Research on Selection of General Aviation Rescue Airports

Bin Hu¹, Fang Pan²* and Yunfei Zhang¹

¹College of Civil Aviation, Nanjing University of Aeronautics and Astronautics, Nanjing, China
²School of Economics and Management, Nanjing Tech University, Nanjing, China, corresponding author,
Email: carolpan@njtech.edu.cn

Abstract. Considering the complex factors affecting rescue in natural disaster-prone areas in China and the high efficiency of general aviation rescue, this paper combines a hierarchical analysis model and a P-median model to establish a two-stage hierarchical selection. A greedy take-away heuristic algorithm is proposed to combine the qualitative and quantitative analysis of the airport selection method. Finally, the Longmenshan earthquake zone was selected for analysis to verify the practicability of the method.

Keywords. Aviation rescue, Heuristic algorithm, Quantitative analysis, Airport.

1. Introduction
The development of general aviation (GA) industry is booming in recent years. Using GA to solve the problem of emergency rescue after the disaster has become an effective method for large-scale operation. However, judging from several major natural disasters in recent years, actual GA emergency rescue exposed the weakness of China's 3D rescue capability [1].

2. Literature Review
In China, qualitative research dominates [2-3]. Zhu Yan conducted a quantitative research using an analytic hierarchy model, which took into account seven factors affecting the needs of disaster-stricken areas [4]. However, the number of factors considered is relatively small. There have been some airport selection studies using P-median models. For example, He Xiaorong [5] adopted a two-level emergency system location model to distinguish facilities according to the types and capabilities of emergency assistance they can provide. However, in the analysis process, only a few airports are studied for research. The actual problems caused by the regional topography, environment, climate, and facilities are neglected. There are only a few articles directly studying the specific selection method of GA airports outside of China. Hogan.K and Revelle.C adopted the maximum coverage model to solve Adenso-Diaz. B’s research problems and proposed two alternative coverage models. In most selection problems, the classical addressing models include maximum coverage model, P-median model, P-center model, and set coverage model [6-7]. In this paper, a combination of AHP model and P-median model is used for research. Both the demand of disastrous areas and the airports are taken into account.
3. Selection of Rescue Airport Based on AHP and P-Median Model

3.1. Hierarchical Analysis Model based on the Two-layer Rule Hierarchy

6 influencing factors are selected: topographical factors, probability of disasters, meteorological conditions, convenience of ground transportation, population, and efficiency of supplies delivery. 10 sub-influencing factors such as altitude, geological conditions, natural disaster occurrence probability, and visibility are considered in detail. A hierarchical analysis model based on the two-layer rule hierarchy is constructed to obtain the total level sequence of the rule hierarchy C as well as weight vector for each disaster area. The aim is to find out the urgency lev of the emergency rescue once the disaster occurs.

3.2. Weights Analysis of Airport Construction Demand for the Disaster Areas and Its Neighborhood

The whole structure consists of target layer A, rule hierarchy B, rule hierarchy C, and scheme layer P. First, determine the relative importance of the six influencing factors, obtain a judgment matrix among the influencing factors Bi(i=1,2,3,4,5,6) called the A-B judgment matrix [4, 8].

The eigenvectors of the matrix A-B is calculated by Matlab, and can be obtained by normalization: [0.0794 0.2781 0.0333 0.0794 0.4503 0.0794]. Maximum eigenvalue $\lambda_{max} = 6.0772$. The consistency check equation is:

$$CR = CI / RI$$

$$\text{Among the equation, } CI = \frac{\lambda_{max} - n}{n-1}, \quad n \text{ is the order of the judgment matrix, } RI \text{ is the average random consistency index.}$$

Calculated from equation (1): $CR$ of A-B matrix = 0.0125 < 0.1, the matrix has satisfactory consistency and no adjustment is needed. In the same way, the judgment matrix, eigenvector, and maximum eigenvalue of the influencing factors in rule hierarchy C and B can be obtained. Using Matlab, the maximum eigenvalues and eigenvectors of each judgment matrix are calculated and normalized. It can be seen that each matrix has satisfactory consistency and no adjustment is required. Next, calculate the relative importance weight of the rule hierarchy C relative to the target layer, that is, the total sequencing of the hierarchy. Consistency test shows that the calculation results of the hierarchical sequencing satisfy the consistency, and can be used as the weight of each influencing factor in the rule hierarchy C in the case analysis.

3.3. Airport Selection Method based on P-median Model

3.3.1. P-median Model. In order to facilitate the construction of GA airport selection model, the following basic assumptions are proposed: Each disaster area (hereinafter referred to as DA), and candidate airports are treated as geometric points and the locations of the candidate airports are known. Each rescue airport (hereinafter referred to as RA) is independent of each other, and there is no relationship of mutual cooperation for emergency rescue. The distance from the DA to the RA is calculated as a straight line. Rescue services provided by all RAs are homogeneous, and equipment such as helicopters are working at the same efficiency. When a RA is occupied by a DA, if there is demand in another DA and no rescue equipment is available, it enters the waiting queue. The scale of needs of the DA will not be considered, i.e., the needs of the DA to be rescued can be met by the corresponding RA. The degree of demand in each DA is represented by the weight vector calculated by the analytic hierarchy model.

The P-median model can be described by a mathematical formula, and the sum of the product of the weight of the affected site and the distance between DA and RA is used as the objective function that needs to be optimized. The objective function of the P-median model is:

$$\min Z = \sum_{i \in N} \sum_{j \in M} w_i d_{ij} y_{ij}$$

(2)
Constraint conditions are as followed:

\[ \sum_{j \in M} y_{ij} = 1, \quad i \in N \]  \hspace{1cm} (3) 

\[ \sum_{j \in M} x_j = p \]  \hspace{1cm} (4) 

\[ y_{ij} \leq x_j, \quad i \in N, \quad j \in M \] \hspace{1cm} (5) 

\[ x_j \in \{0,1\}, \quad j \in M \] \hspace{1cm} (6) 

\[ y_{ij} \in \{0,1\}, \quad i \in N, \quad j \in M \] \hspace{1cm} (7) 

where: \( N \) is the set of \( n \) DAs in the research object, \( N = \{1,2,\ldots,n\} \). \( w_i \) is the weight of the \( i \)th DA. \( M \) is the set of \( m \) candidate RAs in the research object, \( M = \{1,2,\ldots,m\} \). \( d_{ij} \) represents the linear distance from the DA \( i \) to the RA \( j \). \( p \) is the number of planned RAs (\( p \leq m \)). \( y_{ij} \) indicates 1 when the DA \( i \) is provided with rescue services by the RA \( j \), otherwise 0. \( D \) \( x_j \) indicates 1 when the RA is established at \( j \), otherwise 0. Equation (2) is the objective function of the P-median model; constraint condition (3) guarantees that there is only one RA for each DA to provide rescue services; equation (4) limits the total number of RA top; Equation (5) effectively guarantees that each DA has a corresponding RA for rescue [9-10].

3.3.2. Solve the P-Median Model Problem with a Greedy Take-Away Heuristic Algorithm. Using greedy take-away heuristic algorithm to calculate the P-median model problem is more classic to solve the selection problem. The algorithm and model have never been used in civil aviation's research on the selection of airports. This paper combines the algorithm with the analytic hierarchy process to propose a new and more scientific method of airport selection.

4. Case study

Sichuan is one of the regions with complicated terrain and frequent geological disasters. A typical one is the Longmenshan earthquake zone. This zone has a general trend from northeast to southwest, as shown by the red arrow in figure 1. In this paper, the Longmenshan earthquake zone covering the area of Wenchuan County and the surrounding area of about 72,619 km\(^2\) are selected for research. By studying historical data, Baoxing (BX), Luding (LD), Hongya (HY), Qionglai (QL), Dujiangyan (DJY), Mianzhu (MZ), Wenchuan (WC) and Mao (MX) are selected. The affected area, as shown by the cross in figure 2, is the center point of each area.

Figure 1. Satellite picture of Longmenshan earthquake zone.

Figure 2. Disaster area and candidate airports.
Figure 3. Hierarchical analysis model for determining the optimal selection influential factors of scheme layer P.

Taking into account the practical feasibility of GA emergency rescue, the basic conditions for candidate airports should be a civil aviation airport or a GA airport, or a city that is about to build an airport in the next few years. It is known that Chengdu (CD), Xinjin (XJ), and Guanghan (GH) already have civil aviation airports or GA airports; after referring to "Sichuan Province GA Airport Plan (2016-2030)", Mianyang, Guanghan, Chengdu, Xinjin, Leshan, Meishan and Ya'an have been selected as candidate RAs.

4.1. Using Analytic Hierarchy Model to Calculate the Total Hierarchical Sequencing of the Disaster Points

The analytic hierarchy model that clarifies the most influential factors of the scheme layer P is shown in figure 3.

4.1.1. Analysis of the relative importance of each disaster area to each influencing factor. Consider the relative importance of the DA P1 to P8 for each influencing factor in the rule hierarchy C, establish a corresponding judgment matrix. All the matrices have satisfactory consistency and no adjustment is required.

4.1.2. Calculate the total hierarchical sequence of the Das. Combining with the hierarchical total sequence of the rule hierarchy C of PART3, the total hierarchical sequence of the P can be obtained as the weight of each DA. Consistency test for Wi: [0.0537 0.1351 0.1038 0.1369 0.1558 0.1962 0.0805 0.1379]; $CI = \sum_{i=1}^{10} c_i(CI)_i = 0.0057$, $RI = \sum_{i=1}^{10} c_i(RI)_i = 1.41$, Then, $CR = \frac{CI}{RI} = 0.00404 < 0.1$. Therefore, the calculation result of the hierarchical sequence satisfies the consistency, and can be used as the weight vector of the DAs P1 to P8.

4.2. Using P-median Model to Analyze the Optimal Selection of RAs

Assume that the dimension of the total area is A, the rescue coverage area of an RA is B, and the number of emergency RAs is P. According to the analysis above, the average rescue radius of the rescue aircraft is 100 km. The actual number of RAs needed can be estimated: $P = \frac{A}{B} = 2.32$

Therefore, 3 RAs are needed to meet the requirements. The set of 7 candidates RAs is [P1, P2, P3, P4, P5, P6, P7, P8]. Consider the transport distance $d_{ij}$ from the candidate RAs to each DA. In the first section of this chapter, the weight of each disaster area has been converted to Wi. It is known that 3 RAs
(ie, p = 3) are selected from the candidate RAs as the final result of GA rescue, so that the sum of the weighted distances is minimized. k = 5, so that the i-th DA is assigned to the closest RA in dij.

First allocation result: (P1, P2, P3, P4, P5, P6, P7, P8) = (R7, R7, R7, R4, R3, R2, R2, R1)

The sum of the weighted distances is \( Z = \sum_{ij} w_i d_{ij} y_{ij} \). The removed candidate points R7, R4, R3, R2, R1 are analyzed, and the respective weighted distance increments are calculated:

Assuming that the candidate RA R7 is removed, then the sum of the weighted distance increments is 14.2849. Assuming that the candidate RA R4 is removed, then the sum of the weighted distance increments is 2.5327. Assuming that the candidate RA R3 is removed, then the sum of the weighted distance increments is 1.1841. Assuming that candidate RA R2 is removed, then the sum of the weighted distance increments is 2.3737. Assuming that candidate RA R1 is removed, then the sum of the weighted distance increments is 1.1032.

It can be seen that the incremental increase of removing the emergency rescue airport R1 is the smallest. Therefore, the emergency rescue airport R1 should be eliminated first, that is, the second allocation result is: (P1, P2, P3, P4, P5, P6, P7, P8) = (R7, R7, R7, R4, R3, R2, R2, R2). \( Z = 57.0548 \), then analyze the removal candidate R7, R4, R3, R2, and analyze each the weighted distance increment is calculated:

Assuming the alternative candidate R7 is removed, then the sum of the weighted distance increments is 14.2849. Assuming that the candidate R4 is removed, then the increment of the weighted distance sum is 2.5327. Assuming that the candidate R3 is removed, then the increment of the sum of the weighted distances is 1.1841. Assuming that the alternative candidate R2 is removed, then the increment of the sum of the weighted distances is 15.754. It can be seen that removing RA R3 has the smallest increment. Therefore, in the second step, R3 should be eliminated, that is, the third allocation result is: (P1, P2, P3, P4, P5, P6, P7, P8) = (R7, R7, R7, R4, R2, R2, R2, R2) \( Z = 58.2389 \).

At this time, k = 3. The calculation results show that R7, R4, and R2 are the best locations for GA rescue. The optimal choice of RAs and the corresponding plan for the DAs are: (R7-P1, P2, P3) (R4-P4) (R2-P5, P6, P7, P8), that is, Ya'an City provides rescue for Baoxing, Luding and Hongya; Xinjin provides rescue for Qionglai; Guanghan for Doujiangyan City, Mianzhu, Wenchuan and Mao.

5. Conclusions and Prospects

In this paper, a hierarchical analysis model is used as the core and a P-median model is used as a means. A two-stage hierarchical site selection model of the two models is established, and each influencing factors of the demand level of the disaster area is analyzed and discussed. It is hoped that relevant research can be carried out throughout the country, and a more stable and reasonable model can be derived by integrating disaster-prone areas in different regions. Or, if more data is available, consider combining the characteristics of the airspace structure in different regions of the country, and add this factor to the consideration to obtain a more scientific conclusion.

References

[1] Yang W J and Liu S J 2009 A study on the layout of general aviation emergency rescue spots China Civil Aviation 102 27-29
[2] Wang Z Q and Sun Y 2011 Study on network layout of Jiangsu aviation emergency rescue Modern Transportation Technology 8 61-65
[3] Chen X, Wang Z H, Fan D T and Guo X C 2010 Development of general aviation and its application in emergency rescue Transportation Enterprise Management 25 71-73
[4] Zhu Y, Shao Q, Jia M, Zhang H J and Zhang J S 2015 Research on general aviation emergency rescue point layout method Henan Science 33 265-270
[5] He R X and Qin J T 2010 Location model of multi-level emergency system Industrial Engineering 13 pp 94-97
[6] Huang R, Kim S and Menezes M B C 2010 Facility location for large-scale emergencies Annals of Operations Research 181 271-286
[7] Hogan K and Revelle C 1986 Concepts and applications of backup coverage Management Science 32 1434-1444
[8] Tang S S and Li X P 2013 Study on method for assessment of vulnerability of railway emergency rescue system Journal of the China Railway Society 35 14-20
[9] Zhang C Q and Zhao L 2014 Division location model of power grid maintenance company based on p-median model Journal of System Management 23 501-506
[10] Tong X, Liang H, Zheng L N, Wang Y Y and Luo R Y 2016 Research on location of logistics center based on p-median model Progress in Applied Mathematics 5 276-281