise parameter used in this example has been modeled by an appropriate possibility distribution in the form of a symmetric triangular fuzzy number with symmetrical parts being equivalent to ten percent of the central values. These fuzzy numbers have been estimated according to both available historical data and subjective opinions of the experts considering their experiences and feelings. In this way, we have only represented the central value of respective symmetric triangular fuzzy numbers at each table. Fixed cost of opening each temporary location has been estimated around the $\widetilde{12} \times 10^4$ \$. Table 1 provides estimated fuzzy travel times between each pair of nodes where $\tilde{p}_{ij}$ is equal to $\tilde{p}_{ji}$. The estimated road damage percentage between nodes are shown in Table 2. Note that in Table 2, powers of numbers denote the required time periods for repairing roads. Also, travel costs between all of nodes are considered fixed and equal to $\widetilde{200}$ \$.

Table 1 – Fuzzy travel times

demand point	temporary location				demand point				
	1	2	3	4	1	2	3	4	5
1	3	5	4	8	–	5	6	8	7
2	2	2	3	4	5	–	4	5	5
3	5	2	6	5	6	4	–	4	8
4	7	4	5	2	8	5	4	–	4
5	6	7	3	3	7	5	8	4	–

Table 2 – Fuzzy roads' damage percentages

demand point	temporary location				demand point				
	1	2	3	4	1	2	3	4	5
1	0.2 ¹	0.9 ⁴	0.7 ³	0.6 ²	–	0.9 ³	0.8 ³	0.8 ³	0.1 ¹
2	0.6 ²	0.6 ²	0.9 ⁴	0.3 ¹	0.9 ³	–	0.3 ¹	0.8 ³	0.1 ¹
3	0.1 ¹	0.2 ¹	0.2 ¹	0.4 ²	0.8 ³	0.3 ¹	–	0.3 ¹	0.5 ²
4	0.5 ²	0.1 ¹	0.8 ³	0.6 ²	0.8 ³	0.8 ³	0.3 ¹	–	0.6 ²
5	0.9 ⁴	0.9 ⁴	0.7 ³	0.1 ¹	0.1 ¹	0.1 ¹	0.5 ¹	0.6 ³	–

After a disaster, affected people need several commodities. Here, we supposed that demand points need two critical items periodically (i.e., drinking water and basic medical kit). Needed quantity per day per survivor and volume of the items are represented in Table 3.

Table 3 – Data related to relief items

Item	quantity per day per survivor	survivors served	Volume (ft ³)
drinking water	1 gallon	1	1
basic medical kit	1 kit	3	1

Based on initial post-disaster surveys, Table 4 provides fuzzy demand of each demand point and available goods in each period. Finally, Table 4 provides other required data.

Table 4 – Fuzzy demand of each demand point and available goods

demand point	demand of each item type									
	$t=1$		$t=2$		$t=3$		$t=4$		$t=5$	
	1	2	1	2	1	2	1	2	1	2
1	4290	1430	5300	1767	3230	1077	3167	1056	4612	1537
2	3638	1213	5736	1912	3406	1135	4611	1537	4635	1545
3	4893	1631	3026	1009	4412	1471	4655	1552	3126	1042
4	4497	1499	5468	1823	4948	1649	5836	1945	3750	1250
5	4978	1659	5834	1945	5064	1688	3699	1233	5413	1804

Results

The problem has been coded in GAMS and solved by the CPLEX solver using a PC with Intel Core i5 CPU, 2.53 GHz using 6 GB of RAM. Table 6 provides the obtained results in which the weight vector (θ) and γ are set respectively to (0.3, 0.3, 0.4) and 0.5 for different α -levels.

Table 5 – Other required data

	T	w	K	Q_k	H	G
Respective value	$\{1, 2, \dots, 5\}$	30000	$\{1, 2, \dots, 6\}$	$\{6, 6, 6, 8, 8, 8\} \times 10^3$	15	4

Table 6 – The summary of results for different α -levels

α -level	Z_1	Z_2	Z_3	$\mu_1(Z_1)$	$\mu_2(Z_2)$	$\mu_3(Z_3)$
1	130000	109.3	13.5	0.995	0.193	0.382
0.9	130000	110.4	13.6	0.995	0.169	0.302
0.8	250000	85.360	18.4	<0.001	0.614	0.898
0.7	250000	82.320	17.5	<0.001	0.689	0.777
0.6	250000	78.2	17.8	<0.001	0.788	0.798

The TH method is an interactive method by which the DM is allowed to participate in the solution procedure by altering his/her preferences regarding the objectives' weights and the coefficient of compensation at each round of solution process. Table 7 provides the results of a sensitivity analysis on these parameters. Note that only distinct solutions have been highlighted.

Table 7 – Results of sensitivity analysis on interactive parameters with $\alpha = 0.9$

γ		$(\theta_1, \theta_3, \theta_3)$				
		(0.1,0.3,0.6)	(0.3,0.4,0.3)	(0.4,0.4,0.2)	(0.35,0.3,0.35)	(0.4,0.2,0.4)
0-0.1	$\mu_1(Z_1)$	<0.001	<0.001	0.995	<0.001	0.995
	$\mu_2(Z_2)$	0.723	0.815	0.446	0.797	0.169
	$\mu_3(Z_3)$	0.940	0.647	0.047	0.864	0.302
0.3-0.7	$\mu_1(Z_1)$	<0.001	0.995	0.995	0.995	0.995
	$\mu_2(Z_2)$	0.723	0.169	0.446	0.169	0.169
	$\mu_3(Z_3)$	0.940	0.302	0.047	0.302	0.302
0.9-1	$\mu_1(Z_1)$	0.995	0.995	0.995	0.995	0.997
	$\mu_2(Z_2)$	0.169	0.169	0.169	0.169	0.145
	$\mu_3(Z_3)$	0.302	0.302	0.302	0.302	0.187

Conclusions

Natural disasters often damage parts of relief distribution infrastructure (e.g., bridges, roads) and leave immense amounts of debris in affected areas. The damaged roads not only hinder the providing of rescue and relief items, but also are a treat for drivers' safety and can be cause of not arriving vehicles to the demand points. This paper addresses a practical post-disaster relief logistics model coordinating the relief distribution and road restoration operations leading to an efficient, effective and safe decision. A novel multi-objective possibilistic mixed integer linear programming model is proposed to formulate the problem. After applying appropriate strategies to defuzzify the original possibilistic model, the TH method is applied to solve the equivalent multi-objective crisp model. An illustrative example is also provided and the numerical results demonstrate the applicability and usefulness of the proposed model and solution method.

Although the proposed method can find efficient solutions, it should be noted that the corresponding computational time grows exponentially with the problem size. Therefore, in order to solve the real-sized problem instances more efficiently, developing appropriate heuristic or metaheuristic solution methods is of great interest.

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