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Location-Routing Model for Post-disaster Initial Stage Relief Supplies Based on Priority Level

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According to the location-routing problem that the total relief supplies are limited and insufficient in initial stages of post-disaster, the priority allocation coefficient of each point is determined with variable set theory and then the allocation amount of relief supplies in each stricken point is obtained. Considering the construction time of relief facilities and relief transportation capacity constraints, the location- routing model is proposed with the goal of minimum time in the entire rescue process. And then genetic algorithm is used to solve the facility location and relief supplies distribution routing. At last, the effectiveness and feasibility of the model and algorithm are verified with numerical example.

1. Introduction

In recent years, strong earthquakes occurred frequently in China. For example, an 8.0 earthquake took place on May 12, 2008 in Wechuan, Sichuan Province, a 7.1 earthquake took place on April 17, 2010 in Yushu, Qinghai Province, a 5.8 earthquake took place on March 10, 2011 in Yinjiang, Yunnan Province, a 5.6 earthquake took place on September 7, 2012 in Yiliang, Yunnan Province, a 5.6 earthquake took place on March 29, 2013 in Jichang, Xinjiang Province, 7.0 earthquake took place on April 20, 2013 in Ya'an, Sichuan Province. It is of great possibility that the earthquakes with strong and irreparable damage will occur in the next 50 years in China (Nie et al., 2001). As the key of post-disaster rescue, to timely and reasonably allocate the relief supplies and to meet the demand for relief supplies quickly in limited time, space and resource constraint have great significance to save the stricken lives and to reduce the impact of disasters(Lang, et al. 2014; Zheng and Ma, 2014).Domestic and foreign scholars have made certain achievements on the problems of emergency facilities location(Ma, et al. 2015; Ni, et al. 2015; Zhu, 2015; Yuan et al., 2015) and relief supplies' routing optimization(Tzeng and Cheng, 2007; Shen et al., 2009; Widener and Horner, 2011) of post-disaster.

The urgency degree and demand for relief supplies at each point are different after the earthquake occurs. The amount of relief supplies in initial stage of post-disaster is quite limited, so the priority level analysis for the relief supplies demand in stricken area is the premise of rational allocation of relief supplies. However, most of the existing literatures set the demand of each stricken point as identified demand or random demand, seldom of them took the priority level of post-disaster demand for relief supplies into consideration. Therefore, this paper aims to sort the priority level of relief supplies in each stricken point based on the key factor of stricken area's demand and takes the connectivity of transportation network and the timeliness of relief supplies into consideration. A collaborative optimization model of emergency facility location-routing of post-disaster is proposed, genetic algorithm is used to solve the model and then determine the rational facility location and distribution routing for relief supplies.

2. Problem Description and Explanation

2.1 Problem Description

In the initial stage of earthquake, the relief supplies often cannot meet all the demand of stricken points, in this case the points in emergency need are sorted by priority level and thus to determine the reasonable prior allocation for supplies at each stricken point. Taking the time constraint into consideration, the logistic network

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structure of relief supplies has been built to determine the distribution points, delivery centers and distribution route with appropriate scale and amount of post-disaster relief supplies. In limited space and resource constraint, the emergency system will transport the relief supplies from periphery distribution points in stricken area to emergency delivery centers and then distribute the supplies to each stricken point to meet the demand with minimum time. Due to the transportation infrastructures are destroyed after earthquake and the relief supplies transported from emergency distribution centers to emergency delivery centers is of large quantity, the helicopters can be applied to supplies' distribution and the road transportation with stronger flexibility can be utilized between emergency delivery centers and each stricken point.

2.2 Symbol explanation

The mathematical notation and formulation are as follows:

I represents the stricken point set of post-disaster, $i \in I$.

K represents the distribution point set of relief supplies of post-disaster, $k \in K$.

L represents the emergency delivery center set of post-disaster, $l \in L$.

N represents the emergency delivery center and stricken point set, $n \in N$.

F represents the helicopter set, $f \in F$.

V represents the transport vehicle set, $v \in V$.

Y represents the total amount of relief supplies for pending deployment.

β_{iab} represents the relative optimal membership degree vector of relief supplies demand.

c_{ij}' represents the eigen value of stricken point i at target *j.*

c_{ij} represents the value of relative optimal membership degree, and it's the value after the normalized treatment for c_{ij}'.

w_j represents the weight of key factor j of supplies demand.

t_k represents the time spent to build the distribution point *k*.

t_l represents the time spent to build the emergency delivery center *l.*

s_f represents the maximum transport capacity of helicopter *f*.

s_v represents the maximum transport capacity of vehicle *v*.

h_f represents the average flight speed of helicopter *f*.

h_v represents the average driving speed of vehicle *v*.

α_i represents the allocation coefficient of priority level at point *i*.

d_i represents the prior allocation amount of relief supplies at point *i*.

e represents the distance between the nodes.

z_k represents a 0-1variable that whether to establish distribution point.

z_l represents a 0-1variable that whether to establish emergency delivery center.

z_{kf} represents a 0-1variable that whether the transport helicopter is allocated to distribution point.

z_{lv} represents a 0-1variable that whether the transport vehicle is allocated to delivery center.

y_{iv} represents a 0-1variable that whether the supplies are distributed by transport vehicle v at stricken point i.

x_{klf} represents a 0-1variable that whether the helicopter transport from distribution point k to delivery center l .

c_{inv} represents a 0-1variable that whether the vehicle transport between the nodes.

3. Model Building

3.1 How to determine the priority level of relief supplies

The uncertainty to forecast the relief supplies' demand of post-disaster is the key of allocation when the supplies is insufficient. Through the example of supplies' distribution like Wenchuan earthquake, literature[2] verified that the allocation decision model based on variable set theory is of high reliability. This paper aims to take the stricken population, the disaster extent and the size of stricken area as the key factor of relief supplies' demand of post-disaster and utilize the variable set theory to determine the priority level order of relief supplies for each stricken point. The variable optimization model is proposed as follows.

$$d_i = \alpha_i Y, i = 1,2,\cdots,m \tag{1}$$

$$\alpha_i = \frac{\sum_{a=1}^{2}\sum_{b=1}^{2}\beta_{iab}}{\sum_{i=1}^{m}\sum_{a=1}^{2}\sum_{b=1}^{2}\beta_{iab}} \qquad i = 1,2,\cdots,m \tag{2}$$

$$\beta_{iab} = \frac{1}{1+\left(\frac{\left\{\sum_{j=1}^{n}\left[w_j\left(1-c_{ij}\right)\right]^b\right\}^{\frac{1}{b}}}{\left[\sum_{j=1}^{n}\left(w_j c_{ij}\right)^b\right]^{\frac{1}{b}}}\right)^a} \qquad i=1,2,\cdots,m;a=1,2;b=1,2 \tag{3}$$

$$c_{ij} = \frac{c'_{ij} - \min_j\left(c'_{ij}\right)}{\max_j\left(c'_{ij}\right) - \min_j\left(c'_{ij}\right)} \qquad i=1,2,\cdots,m;\ j=1,2,\cdots n \tag{4}$$

$$c_{ij} = \frac{\max_j\left(c'_{ij}\right) - c'_{ij}}{\max_j\left(c'_{ij}\right) - \min_j\left(c'_{ij}\right)} \qquad i=1,2,\cdots,m;\ j=1,2,\cdots n \tag{5}$$

The cost-focused target eigenvalue is calculated through Eq (4) and the benefit-focused target eigenvalue is calculated through Eq (5) with the goal of united type and non-dimensionalization.

3.2 Location-routing model building

After determining the prior allocation of relief supplies of each stricken point, the optimization model of location-routing of post-disaster is proposed with the goal of least time consuming in order to determine the emergency facilities location and the distribution routing. The objective function includes the time consuming of emergency distribution point construction and delivery center construction, the time consuming that relief supplies transported from distribution point to delivery center and the time that the emergency delivery center takes to distribute the relief supplies for each stricken point.

$$min\ \ M = \sum_{k\in K} t_k z_k + \sum_{l\in L} t_l z_l + \sum_{f\in F}\sum_{k\in K}\sum_{l\in L}\frac{e_{kl}}{h_f}x_{klf} + \sum_{v\in V}\sum_{n\in N}\sum_{n'\in N}\frac{e_{nn'}}{h_v}x_{inv} \tag{6}$$

The Eq (7) represents the relief supplies' amount transported from distribution point is less than the total amount of relief supplies.

$$\sum_{k\in K}\sum_{l\in L}\sum_{f\in F} s_f x_{klf} \le Y \tag{7}$$

Eq (8) to (10) represent that the transport helicopter *f* must be allocated to the enabled distribution point *k*, and the transport helicopter shouldn't be allocated to the distribution point *k* without being enabled, namely the transport helicopter should be allocated to enabled distribution point *k* only.

$$\sum_{f\in F}\sum_{l\in L} x_{klf} - z_k \ge 0 \qquad \forall k\in K \tag{8}$$

$$\sum_{l\in L} x_{klf} - z_k \le 0 \qquad \forall f\in F, k\in K \tag{9}$$

$$z_{kf} \le z_k \qquad \forall f\in F, k\in K \tag{10}$$

Eq (11) represents the capacity constraint in emergency delivery center.

$$\sum_{f\in F}\sum_{k\in K} s_f x_{klf} \le z_l s_l \qquad \forall l\in L \tag{11}$$

Eq (12) to (14) represent that the transport vehicle *v* must be allocated to the enabled delivery center *l*, and the transport vehicles shouldn't be allocated to the delivery center *l* without being enabled, namely the transport vehicles should be allocated to the enabled delivery center *l* only.

$$\sum_{v\in V}\sum_{i\in I} x_{ilv} - z_l \ \geq 0 \qquad \forall l \in L \tag{12}$$

$$\sum_{i\in I} x_{ilv} z_v - z_l \ \leq 0 \qquad \forall v \in V, l \in L \tag{13}$$

$$z_{lv} \leq z_l \qquad \forall v \in V, l \in L \tag{14}$$

Eq (15) represents that the delivery route of each vehicle starts from its attached emergency logistic center only.

$$\sum_{i\in I} x_{ilv} = z_{vl} \qquad \forall v \in V, l \in L \tag{15}$$

Eq (16) represents the continuity of vehicles' transport route.

$$\sum_{n'\in N} x_{nn'v} - \sum_{n'\in N} x_{n'nv} = 0 \qquad \forall v \in V, n, n' \in N \tag{16}$$

Eq (17) represents that the rescue point *i* should be allocated to vehicle *v* if and only if vehicle *v* passes by it when starting from the emergency delivery center *l*.

$$\sum_{n\in N} x_{inv} + \sum_{n\in N} x_{lnv} - y_{iv} \leq 1 \qquad \forall i \in I, l \in L, v \in V \tag{17}$$

Eq (18) represents that the demand of each stricken point along the delivery route shouldn't exceed the vehicle's loading capacity.

$$\sum_{n\in N}\sum_{i\in I} d_i x_{inv} \leq s_v \qquad \forall v \in V \tag{18}$$

Eq (19) represents the 0-1 decision variable.

$$z_k, z_l, z_f, z_v, y_{iv}, x_{klf}, x_{inv} \in \{0,1\} \ \forall i \in I, l \in L, k \in K, f \in F, v \in V, n \in N \tag{19}$$

4. Numerical Simulation

4.1 Simulation data

With a sudden earthquake happened somewhere in China, there has two distribution points for preparation, the coordinates are respectively (20,270) and(245,60) , and the time consuming of each construction is respectively 4 hours and 3 hours; There has four emergency delivery centers points for preparation, the coordinates are respectively(200,180), (50,75), (180,90)and(100,250), and the time consuming of construction is respectively 2 hours, 1.5 hours, 2 hours and1 hours, and the capacity is respectively 25000 units, 35000 units, 25000 units and 30000 units; There has five helicopters and the capacity is 30000 units, the flight speed is 300km/h; There has 15 transport vehicles, among which 12 vehicles have a capacity of 8000 units and the remaining 3 vehicles have a capacity of 6000 units, the driving speed is 80km/h; There has 30 stricken points and the basic information of each point is shown in Table 1. In the initial stage of post-disaster the stock of relief supplies is just 100,000 units, determine the priority level of relief supplies and make location distribution with the goal of minimum time consuming according to the basic information of each stricken point.

4.2 Simulation results

The parameters are set as follows:*Pop*=100, *GGAP*=0.9, *maxgen*=300, p_c=0.7, p_m=0.08. The genetic algorithm is implemented with Matlab7.0, the total time consuming of post-disaster emergency delivery based on priority level reaches 45.2 *h*.From the genetic algorithm convergence Figure 1, it is indicated that the algorithm is of good convergence effect.

Table 1: Basic Information of Each Stricken Point

Number	1	2	3	4	5	6	7	8
Stricken population(10,000)	3.8	2.7	3.7	4.9	2.2	3	1.7	2.1
Stricken area (10,000km)	0.7	2.3	0.9	3.9	3.1	2.8	0.5	0.4
Afflicted strength	5.3	5.3	5.3	5.2	5.6	5.2	5.9	5.9
Coordinate x (km)	44	64	75	101	61	70	118	66
Coordinate y (km)	63	128	117	32	107	118	90	61
Number	9	10	11	12	13	14	15	16
Stricken population(10,000)	1.9	3.3	2.3	10	1.5	1	2.9	2.6
Stricken area (10,000km)	1.4	0.8	1	5	3.7	2	2.1	3.4
Afflicted strength	5.2	5.1	5.7	7	5.3	5.5	6.5	5.7
Coordinate x (km)	36	45	118	56	85	46	131	127
Coordinate y (km)	124	152	204	145	144	123	164	100
Number	17	18	19	20	21	22	23	24
Stricken population(10,000)	3.4	4.2	50	6.9	3.3	7.6	4.6	6
Stricken area (10,000km)	3.1	1.9	15	3.5	2.3	2.9	0.9	3.8
Afflicted strength	5.7	5.7	7.2	6.1	5.6	6.7	6.2	5.3
Coordinate x (km)	131	154	154	186	180	193	155	136
Coordinate y (km)	75	159	29	74	31	36	142	149
Number	25	26	27	28	29	30		
Stricken population(10,000)	6.2	3.1	4.2	3.7	4.5	1.6		
Stricken area (10,000km)	1.6	2.9	2.6	2.4	1.6	2.4		
Afflicted strength	5.2	6.3	5.8	6.3	6.4	6.3		
Coordinate x (km)	159	103	184	121	160	142		
Coordinate y (km)	186	196	189	160	196	143		

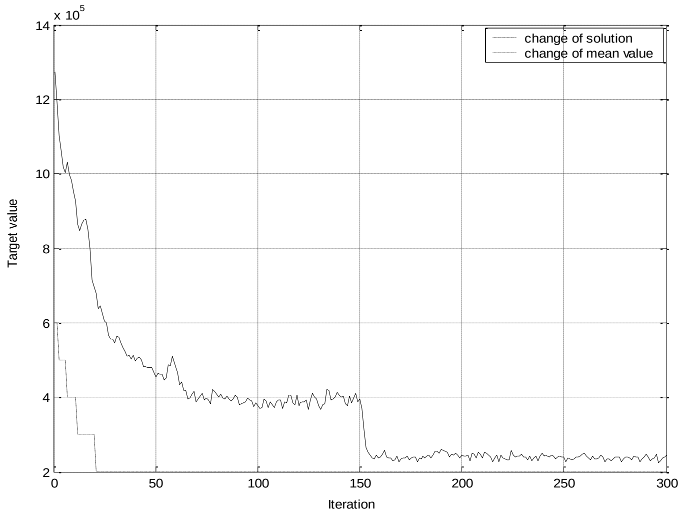

Figure 1: Genetic Algorithm Convergence Diagram

5. Conclusions

To timely meet the need of stricken individuals for relief supplies after the earthquake occurs, this paper firstly identified the key factors of relief supplies' allocation of post-disaster, construct the relative membership degree matrix of index and sort the demand urgency of relief supplies according to the priority level by utilizing variable set theory, and then determine the prior allocation amount of relief supplies of each stricken point. On the basis of this, the emergency facility location-distribution routing model is proposed and the genetic algorithm is designed to solve the model according to its characteristics. The example analysis indicates that the model and algorithm can be used as the auxiliary decision of relief supplies' delivery of post-disaster.

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Reference

Lang K., Zhang M.Y., Yuan Y.B., 2014, Allocation Model of Emergency Supplies in Earthquake Disasters Based on Variable Sets. Journal of Catastrophology, Vol.29, No.1, 201-206.

Ma D.X., Chu J.Y., Wang Z., Chen L.L., 2015, Study on Location Model of Disaster Emergency Shelter Based on Multi-objective Programming. Journal of Natural Disasters, Vol.24, No.2, 1-7.

Ni G.Q., Xu Y.F., Xu J.P., 2015, The Location Models and Algorithms for Emergency Shelter with Traffic Capacity Constraint. Chinese Journal of Management Science, Vol.23, No.1, 82-88.

Nie G.Z., Gao J., G., 2001, The Natural Disasters of China in The 21st Century: Earthquake, Drought and Flood. Quaternary Sciences, Vol.21, No.1, 249-261.

Shen Z., Desscuky M., Ordóñez F., 2009, A two-stage vehicle routing model for large-scale bioterrorism emergencies. Networks, Vol.54, No.4, 255-269.

Tzeng G.H., Cheng H.J., 2007, Multi-objective optimal planning for designing relief delivery systems. Transportation Research Part E, Vol.43, No.6, 673-686.

Widener M.J., Horner M.W., 2011, A hierarchical approach to modeling hurricane disaster relief goods distribution.Journal of Transport Geography, Vol.19, No.4, 82-828.

Yuan Y., Liu Y., Zhu S.H., Wang J.B., 2015, Maximal Preparedness Coverage Model and Its Algorithm for Emergency Shelter Location. Journal of Natural Disasters, Vol.24, No.2, 8-14.

Zheng B., Ma Z.J., 2014, Multi-period Joint Location-Transportation during Post- earthquake Restoration. Journal of Transportation Systems Engineering and Information Technology, Vol.14, No.4, 230-238.

Zhu J.M., 2015, Methods of Multi-objective Decision-making for Emergency Facility Location Problem under Failure Scenario. Systems Engineering- Theory & Practice, Vol.35, No.3, 720-727.