Evacuation and Settlement Model of Personnel in Major Flood Disasters and Its Application

Yanping Wen¹, Naiping Zhang¹

¹School of Safety Science and Emergency Management, Wuhan University of Technology, Wuhan, Hubei province, 430070, China

¹Naiping Zhang (1969-), Doctor of Management, Associate Professor, School of Safety Science and Emergency Management, Wuhan University of Technology, Mainly engaged in public safety and emergency management, innovation management and other research.

*Corresponding author’s e-mail: zhping@126.com

Abstract. In order to select the most suitable rescue boat stop and personnel resettlement point for rapid evacuation and placement of "isolated island" victims. According to the characteristics of "isolated island" problem, considering the factors of total evacuation time and total evacuation cost, a dual-objective emergency evacuation model is constructed. By using the method of fuzzy matrix, the dual-objective problem is transformed into a single-objective problem. Finally, the Hungarian method is used to solve the problem. The results of an example show that the model can realize the selection of the best berth point and personnel placement point.

1. statement of problem
In recent years, floods have occurred frequently, causing huge casualties and economic losses to the people. Due to continuous heavy precipitation, some areas even experienced landslides and mudslides. Floods flooded the dams, and the terrain was low. The roads and bridges leading to the outside world were flooded and became "isolated islands". In July 2016, Liangquan Township, Wangjiang County, Anhui Province was affected by heavy rain, and the levee was flooded. It turned into a vast ocean, and residents were trapped on the roof. In June 2018, Wenxian County of Gansu Province suffered from heavy precipitation, large blocks were flooded, and 15,000 people needed emergency transfer. In September 2018, residents of Rao Town, Shantou Valley, Guangzhou were trapped by floods, roads were unable to pass, water and electricity were cut off, and the safety of residents' lives and property was threatened and urgently needed to be transferred. The occurrence of floods and disasters has seriously affected the lives of the people and hindered social development and economic construction. However, after the flood disaster, scientific and reasonable organization and evacuation of personnel, implementation of emergency rescue activities, can effectively curb the deterioration of the disaster situation, and reduce or even avoid the probability of secondary disasters, is the key to reducing economic losses and casualties.

2. Research status
At present, most of the researches on flood disasters at home and abroad are directed at material distribution, and there is relatively little research on evacuation of personnel after disasters. In response to the problem of evacuation of personnel. Shifeng Niu [1] and others proposed the concept of partitioned
data, designed the method of partitioning the affected area, and introduced BP neural network to establish an evacuation traffic prediction model based on the partitioned set data, which has good effect; Lei Zhang [2] and others based on the characteristics of urban water logging conditions; comprehensive consideration of emergency efficiency, rescue reliability, rescue time and other factors, built a multi-target rescue assignment model, and solved the model through the inverse point method; Hang Shen [3] and others proposed the “point-line-surface” flood disaster avoidance idea, combined with GIS spatial analysis technology, adopting the hybrid split evacuation mode, aiming at the shortest total evacuation time, comprehensively considering multiple factors, and constructing an evacuation network model; Liu Yongzhi [4] et al. proposed a combination of GIS-based storm surge flood risk system and avoidance traffic simulation model OREMS for the refuge transfer process of dam break simulation flood disaster, but only static traffic assignment was used in this paper, and there is no real-time with GIS system. Information exchanged has certain limitations on emergency evacuation route planning; For the problem of “isolated island”; Chen Ling [5] et al. propose an optimization algorithm based on dynamic network flow and applied it to the safety evacuation research of flood storage area. Through evacuation simulation, sensitivity analysis, scene analysis and other research, the evacuation optimal path and estimated evacuation time are obtained, which has certain learning reference value.

3. Model establishment
Since the “isolated island” problem is different from terrestrial disasters, after the flood disaster occurs, it is impossible to evacuate personnel of the disaster site to the resettlement point by relying on the single transportation mode of the vehicle. At this time, the water transport tool—the rescue boat needs to be considered. In advance, some resettlement points are set up in places that are not easily eroded by floods and convenient for transportation. The capacity meets the resettlement of a disaster-stricken point; several stops are arranged in places where rescue boats are docked and people are up and down; When a disaster occurs at a disaster point, the emergency team immediately responds and gathers near the stop. The rescue boat is responsible for receiving the affected personnel from the disaster point to the stop point, and then the land vehicle sends the personnel to the resettlement site, regardless of the location. The change in speed after the vehicle is loaded by the personnel.

Due to the special nature of emergency evacuation after the disaster, once a flood disaster occurs, the first time must be the fastest time, the minimum casualties are the target. Usually, economic expenditure is not the key consideration, but it is not at the expense of unlimited economy, resulting in excessive resources are idled and wasted, so emergency rescue should also consider its cost to some extent. By comparing the timeliness and economy of each emergency team from the resettlement point to the disaster-affected points to recover the affected personnel, find the optimal resettlement site and the rescue boat stop.

3.1 flood evacuation network
Assume that the evacuation network G(I, J, K, M, N), the stops set I = {i | i = 1, 2, ...}, the disaster points set J = {j | j = 1, 2, ...}, the settlement points set K={k | k=1,2,...}, the rescue boats set M={m | m=1,2,...}, the rescue vehicles set N={n | n=1 , 2, ... }. Then the flooding network diagram is shown in Figure 1.
3.2 Analysis of flood evacuation model

The flood evacuation model considers the minimum evacuation time and the lowest total cost.

1) Total time sub-goal

\[
\text{Min } Z_1 = 2 \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{m=1}^{M} x_{ijm} \cdot t_{ijm} + \sum_{i=1}^{I} \sum_{k=1}^{K} \sum_{n=1}^{N} x_{ikn} \cdot t_{ikn} \quad (1)
\]

2) Total cost sub-goal

\[
\text{Min } Z_2 = 2 \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{m=1}^{M} x_{ijm} \cdot a \cdot t_{ijm} + \sum_{i=1}^{I} \sum_{k=1}^{K} \sum_{n=1}^{N} x_{ikn} \cdot b \cdot t_{ikn} + W_1 + W_2 \quad (2)
\]

a, b in sub-objectives (1) and (2) respectively represent the cost of the rescue boat and the vehicle unit time; \( t_{ijm} \) represents the time taken by the rescue boat \( m \) from the disaster point \( j \) to the stop point \( i \); \( t_{ikn} \) indicates the time taken by the vehicle \( n \) to transport the affected person from the stop point \( i \) to the resettlement point \( k \); \( W_1 \) indicates that the rescue boat \( m \) takes the extra cost from the stop point \( i \) to the disaster point \( j \), and returns the return of the disaster victim to the stop point \( i \), and \( W_2 \) represents the additional cost of the vehicle \( n \) from the stop point \( i \) to the resettlement point \( k \). \( x_{ijm} \) is a 0-1 variable. If the \( m \)th emergency boat completes the task from the stop point \( i \) to the disaster point \( j \), and the transport victims return to the stop \( i \), it is 1, otherwise 0; Similarly, \( x_{ikn} \) is also a 0-1 variable, and 1 indicates that the \( n \)th car completes the task of transporting the affected person from the stop \( j \) to the disaster point \( k \).

For the selection of the evacuation problem after the flood, the most ideal solution is to select the appropriate stop and resettlement points, which can minimize the total time and minimize the total cost to transport the affected personnel safely and timely to the resettlement site. Multi-objective expressions can be expressed as

\[ M = \{ \text{Min } Z_1, \text{Min } Z_2 \} \]

4. model solving

This model is a multi-objective programming problem. Each target is subjected to dimensionless processing using the extremum method \([6]\), and then the fuzzy relation matrix is combined with the Hungarian method \([7]\) to obtain the optimal solution.

4.1 dimensionless processing

Let the rescue boat \( m \) take the time from the stop point \( i \) to the disaster point \( j \) as \( t_{ij} \), the corresponding
initial time matrix is $F_1$, the dimensionless quantity is $F_1^*$; And the economic cost of the rescue boat $m$ from the stop point $i$ to the disaster point $j$ is $p_{ij}$, the corresponding initial cost matrix is $P_1$, and the dimensionless quantity is $P_1^*$.

$$F_1 = \begin{bmatrix} (1,1) & \cdots & (1,j) \\ \vdots & \ddots & \vdots \\ (1,1) & \cdots & (i,j) \end{bmatrix}, \quad F_1^* = \frac{t_{ij} - t_{ij,\text{min}}}{t_{ij,\text{max}} - t_{ij,\text{min}}} 1 \leq i \leq l, 1 \leq j \leq J$$

$$P_1 = \begin{bmatrix} (1,1) & \cdots & (1,j) \\ \vdots & \ddots & \vdots \\ (1,1) & \cdots & (i,j) \end{bmatrix}, \quad P_1^* = \frac{p_{ij} - p_{ij,\text{min}}}{p_{ij,\text{max}} - p_{ij,\text{min}}} 1 \leq i \leq l, 1 \leq j \leq J$$

It is assumed that the time taken by the emergency vehicle $n$ from the stop point $i$ to the resettlement point $k$ is $t_{ik}$, the corresponding initial time matrix is $F_2$, the dimensionless quantity is $F_2^*$; and the economic cost is $p_{ik}$, its corresponding initial cost matrix is $P_2$, and the dimensionless quantity is $P_2^*$.

$$F_2 = \begin{bmatrix} (1,1) & \cdots & (1,k) \\ \vdots & \ddots & \vdots \\ (1,1) & \cdots & (i,k) \end{bmatrix}, \quad F_2^* = \frac{t_{ik} - t_{ik,\text{min}}}{t_{ik,\text{max}} - t_{ik,\text{min}}} 1 \leq i \leq l, 1 \leq k \leq K$$

$$P_2 = \begin{bmatrix} (1,1) & \cdots & (1,k) \\ \vdots & \ddots & \vdots \\ (1,1) & \cdots & (i,k) \end{bmatrix}, \quad P_2^* = \frac{p_{ik} - p_{ik,\text{min}}}{p_{ik,\text{max}} - p_{ik,\text{min}}} 1 \leq i \leq l, 1 \leq k \leq K$$

### 4.2 Weighting

Assuming that the weights of the time sub-objectives and the cost sub-goals are $\gamma_1$ and $\gamma_2$, respectively, the evacuation problem after flooding can be expressed as

$$M = \{\text{Min } Z_1, \text{Min } Z_2\} = \gamma_1 \cdot F + \gamma_2 \cdot P$$

### 4.3 Weight coefficient determination

The weighting factor is determined by the expert scoring method. Through the anonymous way to consult relevant experts, experts based on past experience and subjective judgment, statistics, collation, analysis of expert opinions, determine the weight coefficient of time and economic costs.

### 4.4 Hungarian method solving model

The Hungarian law is a common method for solving the assignment problem. It is characterized by considering how to assign $m$ jobs to $n$ people, making the most efficient assignment problem.

### 5. Example analysis

Suppose there are three disaster points: $D_1$, $D_2$, $D_3$; five stops are preset: $S_1$, $S_2$, $S_3$, $S_4$, $S_5$; four resettlement points: $P_1$, $P_2$, $P_3$, $P_4$. (The cost of the rescue boat unit time is 20,000 yuan, the additional cost is 0.3 million yuan; the cost of the vehicle unit time is 30,000 yuan, and the additional cost is 0.5 million yuan)

Assume that the data obtained by the expert scoring method is shown in Table 1.

| Expert1 | Expert2 | Expert3 | Expert4 | Expert5 | Expert6 | average | Proportion |
|---------|---------|---------|---------|---------|---------|---------|------------|
| time    | 80      | 85      | 70      | 90      | 88      | 81      | 0.81       |
| cost    | 20      | 15      | 30      | 10      | 10      | 12      | 25         | 19         | 0.19       |

From the table, $\gamma_1 = 0.81$, $\gamma_2 = 0.19$.

#### 5.1 Disaster point to stop (rescue boat)

| disaster site $D_1$ | disaster site $D_2$ | disaster site $D_3$ |
|---------------------|---------------------|---------------------|
| Stop $S_1$          | 0.60                | 0.75                | 0.40                |
| Stop $S_2$          | 0.50                | 0.60                | 0.65                |
As can be seen from Table 2, the initial time matrix $F_1$, and the dimensionless processing is the matrix $F_1^*$ as follows.

$$F_1 = \begin{bmatrix}
0.60 & 0.75 & 0.40 \\
0.50 & 0.60 & 0.65 \\
0.35 & 0.50 & 1.20 \\
0.45 & 0.80 & 0.50
\end{bmatrix}, \quad F_1^* = \begin{bmatrix}
0.33 & 0.53 & 0.07 \\
0.20 & 0.33 & 0.40 \\
0.10 & 0.85 & 0.73 \\
0.13 & 0.60 & 0.20
\end{bmatrix}$$

As can be seen from Table 3, the initial cost matrix $P_1$, and dimensionless processing is the matrix $P_1^*$ as follows.

$$P_1 = \begin{bmatrix}
1.50 & 1.80 & 1.10 \\
1.30 & 1.50 & 1.60 \\
2.50 & 2.30 & 2.10 \\
1.00 & 1.30 & 2.70 \\
1.20 & 1.90 & 1.30
\end{bmatrix}, \quad P_1^* = \begin{bmatrix}
0.29 & 0.47 & 0.06 \\
0.18 & 0.29 & 0.35 \\
0.88 & 0.76 & 0.65 \\
0 & 0.18 & 1.00 \\
0.18 & 0.53 & 0.18
\end{bmatrix}$$

$$M_1 = y_1 \cdot F_1^* + y_2 \cdot P_1^* = 0.81F_1^* + 0.19P_1^* = \begin{bmatrix}
0.3224 & 0.5186 & 0.0681 \\
0.1962 & 0.2673 & 0.3905 \\
0.9772 & 0.8491 & 0.7148 \\
0.1395 & 0.5867 & 0.1962
\end{bmatrix}$$

Using the Hungarian method, gradually transform the matrix $M_1$ until the result is:

$$\begin{bmatrix}
0.3224 & 0.5186 & 0.0681 \\
0.1962 & 0.2673 & 0.3905 \\
0.9772 & 0.8491 & 0.7148 \\
0.1395 & 0.5867 & 0.1962
\end{bmatrix} \rightarrow \begin{bmatrix}
1829 & 3224 & 0 & 0 & 0 \\
567 & 711 & 3224 & 0 & 0 \\
8377 & 6529 & 6467 & 0 & 0 \\
3905 & 1281 & 0 & 0 & 0
\end{bmatrix} \rightarrow \begin{bmatrix}
1829 & 3224 & 0 & 0 & 0 \\
567 & 711 & 3224 & 0 & 0 \\
8377 & 6529 & 6467 & 0 & 0 \\
3905 & 1281 & 0 & 0 & 0
\end{bmatrix}$$

It can be seen from the optimal route is the disaster point $D_1 \rightarrow \text{stop point S3}$, the disaster point $D_2 \rightarrow \text{stop point S5}$, the disaster point $D_3 \rightarrow \text{stop point S4}$.

### 5.2 Stop to the resettlement point (vehicle)

| Stop | resettlement point $P_1$ | resettlement point $P_2$ | resettlement point $P_3$ | resettlement point $P_4$ |
|------|--------------------------|--------------------------|--------------------------|--------------------------|
| $S_1$ | 2.0                      | 2.4                      | 5.2                      | 4.3                      |
| $S_2$ | 3.2                      | 2.9                      | 4.7                      | 5.3                      |
| $S_3$ | 1.8                      | 3.9                      | 3.2                      | 2.7                      |
| $S_4$ | 1.3                      | 5.1                      | 6.3                      | 5.8                      |
| $S_5$ | 2.6                      | 5.6                      | 2.4                      | 7.1                      |

| resettlement point $P_1$ | resettlement point $P_2$ | resettlement point $P_3$ | resettlement point $P_4$ |
|--------------------------|--------------------------|--------------------------|--------------------------|
| $S_1$ | 6.5                      | 7.7                      | 16.1                     | 13.4                     |
| $S_2$ | 10.1                     | 9.2                      | 14.6                     | 16.4                     |
From Table 4, the initial time matrix $F_2$, dimensionless processing is the matrix $F_2^*$ as follows.

$$
F_2 = \begin{bmatrix}
2.0 & 2.4 & 5.2 & 4.3 \\
3.2 & 2.9 & 4.7 & 5.3 \\
1.8 & 3.9 & 3.2 & 2.7 \\
1.3 & 5.1 & 6.3 & 5.8 \\
1.6 & 5.6 & 2.4 & 7.1 \\
\end{bmatrix}
$$

$F_2^* = \begin{bmatrix}
0.12 & 0.19 & 0.67 & 0.52 \\
0.33 & 0.28 & 0.59 & 0.69 \\
0.09 & 0.45 & 0.33 & 0.24 \\
0 & 0.66 & 0.86 & 0.78 \\
0.06 & 0.74 & 0.19 & 1.00 \\
\end{bmatrix}
$

As can be seen from Table 5, the initial cost matrix $P_2$, dimensionless processing is the matrix $P_2^*$ as follows.

$$
P_2 = \begin{bmatrix}
6.5 & 7.7 & 16.1 & 13.4 \\
10.1 & 9.2 & 14.6 & 16.4 \\
5.9 & 12.2 & 10.1 & 8.6 \\
4.4 & 15.8 & 19.4 & 17.9 \\
8.3 & 17.3 & 7.7 & 21.8 \\
\end{bmatrix}
$$

$P_2^* = \begin{bmatrix}
0.12 & 0.19 & 0.67 & 0.52 \\
0.33 & 0.28 & 0.59 & 0.69 \\
0.09 & 0.45 & 0.33 & 0.24 \\
0 & 0.66 & 0.86 & 0.78 \\
-0.22 & 0.74 & 0.19 & 1.00 \\
\end{bmatrix}
$

Using the Hungarian method, gradually transform the matrix $M_2$ until the result is:

$$
M_2 = \gamma_1 \cdot F_2^* + \gamma_2 \cdot P_2^* = 0.81F_2^* + 0.19P_2^* = \begin{bmatrix}
0.1200 & 0.1900 & 0.6700 & 0.5200 \\
0.3300 & 0.2800 & 0.5900 & 0.7000 \\
0.0900 & 0.4500 & 0.3300 & 0.2400 \\
0 & 0.6600 & 0.8600 & 0.7800 \\
0.0904 & 0.7400 & 0.1900 & 1.0000 \\
\end{bmatrix}
$$

From $\begin{pmatrix} 1 & 2 & 3 & 4 & 5 \end{pmatrix}$, the optimal route is the stop S1 $\rightarrow$ the resettlement point P4, the stop S2 $\rightarrow$ the resettlement point P1, stop point S3 $\rightarrow$ the resettlement point P1 (the resettlement point P5 is a virtual point, so it can be evacuated to the resettlement point P1), the stop S4 $\rightarrow$ the resettlement point P3, and the stop S5 $\rightarrow$ the resettlement point P2.

In summary, if the disaster point is D1, the stop selects S3, and the resettlement point is P1; if the disaster point is D2, the stop selects S5, and the resettlement point is P2; if the disaster point is D3, the stop selects S4, and the resettlement point is P3.

6. Conclusion

The author builds a two-objective rescue assignment decision model for the "island" problem caused by flooding, and finally uses the Hungarian method to solve the model. By way of example, the model can find suitable stops and resettlement points, which is feasible.

The model requires two Hungarian algorithms, which need to be corrected and improved in future research using measured evacuation data.

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