# Fuzzy location-routing problem for emergency logistics systems

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**Abstract**

To optimize the post-earthquake emergency logistics system with two-echelon multi-facilities, this study develops a model for fuzzy location-routing problem by considering fuzzy demand of relief materials, timeliness and limited resources. The goal of the model is to minimize the total cost and the relief time of system. Furthermore, this research proposes an improved genetic algorithm based on weighted coefficient transformation. The result of a numerical example shows that the model and algorithm are effective for resolving the joint decision-making of facility location-allocation problem and vehicle routing problem in post-earthquake.

*Keywords:* Emergency Logistics, Location-routing Problem, Earthquake Disasters, Multi-objective Optimization, Improved Genetic Algorithm

## 1 Introduction

According to the statistical findings of Sichuan Red Cross, after the world-shocked earthquake happened in Wenchuan, people in the harder hit area demand 4436.2 tons of food, 8115 tons of drinking water every day. The category of relief supplies reached 7 categories and 46 subcategories, which became a great challenge to relevant dispatching department. Due to lack of scientific and reasonable planning emergency logistics system scheme, some of the disaster areas were repeated distributed which resulted in excess supplies, while some harder hit area had not received emergency relief supplies which led to low efficiency of emergency logistics. We can conclude from the actual feedback information of the earthquake relief work, that it is urgent to solve the following problems in the optimization of post-earthquake emergency logistics system: How to locate the emergency facilities? How to optimize the transport routes of emergency supplies? The first question is to solve the emergency facility location-allocation problem (Location-Allocation Problem, LAP). It determines the mode and structure of the whole emergency logistics system. While the second question is mainly to solve the problem of emergency vehicle routing problem (Vehicle Routing Problem, VRP). Both of them are key issues in optimizing post-earthquake emergency logistics system, they are interdependent and interactive. Therefore, from the perspective of optimizing the overall emergency logistics system, investigating the scheme of location-allocation and route problem (LRP) in the earthquake emergency logistics system is quite necessary.

Although many scholars (Min H [1], Nagy G [2], Sérgio Barreto [3]) have studied the LRP in the general logistics systems, most of research (Haghani A [4], Barbarosoğlu G [5], WEI Hang [6], Yuan Yuan [7], Sheu J B [8, 9]) on the optimization of emergency logistics system basically focuses on emergency facility location problem or emergency supplies distribution alone. However, Research on LRP in emergency logistics system is rare. As Yi et al [10] explore the coordination and optimization of materials distribution and treatment and the transportation of the wounded in the natural disaster emergency rescue. They set up a deterministic mixed multiple integer and multispecies goods network flow model, and use CPLEX software to obtain the solution. In the emergency response phase, quickly drawing out the emergency rescue plan is the key of improving the efficiency. Some scholars make some contributions in this stream research, for example, Wang et al[11], designed an "triangle" heuristic algorithm based on the two-stage decomposed thoughts in a two-echelon post-earthquake facility location routing problem (LRP) model. They prove that "triangle" heuristic algorithm has higher efficiency by comparing it with the improved genetic algorithm. Nevertheless, their study does not consider the fuzziness of post-earthquake emergency material demand. In fact, the information of relief materials' supply and demand, traffic, the emergency resource and other factors is often uncertain. It is a fuzzy decision process. Besides, natural disaster emergency logistics shows particularity characteristics, such as relief materials demand can be divided, and each material requirement can be accessed multiple times. Full load direct distribution and touring (circuit) distribution methods can be used alternately through analysing the different categories of disaster relief materials. The demand and supply of natural disaster emergency materials have great uncertainty, it is necessary to coordinate the relief materials supply and the inaccurate

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prediction of demand [12]. Earthquake emergency logistics has the typical features of sudden, uncertainty and timeliness, therefore, this study aims at optimizing the post-earthquake emergency logistics system with two-echelon multi-facilities, setting up an optimized multi objective model for fuzzy location-routing problem (LRP), proposing an improved genetic algorithm based on weighted coefficient transformation, and to test the improved genetic algorithm from the standpoint of its robustness and its parameters setting.

## 2 Model construction

### 2.1 PROBLEM DESCRIPTION

After the earthquake, it is necessary to establish a number of relief materials collector-distributor points in the periphery to conduct the transfer and allocation of all donations and emergency procurements. It can help to quickly deliver the materials to the temporary emergency distribution center and then send them to the disaster area settlements (shelters). Because of the fuzzy demand of relief materials, the last visited settlements (shelters) of each route may appear unmet demand. It needs to dispatch helicopters from the airport to the existing relief materials distribution point to load supplies, and then do urgent touring (circuit) distribution to satisfy these settlements (shelters)' demands. The decision problem is how to establish several relief materials collector-distributor points and emergency distribution centres, and how to determine a set of emergency transportation routes after considering the facility capacity and rescue vehicles, helicopters capacity constraints, meanwhile, to minimize the operation time of emergency logistics system and the total cost. Assumptions before modelling show as follows:

(1)This study only consider about the distribution of some kind of relief materials.

(2)No material transport between the relief materials collector-distributor points.

(3)Assuming the vehicle capacity of the collector-distributor points and emergency distribution centres can meet the transportation demands.

(4)Large demand settlements (shelters) can be accessed several times, use some idle vehicles with full load direct distribution, the remaining less than a car of materials with touring (circuited) distribution.

(5)Since the demand for each settlement (shelter) is fuzzy, it can be represented by triangular fuzzy number.

(6)Helicopters can be dispatched urgently from the airport to the existing collector-distributor points to load materials for touring (circuited) distribution, when the settlement (shelter) of each route appears unmet needs.

### 2.2 SYMBOL ILLUSTRATION

$S=\{r\,|\,r=1,2,3,...,R\}$ indicates alternative collector-distributor points set; $SQ_r$ indicates the maximum management capacity of distribution $r$ (capacity).

$W=\{p\,|\,p=1,2,3,...,P\}$ indicates alternative distribution centers set; $WQ_p$ indicates maximum management capacity of center $p$ (capacity).

$O=\{a\,|\,a=1\}$ indicates helicopter airports set, the airports locations are determined.

$C=BC\bigcup SC$ indicates the disaster settlements (shelters) set. $BC$ indicates settlement (shelter) with large demand (Demand exceeds the maximum capacity of the vehicle) (Large Shelter); $SC$ indicates settlement (shelter) with small demand (Demand is less than the maximum loading capacity of the vehicle) (Small Shelter).

$N=S\bigcup W\bigcup O\bigcup C$ is the set of all the nodes.

$V=\{k\,|\,k=1,2,3,...,K\}$ is the set of vehicles.

$VQ_k$ indicates the loading capacity of vehicle $k$; $VQ$ indicates the maximum loading capacity of the largest volume vehicle.

$U=\{h\,|\,h=1,2,...,H\}$ indicates the helicopters set; $UQ_h$ indicates the capacity of helicopter $h$.

$DT$ indicates the time cost by the full loading vehicle with per unit of material and distance from distribution centre to the big shelter.

$CV_k$ stands for the dispatch money of vehicle $k$.

$CU_h$ stands for the dispatch money of helicopter $h$.

$CB$ stands for the transportation expenses of per unit of material and distance from collector-distributor point to emergency distribution centre (or from distribution centre to the big shelter).

$D$ stands for the transportation expenses of (tour) circuited vehicle with certain unit of distance.

$A$ stands for the transportation expenses of (tour) circuited helicopter with certain unit of distance.

$CR_r$ stands for the cost of establishing $r$ collector-distributor point, assuming that it is positive associated with the scale of the distribution point.

$CW_p$ stands for the cost of establishing distribution center at point $p$, assuming that it is positive associated with the scale of the distribution centre.

$\beta_{ij}$ stands for the road damage rate between node $i$ and node $j$( $i,j\in N$ ), represented by the ration of the length of damage road to the length of the whole road.

$\eta$ , $\gamma$ separately stands for the average cost and average time spent on road repairing of per unit distance between node $i$ and node $j$( $i,j\in N$ ).

$\alpha_{ij}\in\{1,0\}$ stands for the road situation, 1 indicates that the road between node $i$ and $j$( $i,j\in N$ ) is connected, 0 indicates that the road is blocked. $\beta_{ij}$ , $\eta$ , $\alpha_{ij}$ , $\gamma$ can be identified by the remote sensing data of satellite, aerial technology, some practical road feedback information and calculation of the amount of construction.

$\tilde{d}_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$ indicates the Euclidean distance between node $i$ and node $j$ ( $i, j \in N$ ), $x_i$ , $y_i$ ( $i \in N$ ) indicates the abscissa and ordinate of node $i$.

$d_{ij}$ indicates the actual distance between node $i$ and node $j$( $i, j \in N$ ). This can be obtained by GIS calculation, here we replace it with the Euclidean distance transformation, that is $d_{ij} = m(1-\alpha_{ij}) + \delta \tilde{d}_{ij}$ , $\delta$ represents the coefficient of the plane Euclidean distance transforms into actual distance ( $\delta > 1$), the value can be estimated according to the disaster area road network information; $m$ is a sufficiently large positive number.

$q_j$ indicates the demand of shelter $j$( $j \in C$ ), which can be represented by Triangular fuzzy number ($a_j$, $b_j$, $c_j$), $a_j$, $b_j$, $c_j$ can be estimated by the decision makers based on intuition, experience or some available information.

$\bar{q}_j$ indicates the unmet demand of the last visited settlements (shelters) $j$( $j \in C$ ) of each route, $\bar{q}_j \geq 0$ , it is a definite number, for if the surplus materials on the car can meet the needs of the settlements (shelters) can be known once the car reach the final service settlements (shelters).

$ST_{jk}$ indicates the time that vehicle $k$ spends on arriving at the small settlement (shelter) $j$( $j \in SC$ ), when $j \in W$ , $ST_{jk}$=0.

$v_k$ indicates the average speed of the No. $k$ car.

$\tau_{ijk}$ indicates the time that vehicle costs from node $i$ to node $j$( $i, j \in W \bigcup SC$ ), $\tau_{ijk} = d_{ij} / v_k$ .

$BT_j$ indicates the traffic time of sending full load vehicle to the big settlement (shelter) $j$( $j \in BC$ ).

$ET_{jh}$ indicates the traffic time of helicopter $h$ reaching the demand-unmet small settlement (shelter) $j$( $j \in SC$ ), when $j \in S \bigcup O$ , $ET_{jh}$=0.

$v'_h$ indicates the average speed of the No. $h$ helicopter.

$\zeta_{ijh}$ indicates the time that helicopter $h$ costs from node $i$ to node $j$( $i, j \in O \bigcup S \bigcup SC$ ), $\zeta_{ijh} = \tilde{d}_{ij} / v'_h$ .

$\tilde{p}$ indicates the confidence level of vehicle capacity limitation, $\tilde{p} \in [0,1]$ .

$\bar{p}$ indicates the confidence level of capacity limitation of emergency distribution centre, $\bar{p} \in [0,1]$ .

The decision variables:

$x_{ijk}$: while vehicle $k$( $k \in V$ ) transports from node $i$ to node $j$( $i, j \in W \bigcup SC$ ), it's 1, otherwise is 0.

$\varphi_{ijh}$ : While helicopter $h$( $h \in U$ ) transports from node $i$ to node $j$ ( $i, j \in O \bigcup S \bigcup SC$ ), it's 1, otherwise is 0.

$u_r$: while establishing distribution point at alternative point $r$( $r \in S$ ), it's 1, otherwise is 0.

$z_p$: while establishing emergency distribution centre at alternative point $p$( $p \in W$ ), it's 1, otherwise is 0.

$g_{pr}$: while established emergency distribution centre $p$( $p \in W$ ) is assigned to established collector-distributor point $r$( $r \in S$ ), it's 1, otherwise is 0.

$y_{jp}$: while established settlement (shelter) $j$( $j \in C$ ) is assigned to established emergency distribution centre $p$( $p \in W$ ), it's 1, otherwise is 0.

$fs_{rp}$ indicates the transportation capacity from collector-distributor point $r$( $r \in S$ ) to emergency distribution centre $p$( $p \in W$ ).

$fw_{pj}$ indicates the full load transportation capacity from emergency distribution centre $p$( $p \in W$ ) to the big settlement (shelter) $j$( $j \in BC$ ).

## 2.3 MODEL ESTABLISHING

Establishing fuzzy LRP multi-objective optimized model of post-earthquake emergency logistics system as follow:

$$\min f_1 = \sum_{k\in V}\sum_{j\in SC} ST_{jk} + \sum_{j\in BC} BT_j + \sum_{h\in U}\sum_{j\in SC} ET_{jh} + \sum_{r\in S}\sum_{p\in W}\gamma \times \beta_{rp} \times d_{rp} \times g_{rp} + \sum_{p\in W}\sum_{j\in BC}\gamma \times \beta_{pj} \times d_{pj} \times y_{jp} + \sum_{k\in V}\sum_{i\in W\bigcup SC}\sum_{j\in W\bigcup SC}\gamma \times \beta_{ij} \times d_{ij} \times x_{ijk} , \quad (1)$$

$$\min f_2 = \sum_{r\in S} CR_r \times u_r + \sum_{p\in W} CW_p \times z_p + \sum_{k\in V} CV_k \sum_{i\in W}\sum_{j\in SC} x_{ijk} + \sum_{h\in U} CU_h \sum_{i\in O}\sum_{j\in S}\varphi_{ijh} + \sum_{r\in S}\sum_{p\in W}\left(CB\times fs_{rp} + \eta\times\beta_{rp}\right)d_{rp}\times g_{rp} + \sum_{p\in W}\sum_{j\in BC}\left(CB\times fq_{pj} + \eta + \beta_{pj}\right)d_{pj}\times y_{jp} + \sum_{k\in V}\sum_{i\in W\bigcup SC}\sum_{j\in W\bigcup SC}\left(D+\eta\times\beta_{ij}\right)d_{ij}\times x_{ijk} + \sum_{h\in U}\sum_{i\in O\bigcup S\bigcup SC}\sum_{j\in O\bigcup SC} A\times\tilde{d}_{ij}\varphi_{ijh} , \quad (2)$$

$$s.t. \sum_{p\in W} fs_{rp} g_{pr} \leq SQ_r, \forall r \in S , \quad (3)$$

$$\sum_{r\in S} fs_{rp} g_{pr} \leq WQ_p, \forall p \in W , \quad (4)$$

$$\sum_{r\in S} fs_{rp} g_{pr} - \sum_{j\in C} q_j y_{jp} = 0, \forall p \in W , \quad (5)$$

$$\mathrm{Pos}(\sum_{j\in C} q_j y_{jp} \leq WQ_p) \geq \bar{p}, \forall p \in W , \quad (6)$$

$$\mathrm{Pos}(\sum_{j\in SC} q_j \sum_{i\in W\bigcup SC} x_{ijk} \leq VQ_k) \geq \tilde{p}, \forall k \in V , \quad (7)$$

$$\sum_{p\in W} fw_{pj} + \text{rep}(q_j, VQ) + \bar{q}_j \geq q_j, \forall j \in BC, \quad (8)$$

$$\varphi_{ijh} = 1 \Rightarrow x_{jlk} = 0, \forall j \in SC, i \in S \bigcup SC, l \in SC, h \in U, k \in V, \quad (9)$$

$$\sum_{j\in SC} \bar{q}_j \sum_{i\in O\bigcup S\bigcup SC} \varphi_{ijh} \leq UQ_h, \forall h \in U, \quad (10)$$

$$\sum_{i\in W\bigcup SC} x_{ijk} - \sum_{i\in W\bigcup SC} x_{jik} = 0, \forall j \in W \bigcup SC, k \in V, \quad (11)$$

$$\sum_{i\in O\bigcup S\bigcup SC} \varphi_{ijh} - \sum_{i\in O\bigcup S\bigcup SC} \varphi_{jih} = 0, \forall j \in O \bigcup S \bigcup SC, h \in U, \quad (12)$$

$$\sum_{g\in M} \sum_{l\in SC} x_{glk} \geq 1, \forall k \in V, M \subset W, \quad (13)$$

$$\sum_{p\in W} g_{pr} \geq u_r, \forall r \in S, \quad (14)$$

$$g_{pr} \leq u_r, \forall p \in W, r \in S, \quad (15)$$

$$\varphi_{irh} \leq u_r, \forall i \in O, r \in S, h \in U, \quad (16)$$

$$\sum_{r\in S} \varphi_{irh} \leq 1, \forall h \in U, i \in O, \quad (17)$$

$$\sum_{i\in W} \sum_{j\in SC} x_{ijk} \leq 1, \forall k \in V, \quad (18)$$

$$\sum_{k\in V} \sum_{j\in SC} x_{pjk} \geq z_p, \forall p \in W, \quad (19)$$

$$\sum_{j\in SC} x_{pjk} \leq z_p, \forall k \in V, p \in W, \quad (20)$$

$$\sum_{g\in W\bigcup SC} x_{jgk} + \sum_{g\in W\bigcup SC} x_{pgk} - y_{jp} \leq 1, \forall j \in SC, k \in V, p \in W, \quad (21)$$

$$ST_{jk} = ST_{ik} + \tau_{ijk} x_{ijk}, \forall i, j \in W \bigcup SC, k \in V, \quad (22)$$

$$BT_j = DT \times [q_j - \text{rep}(q_j, QV)] \times d_{pj} \times y_{jp}, \forall j \in BC, p \in W, \quad (23)$$

$$ET_{jh} = ET_{ih} + \zeta_{ijh} \varphi_{ijh}, \forall i, j \in O \bigcup S \bigcup SC, h \in U, \quad (24)$$

$$d_{jh} = m(1 - \alpha_{ij}) + \delta \tilde{d}_{ij}, \quad (25)$$

$$\sum_{j=1}^{2} w_j = 1, \quad (26)$$

$$x_{ijk} \in \{0,1\}, \varphi_{ijh} \in \{0,1\}, u_r \in \{0,1\}, z_p \in \{0,1\}, g_{pr} \in \{0,1\},$$
$$y_{jp} \in \{0,1\}, fs_{rp} \geq 0, fw_{pj} \geq 0, \forall i, j \in C, k \in V, h \in U, \quad (27)$$
$$p \in W, r \in S.$$

Among them, the objective function shows as follow: Equation (1) indicates the minimal sum of the time spent on distributing relief materials to each settlement (shelters) and road repairing. Equation (2) indicates the minimal total cost of post-earthquake emergency logistics system, including the cost of facilities establishment, means of dispatching transportation (vehicles and helicopters), relief materials distribution and road repairing. Constraint condition: Equation (3) indicates the volume of materials sending out from the collector-distributor point is less than the capacity of this collector-distributor point. Equation (4) indicates the volume of materials sending from collector-distributor point to each emergency distribution centres is less than the capacity of this emergency distribution centre. Equation (5) indicates transport volume conservation. Equation (6) indicates that the possibility of total demand of all the settlements (shelters) assign to the emergency distribution centre *p* does not exceed its capacity should maintain in the confidence level. Equation (7) indicates that the possibility of the total demand of small settlements (shelters) assign to the circuited (touring) vehicle *k* does not exceed the capacity of this vehicle should maintain in the confidence level. Equation (8) indicates that the relief materials distributed to the big settlement (shelter) *j*( $j \in BC$ ) should meet the demand of this settlement (shelter), $rep(q_j, VQ)$ indicates the remainder of large settlement demand and the capacity of maximum cargo vehicle. Equation (9) indicates that the emergency helicopter distribution can only be used at the last settlement (shelter) with unmet needs of a route. Equation (10) indicates that the unmet demand of each settlement (shelter) assign to helicopter *h* cannot exceed the capacity of this helicopter. Equation (11) and equation (12) indicate the continuous constraints of route. Equation (13) indicates constraints of eliminating circuited distribution, which means each routes should connect to at least one emergency distribution centre. Equation (14) and equation (15) indicate that once the collector-distributor point is established, the emergency distribution centre will assign to it, and the emergency distribution centre only assign to those open collector-distributor point. Equation (16) and equation (17) indicates that the helicopter can only be set out to the open collector-distributor point from the airport, and each helicopter can only go to one collector-distributor point. Equation (18) indicates that each vehicle can only assign to one emergency distribution centre at the most. Equation (19) and equation (20) indicates that once the emergency distribution centre is established, there will be vehicles assign to it, and the vehicles can only be assigned to the open emergency distribution centre. Equation (21) indicates that the small settlement (shelter) *j*( $j \in SC$ ) can assign to the emergency distribution centre *p* only when there is one and only route pass this small settlement (shelter) from centre *p*. Equation (22) to Equation (24) show the mathematical expressions of $ST_{jk}$, $BT_j$ and $ET_j$. Equation (25) indicates the Euclidean distance transforms into actual distance. Equation (26) indicates that the sum of the weight of all targets is 1. Equation (27) is the constraint of 0-1 decision variable and the constraint of nonnegative number.

Constraint equation (6) and equation (7) cannot be figured out directly because there is fuzzy parameter $q_j$ in it. They require for proper processing. Assume that $\Delta VQ_\theta$ is the remaining capacity of rescue vehicle $k$ after it finish the service of several (the number is $\theta$ ) settlements (shelters). $\Delta WQ_\varepsilon$ is the remaining capacity of emergency distribution centre $p$ when it finishes the service of several (the number is $\varepsilon$ ) settlements (shelters). $\Delta VQ_\theta$ and $\Delta WQ_\varepsilon$ are Triangular fuzzy numbers (Jian-yong Zhang [13]), there are:

$$\Delta VQ_\theta = (VQ_k - \sum_{j=1}^{\theta} c_j, VQ_k - \sum_{j=1}^{\theta} b_j, VQ_k - \sum_{j=1}^{\theta} a_j), \quad (28)$$

$$\Delta WQ_\varepsilon = (WQ_p - \sum_{j=1}^{\varepsilon} c_j, WQ_p - \sum_{j=1}^{\varepsilon} b_j, WQ_p - \sum_{j=1}^{\varepsilon} a_j). \quad (29)$$

The possibility that demand of next settlement (shelter) is less than the remaining capacity of the vehicle and demand of next settlement (shelter) is less than the remaining capacity of the emergency distribution centre can be indicated by equation (30) and equation (31) as follow:

$$p_1 = \mathrm{Pos}\{q_{\theta+1} \le \Delta VQ_\theta\} = \begin{cases} 1, & b_{\theta+1} \le \Delta VQ_\theta \\ \dfrac{\Delta VQ_\theta - a_{\theta+1}}{b_{\theta+1} - a_{\theta+1}}, & a_{\theta+1} < \Delta VQ_\theta < b_{\theta+1} \\ 0, & a_{\theta+1} \ge \Delta VQ_\theta \end{cases}, \quad (30)$$

$$p_2 = \mathrm{Pos}\{q_{\varepsilon+1} \le \Delta WQ_\varepsilon\} = \begin{cases} 1, & b_{\varepsilon+1} \le \Delta WQ_\varepsilon \\ \dfrac{\Delta WQ_\varepsilon - a_{\varepsilon+1}}{b_{\varepsilon+1} - a_{\varepsilon+1}}, & a_{\varepsilon+1} < \Delta WQ_\varepsilon < b_{\varepsilon+1} \\ 0, & a_{\varepsilon+1} \ge \Delta WQ_\varepsilon \end{cases}. \quad (31)$$

The vehicle will go on visiting next node when $p_1 \ge \tilde{p}$, otherwise it will return to the emergency distribution centre, as $x_{ijk} = 1 \Rightarrow \mathrm{Pos}\{q_j \le \Delta VQ_i\} \ge \tilde{p}$ . This emergency distribution centre can accept next settlement (shelter) when $p_2 \ge \bar{p}$, as $y_{jp} = 1 \Rightarrow \mathrm{Pos}\{q_j \le \Delta WQ_{j-1}\} \ge \bar{p}$ . Therefore, constraint equation (6) and equation (7) are separately equivalent to $x_{ijk} = 1 \Rightarrow \mathrm{Pos}\{q_j \le \Delta VQ_i\} \ge \tilde{p}$ and $y_{jp} = 1 \Rightarrow \mathrm{Pos}\{q_j \le \Delta WQ_{j-1}\} \ge \bar{p}$.

## 3 Algorithm design

Aforementioned model is a fuzzy multi-objective mixed integer programming model, here we proposed an improved genetic algorithm based on weight coefficient transform, that is transform the multi-objective optimization problem into a single objective optimization problem. The solution of the LRP algorithms were formerly based on two stage solution ideas or using the intelligence algorithm [11]. However, this thesis designs a genetic algorithm to solve the LRP as a whole. This can effectively reduce the probability of stagnating in the local optimal solution in the process of evolution. Besides, in order to prevent the premature problem of genetic algorithm, this algorithm adopts stochastic universal sampling, restructuring strategy, variable cross rate and variation rate method.

### 3.1 THE ALGORITHM PARAMETER SETTING

Assume that Pop is the population size, GAPP is the generation gap probability, Maxgen is the Maximum repeatedly algebra, $P_c$ is the probability of crossover; $P_m$ is the probability of metamorphosis.

### 3.2 CODING AND INITIAN

It needs to use specific encoding method. Each chromosome consists of six substrings; there are $n$ gene positions in the first substring. $n$ stands for the number of settlements(shelters). This substring corresponds to numbered settlements (shelters); the value of each gene position is a random number in from 1 to $K$. $K$ stands for the number of vehicles. As for the big settlements (shelters), here we only consider remaining demand after the full-load distribution. In addition, there are $n$ gene positions in the second substring, which correspond to numbered settlements (shelters). The difference is that this part stands for the full-load capacity from distribution centre to the big settlements (shelters) (that is the demand of big settlements minus the remainder of its demand divided by the capacity of maximum vehicle). The value of each gene position is a natural number in from 1 to $P$, $P$ stands for the number of alternative emergency distribution centres. Length of the third substring is $K$, the gene positions of this substring correspond to numbered vehicles, the value of each gene position is a natural number in from 1 to $P$. Length of the forth substring is $R \times P$, there are $R \times P$ gene positions, separately correspond to the numbered emergency distribution centres, $((r-1) \times p+1$ to $r \times p$ indicates the distribution centres assigned to the collector-distributor point $r$, thus each distribution centre assign not only to one collector-distributor point, but the number must be less than the number of established collector-distributor points). The value of each gene position is a natural number in from1 to $R$, $R$ stands for the number of alternative relief materials collector-distributor points. Length of the fifth substring is $n$, this substring corresponds to the numbered demand-unmet settlements (shelters). In addition, the value of each gene position is a random number in from 1 to $H$, $H$ stands for the number of the helicopter. Length of the sixth substring is $H$, the value of each gene position is a natural number in from 1 to $R$. Using this kind of encoding method can implicate the information of guaranteeing every settlements (shelters) to get service, vehicles distributed to the emergency distribution centres, distribution centres be assigned to collector-distributor points and which collector-distributor point will a helicopter take off from during emergency distribution, this will be convenient for dealing with every constraint in the model.

*3.2.1 Constraint of the capacity*

The penalty function method is applied for dealing with the constraint of the capacity of conveyance, emergency distribution centres and emergency materials collector-distributor points. That is to multiply a penalty coefficient to the objective function of the individual, which does not satisfy the constraint.

*3.2.2 Constraint of the settlements (shelters)' demands*

Divide the demand of high-demand settlements (shelters), distribute several vehicles to make full-load distribution and use the circuited (tour) vehicles to satisfy the remaining demand.

*3.2.3 Other constraints*

Use specific code so that the search space and the solution space can match each other. Besides, using genetic algorithm breeding device to mutate the operator can guarantee that the new individual which comes from the mutation maintaining in the corresponding solutions in the solution space.

The genetic algorithm universal function is developed by the University of Sheffield in Britain to set up the initial population. First of all, use crtbase function to establish 3 vector quantity: The length of a basic character vector quantity is $2n$, it is combined with n basic characters$\{0,1,2,\ldots,K\text{-}1\}$ whose cardinal number is $K$ and $n$ basic characters$\{0,1,2,\ldots,P\text{-}1\}$ whose cardinal numbers is $P$. ($n$ stands for the number of the basic characters). Here is the second basic character vector quantity; its length is $K+R\times P$. It's combined with $K$ basic characters$\{0,1,2,\ldots,P\text{-}1\}$ whose cardinal number is $P$ and $R\times P$ basic characters$\{0,1,2,\ldots,R\text{-}1\}$ whose cardinal number is $R$. ($K$ and $R\times P$ stand for the number of the basic characters). The third basic character vector quantity with a length of $n+H$, it is combined with $n$ basic characters$\{0,1,2,\ldots,H\text{-}1\}$ whose cardinal number is $H$ and $H$ basic characters$\{0,1,2,\ldots,R\text{-}1\}$ whose cardinal number is $R$. ($n$ and $H$ stand for the number of the basic characters.) Secondly, using crtbp function to establish 3 matrices *Chrom1*, *Chrom2* and *Chrom3* with the same line number and their elements are random number (their basic characters are determined by the corresponding vector quantity). The line number of the matrices is the population size-Pop. Then we define *Chrom* = [*Chrom1*, *Chrom2*, *Chrom3*]. In order to ensure that the number of the column and the line is not zero in the matrices, we add a 1-matrix with the same dimension and all its entry is 1. Here we get the initial population.

## 3.3 CALCULATING THE DEGREE OF ADAPTATION

In the calculation of target value, due to the different targets with different dimension and magnitude, we cannot do direct weighting. In order to eliminate the influence of different dimension and magnitude, it is necessary to do dimensionless processing. Method of dimensionless processing are many, commonly used methods are standardization processing method, extreme value method, the linear scaling method, normalized method, vector norm method and effect coefficient method [14]. This thesis uses linear scaling method, the target value after dimensionless processing is $f_j' = f_j / f_j^0$, $j = 1,2$, $f_j$ is the actual value of target $j$, $f_j^0$ is the satisfaction value of target $j$.

Assume that $u_i = \text{Fitness}(Chrom_i(gen))$ is the fitness degreed of the No.$i$ chromosome of the gen generation population-Chrom. It is figured out by the transform of the dimensionless target function. So the fitness degreed function is $u_i = 1/(w_1 f_1'(i) + w_2 f_2'(i))$. $f_j'(i)$ is the evaluation of the target $j$ of chromosomes $i$ after dimensionless processing. $w_j$ is the weight of no.$j$ target, it can be given different weight according to the degree of importance of the objective function. In the post earthquake emergency response phase, time is life, so the weight in the target weight is larger. Cost is also a factor which needs to be considered when the emergency resources are very limited but the urgent demand for them is very large. Compare with the weight of time, weight of cost is smaller.

## 3.4 GENETIC OPERATION

*3.4.1 Select operation*

This study uses the stochastic universal sampling and fitness reinsertion method. Stochastic universal sampling can make the population diversity relatively permanent, and prevent the algorithm premature convergence. However, fitness reinsertion will make the most appropriate individuals to be generational reproduced continuously. This can improve the effectiveness of the optimization strategy.

*3.4.2 Crossover operation*

In order to maintain the diversity of population, this study adopt the restructuring strategy based on crossover operator, adopt the crossover operator which has great destructive – multi point crossover operator. This can promote the search of the solution space by the genetic algorithm. Besides, variable cross rate Pc needs to be used.

*3.4.3 Mutation operation*

Using the real variation, and add in the region descriptor to limit the range of variation, in order to ensure that the mutation does not exceed the decision variable boundary. Variable mutation probability in the selection of $P_m$ in this study represents the probability of mutation. That is to use larger value for $P_m$ in the earlier stage of algorithm to expand the search space, and use smaller value for $P_m$ in the later stage of algorithm to speed up convergence.

3.5 THE TERMINATE OF ALGORITHM

If gen<=Maxgen, repeating step(3)~step(4). If gen>Maxgen, output the optimal chromosome and the optimal solution, the algorithm terminates.

## 4 Example analysis

Randomly presents 2 alternative relief materials distribution points, 4 alternative emergency distribution centre, 10 vehicles, 3 helicopters and airport location (coordinates (50,285)), 30 settlements (shelters). Getting the fuzzy demand and the coordinates of each settlements (shelters) according to some available information (as shown in the table 1). The plane coordinates of the emergency facilities and the settlements (shelters) are two-dimension random numbers from 0 to 300.This study uses the simulating method from Zhang et al to make "actual" demand, which comprises the following steps: (1) Generating a random number x in the fuzzy demand number of certain settlement (shelter), and calculate the degree of its relative-membership $\mu_{q_j}$. (2) Generating a random number $\vartheta$ in the range of [0, 1]. (3) Comparing $\vartheta$ and $\mu_{q_j}$, if $\delta$ is smaller than $\mu_{q_j}$, $x$ will be the actual demand of this settlement(shelter), otherwise, repeat the above steps, until we get the actual demand of this settlement (shelter). (4) Repeating the above steps and generate the actual demand of all the settlements (shelters).

TABLE 1 Coordinate of resettlement sites and its fuzzy demand of relief materials

| **Serial Number** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
|---|---|---|---|---|---|---|---|---|---|---|
| Coordinate | (10,51) | (21,32) | (102,205) | (74,86) | (61,25) | (85, 142) | (56,164) | (112,55) | (93,126) | (124,175) |
| Fuzzy Demand | 22,25,30 | 32,36,40 | 35,38,42 | 38,40,45 | 42,45,48 | 34,36,40 | 52,55,60 | 30,36,40 | 42,46,48 | 50,52,55 |
| **Serial Number** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** |
| Coordinate | (46,105) | (185,88) | (92,19) | (205,184) | (225,115) | (282,156) | (253,224) | (154,245) | (248,38) | (300,215) |
| Fuzzy Demand | 40,43,45 | 52,55,58 | 52,56,60 | 640,644,650 | 60,62,65 | 82,85,88 | 42,45,50 | 62,64,68 | 52,56,60 | 82,85,88 |
| **Serial Number** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** |
| Coordinate | (150,27) | (160,55) | (210,25) | (240,50) | (40,210) | (50,150) | (60,250) | (125,80) | (100,75) | (250,150) |
| Fuzzy Demand | 42,44,48 | 62,65,63 | 54,56,60 | 79,82,85 | 63,65,68 | 28,30,35 | 32,35,38 | 42,45,48 | 62,64,68 | 42,46,50 |

Assume the conversion coefficient $\delta = 1.5$, randomly give $\alpha_{ij}$ the value of 0 or 1, and $\alpha_{ij} = \alpha_{ji}$ ($i, j \in N$). $\beta_{ij}$ is a random non negative real number which is between 0 to 1. $\eta =$ 0.05yuan/km, $\gamma =$ 2h/km, $CB$=2yuan/item·km, $D$=1yuan/km, $A$=5yuan/ km, $DT$=0.001h/item·km, $\bar{p}$ and $\tilde{p}$ are all equal to 0.9. Capacity of each vehicle (item), dispatch money (yuan/vehicle), speed(km/h) separately come from set {200, 200, 180, 200, 200, 200, 200, 160, 200, 200}, {2000, 2000, 1800, 2000, 2000, 2000, 2000, 1600, 2000, 2000} and {80, 80, 70, 80, 70, 80, 80, 60, 80, 80}. Capacity of helicopter, dispatch money and speed come from set {50, 50, 50}, {10000, 10000, 10000} and {200, 200, 200}. The coordinates, capacity and the cost of construction of each collector-distributor point and emergency distribution centre come from set {(20, 268), (255, 290)}, {2800, 2600}, {28000, 26000} and set {(55, 52), (100,175), (255,165), (152,125)}, {1000, 1000, 800, 800}, {10000, 10000, 8000, 8000}. The unmet demand of the last visited settlements (shelters) of each vehicle route come from {0, 8, 4, 2, 7, 1, 0, 1, 1, 2, 3, 9, 8, 7, 6, 10, 5, 8, 5, 5, 2, 5, 7, 4, 8, 6, 7, 0, 4, 2}.

Assume Pop (population size) = 100, GAPP (generation gap probability) = 0.9, maxgen (Maximum repeatedly algebra) = 200, $p_c$(probability of crossover) in the earlier stage is 0.5, in the later stage is 0.7. $p_m$ (probability of metamorphosis) in the earlier stage is 0.09, in the later stage is 0.02. Weight of time and cost are respectively 0.8 and 0.2. According to the above algorithm, using MATLAB M language programming calculation, running the program 10 times in the Intel CoreTM 2 Duo 1.83G 1G memory notebook computer, and then selecting the best results. The weighted objective value is 18.24, program running time is 181.86s, the LRP optimization scheme as shown in Figure 1. Figure 2 shows the situation of the population optimal solution of genetic algorithm and the variation of the mean value.

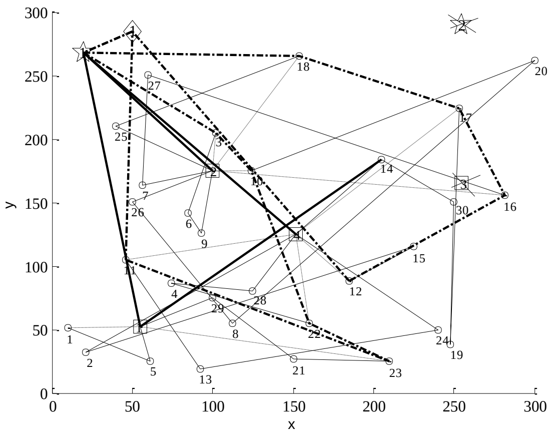


FIGURE 1 One Solution for LRP

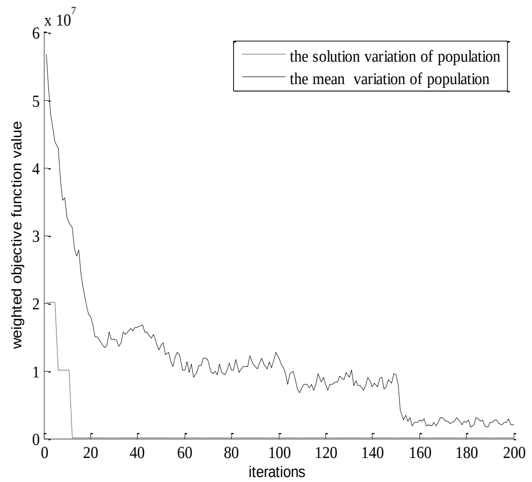


FIGURE 2 A Capability Track Chart of Algorithm

Furthermore, this study tests the robustness of algorithm. We record the optimal value of 10 times operations when the algorithm parameters are fixed. Those operations include 18.57, 19.29, 19.49, 21.05, 19.76, 18.24, 20.71, 18.48, 18.99, and 22.49. The average value of them is 19.70, and the absolute value of the difference between those 10 times operations' optimal value and the average value are respectively 1.14, 0.42, 0.22, 1.34, 0.05, 1.45, 1.00, 1.22, 0.72, 2.78. These values don't have large difference, so the design of the improved genetic algorithm has strong robustness.

When $P_c$ and $P_m$ is fixed, extended population size is 200, maxgen is 400, running for 5 times to get the best result 14.94, the LRP optimization scheme as shown in figure 3. This indicates that the population size and the maximum repeatedly algebra were increased to 200, 400, its target value only decreased a little. Therefore, satisfactory result has appeared in the 100 population size and 200 generation, to increase those two parameters (the population size and the maximum repeatedly algebra) will not make the objective function obviously improved.

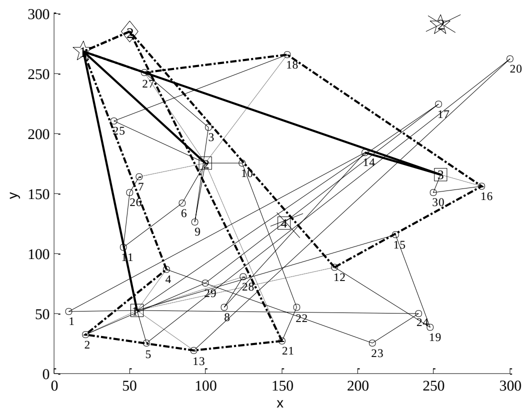


FIGURE 3 Another Solution for LRP

## 5 Conclusions

This study establishes an optimized multi objective fuzzy LRP model, which aims at minimizing the total time of emergency logistics system operation and the total cost of emergency logistics system. We also propose an improved genetic algorithm based on weighted coefficient transformation. After that, we adopt a special real valued coding scheme, the penalty function method and the materials demand segmentation strategy to handle the constraints in the model. The research adopt stochastic universal sampling, restructuring strategy, variable cross rate and variation rate method, in order to prevent the premature convergence of genetic algorithm. Example analysis shows that this model and algorithm can effectively solve the fuzzy LRP of the post-earthquake emergency logistics system.

This study considers about the fuzzy demand of the relief materials of the settlements (shelters), the final (vehicle) visited settlement(shelter) of each route, the possibility of unmet demand, the need of emergency dispatching helicopters from the collector-distributor points to fulfil the needs of this settlement (shelter), and then constructs a single variety emergency materials distribution LPR model. However, as the variety of post-earthquake emergency materials is diverse, the multi-variety LPR needs further research. Besides, the uncertainty of the rescue vehicle's travel time, the time window of the demand of emergency materials and other factors should also be considered.

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