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Research on Fuzzy Dynamic Location-Routing Problem of Victim Search in Flood Disaster

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Abstract

For the dynamic of the number of rescue nodes, the number of person at the rescue node, the number and location of rescue boats, the uncertainty of rescue time (travel time of boats and rescue time of workers), the paper established a dynamic fuzzy rescue time Location-Allocation Problem (LRP) model. To ensure that the decision makers could make new decisions in a very short period of time according to the dynamic data update. A matching hybrid genetic algorithm containing heuristic rule was introduced according the characteristics above. The algorithm used three-stage real-code that represents the search order of boats. The search order and the heuristic rule determined the rescue completed moment of each rescue nodes. The simulated test analysis shows the validity and the correctness of the model and algorithm.

Keywords: *Flood; location-routing problem; dynamic model; hybrid genetic algorithm*

1. Introduction

Flood is an overflowing of a large amount of water beyond its normal confines. Severe floods often make huge losses of life and property. Some sudden floods often result in a large area of land flooded, many people trapped. So the trapped people must be rescued and evacuated to shelters as quickly as possible under limited time, space and resource constraints. In the flood rescue process, the information of rescue nodes and boats is changes with the development of flood relief. The choice of rescue boats routes and which shelters the trapped transfer to must be selected by the rescue boats situation (number of boats, location, capacity, maximum transport distance and speed), the location and capacity of the shelter. The problem involves location-allocation problem of shelters' choice and vehicle-routing problem of boats' routes [1-2]. So it is necessary from the nodes of view of the system to study both of them. A fuzzy dynamic location-routing problem of victim search in flood disaster will be study in the paper. The dynamic means the information of new rescue nodes and boats is dynamic. It could happen at any time in the planning cycle. It could be the travel process, the boats' rescue process at some nodes or the moment after rescue mission was completed. When there was new information, the old solutions often cannot meet the current needs. It needs to be optimized again. Three kinds of dynamic information will be considered: (1) New rescue nodes; (2) The increase of person number at the original nodes. And at the moment, the original person may have not been rescued or parts have already been rescued, also the mission has been finished; (3) The increase of rescue boats.

There is a lot of research about the LRP in general logistics systems [3-6]. But research about LRP in emergency logistics system is not enough. Shelter choice and vehicle routing optimization about emergency logistics system are studied [7-9]. At present there are some literature studies the integrated emergency facility location and vehicle routing

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optimization problem. In total emergency supplies arrived in the shortest time and the objective of minimizing the total cost of the system, the establishment of an emergency supplies fuzzy multi-objective LRP demand optimization model and proposes multi-objective genetic algorithms [10]. In response system resource requirements for each point in time of emergency relief and satisfaction of the largest and the smallest total system cost targets, establish a contingency resource requirements and emergency response time are fuzzy multi-objective LRP model, and proposes a multi-objective genetic algorithm hybrid [11]. Bent and Henteryck propose a simulated annealing approach for assigning customers to vehicles first with minimized number of routes and then use Large Neighbour hood Search method to minimize the total travel cost [12]. Ropke and Pisinger transform all backhaul problems into a given generic form and propose a unified heuristic based on Large Neighborhood Search method incorporating heuristics with different properties and probabilistic move acceptance scheme [13]. Yi W, Özdamar L. Extend the commodity logistics model to integrate the wounded evacuation and emergency medical center location problems and the logistics operations are illustrated by a concrete application on earthquake scenario [14]. Ma Zujun, Dai Ying, Li Shuanglin established a chance-constrained programming model for fuzzy multi-objective open location routing problem with round trips. The objective is to minimize the total time of delivering relief materials to all affected areas and the total system cost [15]. Currently the characteristic of dynamic only appeared in some VRP research [16-18].

LRP of victim Search in flood has its particularity. For example, due to the variability the complexity and the destructive of the disaster, the travel time of rescue boats and the rescue time of the victim is high uncertain; at the beginning of disaster, the number of boats is often limited and may require repeated rescue; the time window of the rescue nodes should be strictly meet and make the maximum efficiency of the entire rescue process; some rescue nodes may require repeated rescue because of the victim number of some nodes may be greater than the capacity of the boats. For the above features, the paper established a fuzzy rescue time Location-Allocation Problem(LRP) model with time windows and designed a hybrid genetic algorithm.

2. Problem Description

When flooding occurs, the rescue routes of boats need to be arranged quickly and the victim should be transferred to the appropriate shelter. The research work of this paper is based on the following assumptions: (1) Assuming there are several boats docking nodes, rescue nodes and shelter nodes, and each boats docking nodes have several different types of rescue boats; (2) The number of the people at some rescue nodes may be greater than the capacity of the boat, it may requires repeated visits. And the rescue should be completed within a certain time window; (3) Different shelter have different capacity limitation; (4) Different types boats have different capacities and transport distance limitations and different speed , the load of boats has no effect on transport distance and speed; (5) Assuming the boats may be in short supply, so boats set out from docking nodes at time zero, search and rescue people to a suitable shelter, according to the needs of the rescue the boats may repeatedly rescue (the fuel would be fill before set out), but does not consider the movement of persons between the shelters; (6) The time boats sail between nodes and the victim rescue are triangular fuzzy numbers; (7) The load factor to boat is $\omega(0 < \omega < 1)$. when the load factor is not less than ω the boat will direct shipment to the appropriate shelter to avoid the pursuit of full load outweigh a longer path. (8) It needs new optimization when there is new information; (9) When it needs to update the decision with new information, there are three types of boats location: at one node, in driving, in a shelter, and the boat state is full load (refers to achieve the load factor required) or not full. There are several ways to solve the problem. ① The boat is rescuing at a node, it will participate in new optimization if the boat cannot full load after completion; ② The boat is rescuing at a node, it will complete the rescue, go to a reasonable shelter and participate in new optimization if the boat will be full load after completion; ③ The boat is in driving and full load, it will go to a reasonable shelter and participate in new optimization; ④ The boat is in driving and not full load, it will participate in new optimization immediately; ⑤ The boat is in a shelter, it will participate in new optimization immediately. The target is pursuit the minimal sum of rescue completed moment of all rescue nodes. The project should give the routes of every boats and the appropriate target shelter of the boats according to the new information updated dynamically, and meet the requirements of boats capacity, transport distance limitations and shelter capacity.

3. Mathematical Model

The symbols are described below:

T is decision period;

τ is the moment need decision, $\tau \in T$;

$B(t)\{k \mid k = 1, 2, \cdots, K\}$ is the set of the boat serial number at the moment of $t(t \in T)$, include the original boats and new boats;

$NB(t)$ is the set of the boat serial number cannot participate rescue at the moment of $t(t \in T)$, include three status: ① The boat is driving in full load, it will participate in optimization after drive to shelter; ② The boat is rescuing at a node, it will complete the rescue, go to a reasonable shelter and participate in new optimization if the boat will be full load after completion; ③ The boat is rescuing at a node, it will participate in new optimization even though it will not be full load after completion;

$YB(t)$ is the set of the boat serial number at the moment of $t(t \in T)$ can participate in new optimization;

$H(t)\{i \mid i = 1, 2, \cdots, I\}$ is the set of rescue nodes at the moment of $t(t \in T)$, include three kind of node: ① The nodes newly appeared; ② The original nodes no boats arrived at the moment of t; ③ The original nodes boats have arrived but the node still have person need to rescue. And there may be nodes that the number of person is increasing in ② and ③;

$N(t)_i$ is the number of person at the rescue node $i(i \in H)$ at the moment of $t(t \in T)$;

$S(t)\{r \mid r = 1, 2, \cdots, R\}$ is the set of shelters at the moment of $t(t \in T)$;

$CS(t)_r$ is the capacity of the shelter $r(r \in S)$ at the moment of $t(t \in T)$, it is the surplus capacity after the corresponding boats in $NB(t)$;

$D(t)\{q \mid q = 1, 2, \cdots, Q\}$ is the set of boats docking nodes at the moment of $t(t \in T)$, the boats docking nodes include four states: ① parked in a node(the boat have arrived the node but it will not full load after completed); ② parked in a shelter; ③ the boat is in driving and not full load, it will participate in new optimization immediately; ④ the new docking nodes;

$\Omega(t) = H(t) \cup S \cup D(t)$ is the set of all nodes at the moment of $t(t \in T)$;

d_{ij} is the distance between the node i and j $(i, j \in \Omega(t))$;

$Need(t)_k$ is the running time before the boat participate in new optimization;

C_k 、 L_k 、 V_k is the capacity constraints, transport distance and average speed limit of boat $k(k \in B)$;

$C(t)_k$ is the residual capacity constraints of boat $k(k \in B(t))$ at the moment of $t + Need(t)_k (t \in T)$;

$L(t)_k$ is the residual transport distance constraints of boat $k(k \in B(t))$ at the moment of $t + Need(t)_k (t \in T)$;

$\tilde{t}_{ijk}$ is the travel time of boat $k(k \in B(t))$ from node $i(i \in \Omega(t))$ to node $j(j \in \Omega(t))$, it is taken as triangular fuzzy number $(T_{1,ijk}, T_{2,ijk}, T_{3,ijk})$, $T_{2,ijk}$ is taken as d_{ijk}/v , $T_{1,ijk}$ is taken as $(d_{ijk}/v)\delta_1$, $T_{3,ijk}$ is taken as $(d_{ijk}/v)\delta_2$, δ_1 and δ_2 could be obtained based on travel environment, rescue experience and the running condition of boats;

$\tilde{t}_i^0$ is time needed rescue a person at node $i(i \in H(t))$, it is taken as triangular fuzzy number $(T'_{1,i}, T'_{2,i}, T'_{3,i})$;

$ROUTE_k\{l = 1, 2, \cdots, R_l\}$ is the set of path belong to boat $k(k \in B(t))$ at the moment of $t + Need(t)_k (t \in T)$. A path of boat $k(k \in B(t))$ is that boat set out from boat docking node(belong to $D(t)$) to a shelter by way of a serial of rescue nodes. The path number is from small to large based on arrival time ;

$R\Omega(t)_{lk}$ is the set of nodes on the path $l(l \in ROUTE_k)$ of the boat $k(k \in B(t))$ at the moment of $t + Need(t)_k (t \in T)$;

$RH(t)_{lk}$ is the set of rescue nodes on the path $l(l \in ROUTE_k)$ of the boat $k(k \in B(t))$ after the moment of $t + Need(t)_k (t \in T)$;

$LR\Omega(t)_{lki}$ is the set of every nodes until node i (include i) on the $k(k \in B(t))$ boats' path $l(l \in ROUTE_k)$ after the moment of $t + Need(t)_k (t \in T)$;

$LRH(t)_{lki}$ is the set of the rescue nodes until node i (include i) on the $k(k \in B(t))$ boats' path $l(l \in ROUTE_k)$ after the moment of $t + Need(t)_k (t \in T)$;

$\tilde{\mathrm{T}}_{lk}$ is the time boat $k(k \in B(t))$ need to complete the rescue task on path $l(l \in ROUTE_k)$;

$\tilde{T}_{lik}$ is the moment boat $k(k \in B(t))$ need to complete the rescue task at node $i(i \in RH(t)_{lk})$ on path $l(l \in ROUTE_k)$;

LT_i is the most late moment of node $i(i \in H(t))$ be rescued; $\tilde{\Pi}$ is the sum of finish time of all nodes;

x_{lijk} equal 1 if boat $k(k \in B(t))$ sailing from node i to node j on the path $l(l \in ROUTE_k)$ after the moment of $t + Need(t)_k (t \in T)$, else it equal 0, ($i \neq j; i,\ j \in R\Omega(t)_{lk}$) ;

y_{lik} is the number of person boat $k(k \in B(t))$ rescued at node $i(i \in RH(t)_{lk})$ on the path $l(l \in ROUTE_k)$ after the moment of $t + Need(t)_k (t \in T)$;

z_{kr} is the number of person boat $k(k \in B(t))$ transported to shelter $r(r \in S(t))$ after the moment of $t + Need(t)_k (t \in T)$.

As the travel time $\tilde{t}_{ijk}$ and the rescue time $\tilde{t}_i^0$ are triangular fuzzy numbers, fuzzy knowledge shows that, $\tilde{\mathrm{T}}_{lk}$ 、 $\tilde{T}_{lik}$ 、 $\tilde{\Pi}$ are also triangular fuzzy number.

$$\tilde{\mathrm{T}}_{lk} = \sum_{i \in R\Omega(t)_{lk}} \sum_{j \in R\Omega(t)_{lk}} x_{lijk} \tilde{t}_{ijk} + \sum_{i \in RH(t)_{lk}} \tilde{t}_j^0 y(t)_{ljk} \ , \ \forall l \in ROUTE_k, \forall k \in B(t)$$

$$\tilde{T}_{lik} = \sum_{j=1}^{l-1} \tilde{\mathrm{T}}_{jk} + \sum_{j \in LR\Omega(t)_{lk}} \sum_{p \in LR\Omega(t)_{lk}} x(t)_{ljpk} \tilde{t}_{ijk} + \sum_{j \in LRH(t)_{lk}} \tilde{t}_j^0 y(t)_{ljk} ,$$

$$\forall i \in RH(t)_{lk}, \forall l \in ROUTE_k, \forall k \in B(t)$$

$$\tilde{\Pi} = \sum_{l \in ROUTE_k} \sum_{i \in RH(t)_{lk}} \sum_{k \in B(t)} \tilde{T}_{lik}$$

The objective aims at minimizing the rescue completed time sum of all nodes.

$$f(x) = \min \tilde{\Pi} \tag{1}$$

S.t.

$$\tilde{T}_{lik} \le LT_i, \forall i \in H(t), \forall l \in ROUTE_k, \forall k \in B(t) \tag{2}$$

$$\sum_{k \in B(t)} z(t)_{kr} \le CS(t)_r, \forall r \in S(t) \tag{3}$$

$$\sum_{i \in RH(t)_{lk}} y(t)_{lik} \le C(t)_k , \forall l \in ROUTE_k, \forall k \in B(t) \tag{4}$$

$$\sum_{i \in R\Omega(t)_{lk}} \sum_{j \in R\Omega(t)_{lk}} x(t)_{lijk} d_{ij} \le L(t)_k , \forall l \in ROUTE_k, \forall k \in B(t) \tag{5}$$

$$\sum_{i \in R\Omega(t)_{lk}} x(t)_{lipk} - \sum_{j \in R\Omega(t)_{lk}} x(t)_{lpjk} = 0 , \forall l \in ROUTE_k, \forall k \in B(t), \forall p \in RH(t)_{lk} \tag{6}$$

$$\sum_{l \in ROUTE_k} \sum_{i \in R\Omega(t)_{lk}} \sum_{k \in B(t)} x(t)_{liqk} = 0, \forall q \in D(t) \tag{7}$$

$$\sum_{l \in ROUTE_k} \sum_{i \in R\Omega(t)_{lk}} x(t)_{lirk} - \sum_{l \in ROUTE_k} \sum_{j \in R\Omega(t)_{lk}} x(t)_{lrjk} \ge 0 , \forall k \in B(t), \forall r \in S(t) \tag{8}$$

Constraints (2) ensure that time windows will be met. (3) is for the shelter capacity constraints; (4) is for boats capacity constraints; (5) is for the transport distance constraints; constraints (6) ensure the continuity of boat traveling ; constraints (7) ensure that no boat sail into a boat docking; constraints (8) guarantee the boat sailed out from a shelter that this boat never sail into.

4. Hybrid Genetic Algorithm

Taking into account the special nature of chromosome code, and the diversity, shortage of the boats(that may require repeated rescue), the victim number of some nodes are large, before generating chromosomes, higher number rescue nodes will be copied and become a number of nodes (called the original node, the nodes were copied and the node itself is named as virtual rescue node and call them homologous nodes), Only one rescue boat will be arranged to a virtual rescue node in order to reach multi-boat access to a rescue node. First copy some point: Note the minimum capacity of all boats as $C_{\min}$. When the number of rescue node i is greater than $C_{\min}$, if N_i is integer multiple of $C_{\min}$, copy node i as $N_i / C_{\min}$ virtual rescue nodes, else copy node i as $[N_i / C_{\min}] + 1$, all the parameters of each virtual rescue node are identical to original node i ; $[\cdot]$ indicates the negative direction rounding. Assuming the virtual rescue nodes set is H' and the number of set is

I' after the copy is complete. Each chromosome consists 3 sub-strings. There is I' gene in sub-string 1st. its value is a natural number randomly select from 1to K (K is the number of rescue boats); The length of sub-string 2nd is I'. its value is a natural number randomly select from 1to I'.There is K gene in sub-string 3rd. its value is a natural number randomly select from 1to K. The length of the chromosome is $I' + I' + K$.

According to the order of sub-string 3rd arrange the boats as the following:

Step1: if $L = 1$, switch to Step2; if $L > 1$ switch to Step3;

Step2: if $0 < N_{H(\tau)_k^1} \leq C(t)_k$, transport the person of node $H(\tau)_k^1$ to reasonable shelter, if the node is virtual, the homologous nodes are updated to 0; if $N_{H(\tau)_k^1} > C(t)_k$, transport $C(t)_k$ people of node $H(\tau)_k^1$ to reasonable shelter, if the node is virtual, the homologous nodes are updated to $N_{H(\tau)_k^1} - C(t)_k$;

Step3: Search the top node in $H(\tau)_k$ that person number greater than zero, if there is not, end, or named node $H(\tau)_k^R$, if $0 < N_{H(\tau)_k^R} < C(t)_k - (1-\omega)C_k$, switch to Step4; if $C(t)_k - (1-\omega)C_k \leq N_{H(\tau)_k^R} \leq C(t)_k$, switch to Step5, if $C(t)_k < N_{H(\tau)_k^R}$ switch to Step6;

Step4: Rescue the person node $H(\tau)_k^R$ to boat, if the node is virtual, the homologous nodes are updated to 0; Search the top node in $H(\tau)_k$ back from $H(\tau)_k^R$ that person number greater than zero, if there is not, transport person rescued to shelter, end, or named node $H(\tau)_k^{R'}$, drive the boat to it, and update the person number to $N_{H(\tau)_k^{R'}} + N_{H(\tau)_k^R}$; order $R = R'$, switch to Step7;

Step5: Rescue the person node $H(\tau)_k^R$ to boat, if the node is virtual, the homologous nodes are updated to 0; Search the top node in $H(\tau)_k$ back from $H(\tau)_k^R$ that person number greater than zero, if there is not, transport person rescued to shelter, end, or named node $H(\tau)_k^{R'}$, drive the boat to reasonable shelter, and go to node $H(\tau)_k^{R'}$, order $R = R'$, switch to Step7;

Step6: Rescue $C(t)_k$ person node $H(\tau)_k^R$ to boat, if the node is virtual, the homologous nodes are updated to $N_{H(\tau)_k^R} - C(t)_k$; Search the top node in $H(\tau)_k$ back from $H(\tau)_k^R$ that person number greater than zero, if there is not, transport person rescued to shelter, end, or named node $H(\tau)_k^{R'}$, drive the boat to reasonable shelter, and go to node $H(\tau)_k^{R'}$, order $R = R'$, switch to Step7;

Step7: if $0 < N_{H(\tau)_k^R} < \omega C_k$, switch to Step4; if $\omega C_k \leq N_{H(\tau)_k^R} \leq C_k$ switch to Step5; if $C_k < N_{H(\tau)_k^R}$, switch to Step6;

5. Simulated Test

There are 20 rescue nodes,8 shelters, 3 boat docking and 5 boats. Data in Table1-Table4:

Table 1. Nodes of Rescues

NO.	x-coordinate/km	Y-coordinate/km	Number of victim	The time rescue one	The last time rescue
1	3	42	3	(0.78,0.90,1.08	2
2	16	48	2	(0.78,0.90,1.08	2
3	19	69	36	(0.78,0.90,1.08	5
4	37	53	5	(0.78,0.90,1.08	2
5	49	64	5	(0.78,0.90,1.08	4

6	55	79	5	(0.78,0.90,1.08	3.5
7	47	87	4	(0.78,0.90,1.08	3
8	40	89	9	(0.78,0.90,1.08	4
9	41	9	2	(0.78,0.90,1.08	3.5
10	47	3	8	(0.78,0.90,1.08	4
11	45	16	25	(0.48,0.60,0.78	4
12	54	3	9	(0.48,0.60,0.78	2
13	55	21	3	(0.48,0.60,0.78	3
14	61	30	2	(0.48,0.60,0.78	3.5
15	64	52	31	(0.48,0.60,0.78	4
16	72	45	9	(0.48,0.60,0.78	5
17	74	31	7	(0.48,0.60,0.78	4
18	85	60	18	(0.48,0.60,0.78	5
19	88	66	8	(0.48,0.60,0.78	2
20	93	62	2	(0.48,0.60,0.78	3

Table 2. Shelters

NO	x-coordinate/km	Y-	Capacity
1	30	28	50
2	75	80	50
3	12	60	100
4	38	77	100
5	62	13	100
6	68	33	50
7	87	49	50
8	95	97	50

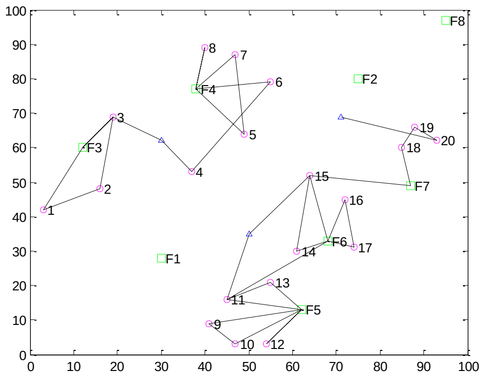
Table 3. Boat Docking

NO	coordinate/k	The NO. Of
1	（30, 62）	1、2
2	（50, 35）	3、4
3	（71, 69）	5

Table 4. Boats

NO.	Transport distance/km	Capacit	Speed km/h
1、	120	10	60
2、	100	20	50
5	90	30	40

The algorithm parameters are as follows: num =100； $MAXGEN$ =300； $\delta_1 = 0.9$ ； $\delta_2 = 1.2$ ； $\alpha = 0.9$ ； $\beta = 1$ ； $\omega = 0.8$ ； $q = 20$ ； Crossover rate is 0.9; mutation rate is 0.05.



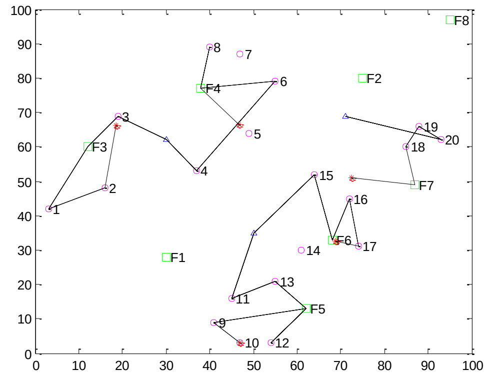


Figure 1. The Best Results in $\tau = 2$ **Figure 2. The Location of Boats at Time τ**

Figure 1 is the best result when $\tau = 0$. The routes and every rescue nodes' completed time won't be given owing to space. Figure 2 is the location (* present the location) of boats when $\tau = 2$. The dates of $\tau = 2$ won't be given, include the performance of boats' rescue mission, the number of person were still in rescue nodes, all kind of relevant dates of the boat, the residual capacity of shelters.

The new dates appeared in $\tau = 2$ in Table 5-Table 6. The nodes 1,5,7, were the original nodes that the number of person was increased.

Table 5. Nodes of Rescues Appeared in $\tau = 2$

NO.	x-coordinate/km	Y-coordinate/km	Number of victim	The time rescue one person/min	The last time rescue completed/h
1	3	42	2	(0.48,0.60,0.78)	1
2	22	43	8	(0.48,0.60,0.78)	2
3	15	72	22	(0.48,0.60,0.78)	4
4	37	85	3	(0.48,0.60,0.78)	2
5	49	64	7	(0.78,0.90,1.08)	2
6	55	18	15	(0.78,0.90,1.08)	2.5
7	61	30	4	(0.78,0.90,1.08)	3
8	59	3	2	(0.78,0.90,1.08)	2
9	78	19	3	(0.78,0.90,1.08)	3.5
10	82	28	25	(0.78,0.90,1.08)	4

Table 6. Boats Appeared in $\tau = 2$

NO.	(X,Y) /km	Transport distance/km	Capacity	Speed km/h
6	(20, 35)	120	10	60

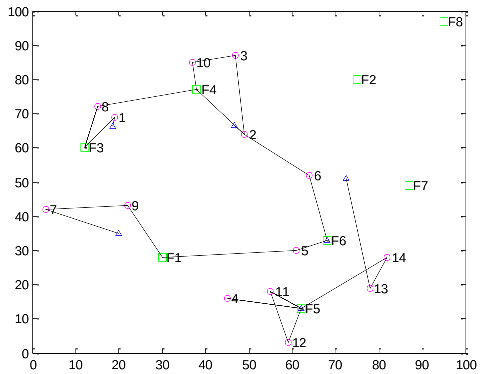


Figure 3. The Best Results in $\tau = 2$

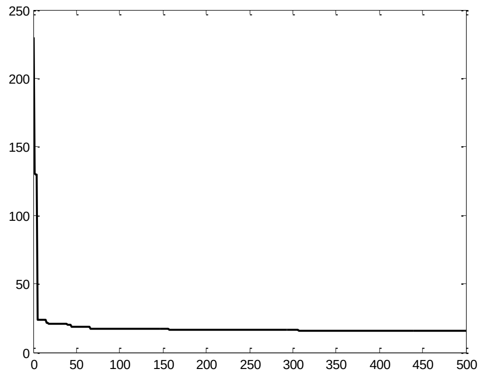


Figure 4. The Convergence State of Algorithm

The dates appeared in $\tau = 2$ and rescue mission have not completed will be combined to optimize. Figure 3 is the best result in $\tau = 2$. Figure 4 is the convergence state of algorithm. About the completed time, there will be several completed time to one rescue node that indicate the node was not rescued by only one boat.

6. Conclusion

Because of the dynamic of dates about person and boats, a fuzzy dynamic location-routing problem of victim search in flood disaster with time windows have been established in the paper. Three kinds of dynamic information have been considered: (1) New rescue nodes; (2) The increase of person number at the original nodes; (3) The increase of rescue boats. The objective aims at minimizing the rescue completed time sum of all rescue nodes. The boats were various types and shortage that they will be required rescue repeatedly. The travel time and rescue time was fuzzy. A hybrid genetic algorithm contains heuristic rules was designed. The simulated test analysis demonstrates indicates that the model and the algorithm provides a method for the decision of search for victims in Flood.

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