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A location-routing model on relief distribution centers

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C H R O N I C L E

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A B S T R A C T

There have been many unexpected natural disasters such as earthquake, flood, etc. in developing countries, which have created catastrophic incidents and we need to do appropriate planning for relief to reduce the possible casualties. Such actions normally face different challenges such as damages on transportation infrastructures including roads, bridges, etc. One of the primary actions for such crises management is associated with facility location for relief distribution centers. This paper presents a multi-objective mathematical problem and applies it for a real-world case study in northern region of Iran. The study uses Lp metric to handle different objectives and fuzzy programming is used to cope with uncertainty. The preliminary results indicate that the proposed study of this paper has been able to provide efficient results.

1. Introduction

The occurrence of unexpected events and natural disasters such as earthquake, flood, etc. require us to do appropriate planning for relief in the event of such crises (Arabani & Farahani, 2012). There have been significant amount of works accomplished on logistics for emergency relieves (Şahin & Süral, 2007; Aslanzadeh et al., 2009; Caunhye et al., 2012). Toregas et al. (1971) are believed to be the first who introduced the idea of relief logistic. Barbarosoğlu and Arda (2004) presented a two-stage stochastic programming model to plan the transportation of necessary first-aid commodities to disaster-affected regions for emergency response. They implemented a multi-commodity, multi-modal network flow formulation to explain the flow of material over an urban transportation network. Kovács and Spens (2009) determined the challenges of humanitarian logisticians associated with various kinds of disasters, phases of disaster relief and the kind of humanitarian organization. Fuhrmann et al. (2008) developed three collaborative geoinformation platforms for mobile collaboration and a web-portal for humanitarian relief logistics. According to Ozguven and Ozbay (2013), an efficient humanitarian inventory control model and emergency logistics system plays an important role in reaching reliable flow of necessary supplies to the victims located in the shelters and reducing the effects of the unforeseen disruptions that can happen.

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Ergun et al. (2010) explained the primary characteristics of disaster supply chains, and highlighted some issues faced when managing these supply chains. Kovács and Spens (2007) aimed to understand planning and carrying out logistics operations in disaster relief. Tomasini and Van Wassenhove (2009) investigated the evolution of supply chain management in disaster relief and the role of new players like the private sector. Döyen et al. (2012) developed a two-stage stochastic programming technique for a humanitarian relief logistics problem in which decisions could be made for pre- and post-disaster rescue centers, the amount of relief items to be stored at the pre-disaster rescue centers, the amount of relief item flows at each echelon, and the amount of relief item shortage. Doerner and Hartl (2008) investigated various transportation problems associated with health care logistics, emergency preparedness and disaster relief. Wang et al. (2012) studied the regional emergency resources storage by analysing the necessity of regional emergency resources storage and developed a two-stage stochastic programming model to solve the region division problem.

According to Luis et al. (2012) and Farahani et al. (2012) disaster relief provides several logistics challenges such as damaged transportation infrastructure, limited communication, and coordination of multiple agents. Operations research techniques may help relief agencies rescue lives and money, keep standards of humanitarianism and fairness and optimize the utilization of limited resources amid post-disaster chaos. Noyan (2012) considered the problem of choosing the response facility locations and the inventory levels of the relief supplies at each facility when there are uncertainty in demand and the damage level of the disaster network. Akkihal (2006) investigated the effect of inventory pre-positioning on humanitarian tasks and identified optimal locations for warehousing non-consumable inventories needed for initial deployment of aid. Afshar and Haghani (2012) developed a mathematical model, which explains the integrated logistics operations in response to natural disasters. The study controlled the flow of various relief goods from the sources through the supply chain and until they would be delivered to recipients. Ishii and Lee (2013) presented a mathematical ranking method for emergency facility location problem with block-wisely various accident occurrence probabilities. Zhang et al. (2013) considered a bottleneck Steiner tree based multi-objective location model and intelligent optimization of emergency logistics systems. Tzeng et al. (2007) proposed a relief-distribution model using the multi-objective programming method for designing relief delivery systems for a case study of earthquake in Taiwan. Chang et al. (2007) presented a scenario planning method for the flood emergency logistics preparation problem under uncertainty.

2. The proposed study

2.1. Relief logistics problem

Consider a relief logistic problem where there are N nodes, M relief goods, I suppliers and K vulnerable spot. The objective is to determine J new relief distribution centers to minimize total costs. To select the storage location of a relief distribution center candidate, we have to consider the storage capacity and vicinity to vulnerable populations.

Assumptions

1. There are multiple nodes in the network to provide relief supplies.
2. Demands for relief goods are associated with uncertainty, which is handled by fuzzy numbers.
3. Three types of relief goods including tents, water and drinks and food packaging are considered.
4. Only the damaged areas are considered, which are accessible via the current transport network.
5. There is no restriction for transportation of goods.

Notations

I	Set of supplier for relief storage centers
J	Set of distribution centers

K	Set of damaged areas
M	Set of relief goods
i	Index for relief storage centers
j	Index for distribution centers
k	Index for damaged areas
m	Index for relief goods

Parameters

F_j	Cost of establishing facility *j*
$\tilde{d}_{mk}$	Demand for item *m* in location *k*
S_{mi}	The amount of accumulated of item *m* which could be supplied by supplier *i*
C_{ij}	The unit cost of transportation of item from point *i* to point *j*
C_{jk}	Cost of distribution of an item from relief location *j* to damaged point *k*
π_k	Shortage cost of a unit in damaged point *k*
N_{ij}	Total amount of capacity used by supplier *i* for demand point in location *j*
N_{jk}	Total amount of capacity used by distribution center *j* for demand point in damaged location *k*

Variables

X_{mij}	Amount of item *m* transported from point *i* to distribution center *j*
Y_{mjk}	Amount of item *m* transported from distribution center *j* to damaged point *k*
Z_j	A binary variable, which is one if distribution center *j* is opened, and zero, otherwise

Objective function

$$\min \tilde{f}_1 = \sum_{m,k} \pi_k (\tilde{d}_{m,k} - \sum_j Y_{mjk}) \equiv \min \tilde{f}_1 = \sum_{m,k} \pi_k (\tilde{d}_{m,k}) - \pi_k \sum_j (Y_{mjk}) \tag{1}$$

$$\max \tilde{f}_2 = \sum_m \min \left\{ \frac{\sum_j Y_{mjk}}{\tilde{d}_{m,k}} \right\} \tag{2}$$

$$\min \tilde{f}_3 = \sum_j \tilde{f}_j Z_j + \sum_{m,i,j} \tilde{C}_{ij} X_{mij} + \sum_{m,j,k} \tilde{C}_{jk} Y_{mjk} \tag{3}$$

The first objective function given in Eq. (1) minimizes the shortage cost while the second objective function given by Eq. (2) maximizes total lowest percentage of coverage of the affected areas. Finally, the third objective function given by Eq. (3) minimizes total costs of establishment of different locations, transportation from suppliers to various distribution centers and from distribution centers to damaged areas.

Constraints

$$\sum_{j,k} y_{mjk} \le \min\{\sum_k \tilde{d}_{m,k}, \sum_i \tilde{s}_{m,i}\} \mid\cong \qquad \forall m \tag{4}$$

$$\sum_{j,k} y_{mjk} \le \lambda \qquad \forall m \tag{5}$$

$$\lambda \le \sum_k \tilde{d}_{m,k} \qquad \forall m \qquad (6)$$

$$\lambda \le \sum_i \tilde{s}_{m,i} \qquad \forall m \qquad (7)$$

$$\sum_i x_{mij} = \sum_k y_{mjk} \qquad \forall m, j \qquad (8)$$

$$\sum_j x_{mij} \le \tilde{s}_{mi} \qquad \forall m, i \qquad (9)$$

$$\sum_j y_{mjk} \le \tilde{d}_{mk} \qquad \forall m, k \qquad (10)$$

$$x_{mij} \le N_{ij} z_j \qquad \forall m, i, j \qquad (11)$$

$$y_{mjk} \le N_{jk} z_j \qquad \forall m, j, k \qquad (12)$$

$$x_{mij} \ge 0 \qquad \forall m, i, j \qquad (13)$$

$$y_{mjk} \ge 0 \qquad \forall m, j, k \qquad (14)$$

$$z_j \in \{0,1\} \qquad \forall j \qquad (15)$$

Eqs. (4-7) indicate that all equipment must be shipped. Eq. (8) shows the balance for any product in any relief distribution center. According to Eq. (9) all items can be shipped from suppliers to distribution centers. Eq. (10) prevents any excessive shipment of goods to damaged areas. Constraints 11 and 12 prevent shipments from any facility, which is not established. Finally, Eqs. (13-15) represent the type of variables. The resulted model is a mixed integer programming problem, which can be solved using a commercial software package as long as there are limited number of binary variables.

2.2 Basic possibilistic chance constrained programming

In this approach, we use experts' feedback in terms of trapezius numbers shown in Fig. 1 to handle uncertainty.

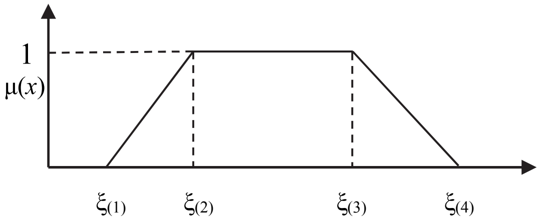

Fig. 1. Trapezius number

Therefore, the objective functions can be reformulated as follows,

$$\min \tilde{f}_3 = \sum_j \tilde{f}_j z_j + \sum_{m,i,j} \tilde{c}_{ij} x_{mij} + \sum_{m,j,k} \tilde{c}_{jk} y_{mjk} \qquad (16)$$

$$\equiv \min E(z) = F x_{mij} + c y_{mjk} + a z_j \qquad (17)$$

$$\equiv \min E(z) = E(\tilde{F}) x_{mij} + E(\tilde{c}) y_{mjk} + E(\tilde{a}) z_j \qquad (18)$$

$$\min E(z) = (\frac{F_1 + F_2 + F_3 + F_4}{4}) x_{mij} + (\frac{C_1 + C_2 + C_3 + C_4}{4}) y_{mjk} + (\frac{a_1 + a_2 + a_3 + a_4}{4}) z_j \qquad (19)$$

Using some simplification to get rid of nonlinear term in the objective function yields the following,

$$\max \tilde{f}_2 = \sum_w w_m \qquad (20)$$

$$w_m \le \frac{\sum_j y_{mjk}}{\tilde{d}_{m,k}} \rightarrow$$
$$(\sum_j y_{mjk} - d_{3mk}) / (d_{4mk} - d_{3mk}) \ge \kappa \qquad (21)$$

$$\frac{\sum_j y_{mjk}}{w_m} \ge \kappa d_{4mk} + (1-\kappa) d_{3mk} \tag{22}$$

$$\min \tilde{f}_1 = \sum_{m,k} \pi_k (\tilde{d}_{m,k}) - \sum_{m,k} \pi_k (\sum_j y_{mjk}) \tag{23}$$

$$\equiv \min \tilde{f}_1 = E(\tilde{d}) \pi_k - \sum_{m,k} \pi_k (\sum_j y_{mjk}) \tag{24}$$

$$\equiv \min \tilde{f}_1 = (\frac{d_1 + d_2 + d_3 + d_4}{4}) \pi_k - \sum_{m,k} \pi_k (\sum_j y_{mjk}) \tag{25}$$

$$st: Ax_{mij} \le (1-\alpha) s_{2mi} + \alpha s_{1mi} \qquad \forall m,i,j \tag{26}$$

$$Nec\{Ax_{mij} \le \tilde{s}_{mi}\} \ge \alpha \rightarrow \qquad \forall m,i,j \tag{27}$$

$$\frac{s_{2mi} - Ax_{mij}}{s_{2mi} - s_{1mi}} \ge \alpha \rightarrow Ax_{mij} \le (1-\alpha) s_{2mi} + \alpha s_{1mi} \qquad \forall m,i,j \tag{28}$$

$$Ry_{mjk} \le (1-\beta) d_{2mk} + \beta d_{1mk} \qquad \forall m,j,k \tag{29}$$

$$Qx_{mij} - Oy_{mjk} = 0 \qquad \forall m,i,j,k \tag{30}$$

$$x_{mij} \le ((1-\mu) N_{2ij} + \mu N_{1ij}) z_j \qquad \forall m,i,j \tag{31}$$

$$y_{mjk} \le ((1-\rho) N_{2jk} + \rho N_{1jk}) z_j \qquad \forall m,j,k \tag{32}$$

$$Ty_{mjk} \le \lambda \qquad \forall m,j,k \tag{33}$$

$$\lambda \le U\tilde{d}_{mk} \rightarrow Nec\{\lambda \le U\tilde{d}_{mk}\} \ge R \rightarrow \qquad \forall m,k \tag{34}$$

$$\frac{d_{2mk} - (\frac{\lambda}{U})}{d_{2mk} - d_{1mk}} \ge R \rightarrow \qquad \forall m,k \tag{35}$$

$$\lambda \le U\{(1-\phi) d_{2mk} + \phi d_{1mk}\} \qquad \forall m,j,k \tag{36}$$

$$\lambda \le V\tilde{s}_{mi} \qquad \forall m,i \tag{37}$$

$$\lambda \le V\{(1-\varphi) s_{2mi} + \varphi s_{1mi}\} \qquad \forall m,i \tag{38}$$

$$x_{mij} \ge 0 \qquad \forall m,i,j \tag{39}$$

$$y_{mjk} \ge 0 \qquad \forall m,j,k \tag{40}$$

$$z_j \in \{0,1\} \qquad \forall j \tag{41}$$

In this paper, we use Lp-metric method to convert the objective functions into a unified objective function as follows,

$$L_p = \{\sum_{j=1}^{k} w_j [\frac{(f_j(x^{\max j}) - f_j(x))}{f_j(x^{\max j})}]^p\}^{\frac{1}{p}}, \tag{42}$$

$$L_p = \{\sum_{j=1}^{k} w_j [\frac{f_j(x^{\max j}) - f_j(x)}{f_j(x^{\max j}) - f_j(x^{\min j})}]^p\}^{\frac{1}{p}}, \tag{43}$$

where $X^{\max j}$ represents the best value of the objective function j and W_j represents the relative weight of each objective function.

3. Case study

Iran is considered as one of the most seismically active countries in the world, being crossed by various major fault lines, which cover, at least 90%, of the country. Therefore, unpleasant natural disasters such as earthquakes in Iran may appear often, which are mostly destructive. Bam earthquake struck, for instance, the Kerman province of southeastern Iran in 2003 with a moment magnitude shock of 6.6. The earthquake was very destructive in the region, with the death toll amounting to 26,271 people and injuring an additional 30,000. For the proposed study of this paper, we consider seven cities as possible damaged points named Sari, Amol, Rasht, Tehran-West, Tehran-East, Karaj and Qom. In the event of natural disaster, we consider six cities as the primary suppliers: Gorgan, Sari, Qazvin, Semnan, Arak and Esfahan. Moreover, six alternative distribution centers; namely Gorgan, Sari, Qazvin, Semnan, Tehran-West and Kashan are considered as suppliers. As stated earlier, three types of relief goods including tents, water and drinks and food packaging are considered. The cost of shortage is equal to 0.35 and the cost of establishment of four units are 900000, 1000000, 1200000 and 1400000. Fig. 2 demonstrates the locations of different cities.

Fig. 2. The city of Iran

Table 1

The amount of accumulated of item *m* which could be supplied by supplier *i* (×1000)

S_{mi}	Gorgan	Sari	Qazvin	Semnan	Arak	Esfahan
S_{mi} (1,2,3,4)	(340,400,500,625)	(662,562,450,382)	(850,750,600,510)	(725,625,500,425)	(925,875,700,595)	(925,875,700,595)

Table 2

Total amount of capacity used by distribution center *j* for demand point in damaged location *j*(×1000)

N_{ij}	Gorgan	Sari	Qazvin	Semnan	Tehran-West	Kashan
N_{ij}(1,2,3,4)	(23,22,21,20)	(18,17,16,15)	(25,24,23,22)	(28,27,26,25)	(27,26,25,24)	(26,25,24,23)

Table 3

Total amount of capacity used by distribution center *j* for demand point in damaged location *k*(×1000)

N_{jk}	Sari	Amol	Rasht	Tehran-West	Tehran-East	Karaj	Qom
N_{jk} (1,2,3,4)	(14,13,12,11)	(12,11,10,9)	(16,15,14,13)	(19,18,17,16)	(18,17,16,15)	(13,12,11,10)	(20,19,18,17)

Table 4

Demand for item *m* in damaged location *k*(×1000)

d_{mk}	Sari	Amol	Rasht	Tehran-West	Tehran-East	Karaj	Qom
d_{mk} (1,2,3,4)	(360,315,270,225)	(300,255,212,170)	(390,320,300,250)	(1935,1710,1485,1215)	(1330,1280,1080,880)	(620,525,437,350)	(555,480,405,330)

Table 5
Unit transportation cost between suppliers *i* and distribution relief centers *j*(×0.01)

DC	Gorgan	Sari	Qazvin	Semnan	Tehran-west	Kashan
Gorgan	(0,0,0,0)	(72,62,50,30)	(172,160,150,137)	(100,90,70,60)	(140,125,110,97)	(220,207,180,166)
Sari	(90,70,50,33)	(0,0,0,0)	(115,102,90,85)	(95,80,70,55)	(99,89,80,63)	(162,142,120,108)
Qazvin	(190,180,150,140)	(110,102,90,85)	(0,0,0,0)	(100,87,70,55)	(85,65,40,28)	(90,79,70,63)
Semnan	(102,92,80,67)	(97,86,75,67)	(105,97,85,71)	(17,13,5,0)	(74,64,50,42)	(164,144,120,105)
Arak	(271,261,250,236)	(175,155,130,118)	(97,81,60,48)	(191,176,150,136)	(80,65,50,35)	(95,85,70,43)
Esfahan	(325,305,280,260)	(220,197,170,158)	(240,230,220,204)	(172,152,130,111)	(132,112,90,68)	(79,70,60,55)

Table 6
Unit transportation cost between distribution relief centers *j* and damaged regions *k*(×0.01)

DC	Sari	Amol	Rasht	Tehran-west	Tehran-East	Karaj	Qom
Gorgan	(97,77,50,35)	(117,95,70,52)	(250,222,200,190)	(170,148,130,111)	(167,152,135,118)	(179,168,140,122)	(192,171,150,132)
Sari	(22,19,5,0)	(33,25,15,7)	(164,145,120,107)	(102,89,80,63)	(87,79,65,55)	(154,138,110,95)	(185,160,140,128)
Qazvin	(115,102,90,85)	(132,114,90,72)	(83,62,40,26)	(88,68,40,28)	(67,51,35,19)	(61,39,20,4)	(67,56,45,31)
Semnan	(98,86,75,67)	(125,103,80,60)	(205,183,160,147)	(76,64,50,42)	(68,58,45,32)	(103,79,60,44)	(137,117,100,87)
Tehran-west	(105,89,80,63)	(115,98,85,67)	(155,136,110,98)	(14,8,5,0)	(17,12,10,4)	(44,33,15,10)	(71,55,35,21)
Kashan	(164,142,120,108)	(176,156,130,113)	(183,171,160,148)	(112,91,70,51)	(105,86,75,57)	(98,82,55,39)	(72,60,35,19)

The proposed study of this paper has been coded in GAMS software package and the results have indicated that three cities of Gorgan, Sari and Qazvin are the most appropriate cities for distribution centers of relief items. The results are discussed with some experts and it appears that in case a natural disaster such as earthquake or flood in capital city of Iran, Tehran, it is possible to use these cities to supply food and shelter. The results appear to make sense since a newly established highway connects defected cities to Qazvin, Sari and Gorgan. The highway has been located in a region, which has less chance of facing earthquake.

4. Conclusion

In this paper, we have presented an empirical investigation to determine a supply chain management for humanitarian relieves in cases of natural disasters such as earthquake, flood, etc. The implementation of the propose model has built a three-level supply chain problem consists of suppliers, distribution centers and damaged areas. To handle uncertainty associated with the proposed study, the method has used for a real-world case study in northern part of Iran using trapezoid fuzzy numbers. The preliminary results have indicated that we were able to find promising results.

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