

# Evaluation of Air Traffic Control Ability Based on Fuzzy Theory and Multiple Evaluation Model

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**Abstract.** This paper constructs the structural model of the system of air traffic controllers' comprehensive ability evaluation. The use of analytic hierarchy process to determine the weight of various indicators should have weight values. The construction of the controller comprehensive capacity assessment model, fuzzy comprehensive evaluation method can be used to weigh matrix and membership matrix corresponding transformation, and then determine the comprehensive capacity of the controller to evaluate the value. In the assessment process, the advantages of various methods are combined, enabling the comprehensive evaluation of the comprehensive capacity of the controller, making the results tend to be reasonable. The research shows that the evaluation results made by this method can provide decision-making basis for aviation safety management at all levels. Using the multiple evaluation model, the controller's comprehensive ability evaluation model is established to evaluate the comprehensive ability of the controller.

**Keywords:** controller ability, analytic hierarchy process, fuzzy comprehensive evaluation, evaluation system

## 1. Introduction

With the gradual increase of air traffic flow, the smoothness and safety of air traffic operation are facing great challenges. Air traffic controllers implement efficient air traffic control. This can ensure the smooth operation of air traffic and flight safety. Due to the continuous growth of the number of aircraft, the ability of air traffic controllers has been greatly challenged. In order to improve the efficiency of air traffic operation and ensure flight safety, it is very meaningful to evaluate the overall ability of air traffic controllers. The evaluation results can help air traffic controllers find shortcomings. It can also help find out the key direction for improving the ability training of air traffic controllers. The ability evaluation of air traffic controllers is a complex process. Many evaluation indexes cannot be quantified. We need to find a scientific method to systematically establish a capability evaluation system and model. At present, the methods to study the ability evaluation of air traffic controllers are single quantitative index evaluation method and empirical evaluation method. Tian Rui proposed seven abilities for controllers. They are quick response and discrimination, spatial imagination, judgment, language expression, overall planning, motor nerve, prediction, decision-making, adaptability, self-emotional control and excellent coordination[1]. Hou et al. screened out 25 ability evaluation indexes based on Delphi method. The competency index system of tower controllers is constructed by factor analysis. The optimal and worst method of triangular fuzzy numbers (ZBWM) is used to determine the index weight. The competency model of tower controller is constructed by five-element connection number method[2]. In the simulation of Bai Peng et al., air traffic controllers (hereinafter referred to as controllers) are responsible for directing the air and ground traffic activities of aircraft in real time. This method screened out three abilities: spatial imagination, short-term memory and situational awareness[3]. These methods do not consider the correlation between ability indicators. A single empirical evaluation lacks scientific argumentation. In this paper, an air traffic controller capability evaluation model based on fuzzy comprehensive evaluation and analytic hierarchy process is proposed. This method can improve the scientificity of evaluation by quantitative analysis based on empirical indicators.

## 2. Preliminaries

### 2.1 Ability evaluation index and index weight of air traffic controller

#### 2.1.1 Selection of ability evaluation index

We organized a questionnaire among air traffic control units and controllers. The evaluation system of 15 kinds of ability indicators in 3 categories was constructed. They are basic ability, cognitive ability, technical ability and emotional ability. Cognitive ability includes reaction ability, psychological quality, logical analysis ability, attention distribution ability and memory ability. Technical ability includes spatial thinking ability, ability to monitor flight dynamics, ability to deal with flight conflicts and formulate emergency response plans, ability to provide flight information services and ability to coordinate with other departments. Emotional ability includes communication ability, cooperation ability, management ability, situational modeling ability and decision-making ability.

#### 2.1.2 Weight calculation of ability evaluation index

In order to improve the efficiency of index weight calculation, we choose analytic hierarchy process to calculate 23 index weights. Analytic Hierarchy Process (AHP) [4-6] is a kind of subjective weighting method and subjective and objective integrated weighting method. It decomposes the elements related to decision-making, divides them into three levels: goal, criterion and scheme, and then makes quantitative and qualitative analysis. The first step is to establish a hierarchical structure according to the relationship between the indicators. The hierarchical structure consists of target layer, criterion layer and scheme layer. The second step is to compare the importance of each element in the same level with the standards in the previous level. We can get the judgment matrix. The third step is to calculate the relative weight of each criterion of the compared factors. And the consistency of the judgment matrix is tested. The fourth step is to calculate the combination weight and combination consistency test of the scheme layer for the target layer. After all the indicators are compared, the evaluation indicators are sorted according to the 9-percentile ratio method to determine the order of relative advantages and disadvantages. And the judgment matrix of the evaluation index is obtained.

Table 1 Importance level and explanation of judgment matrix

Degree of importance	Importance level
1	Indicates that both indicator factors are equally important
3	Indicates that one indicator is slightly more important than the other after comparing the two indicator factors
5	Indicates that one indicator is significantly more important than the other after comparing the two indicator factors
7	Indicates that one indicator is strongly more important than the other after comparing the two indicator factors
9	Indicates that one indicator is extremely more important than the other
2 4 6 8 10	The value assigned when a compromise is needed between the above levels of importance

Construct a comparison matrix (also known as a judgment matrix): When constructing the comparison matrix, it is necessary to compare the influence of each indicator factor at the same level on the previous factor, instead of comparing all factors at the same level with each other. The advantage of doing so is that it can avoid the difficulty of comparison between factors of different nature, and minimize the influence of decision-making factors on the results during comparison. The relative importance level between the two indicators is numerically compared by using 1, 2, 3...9 and reciprocal  $1/2$ ,  $1/3$ ,  $1/9$ .... The meanings of scale values are shown in the table. The sum-product method is used as follows:

Each column of the judgment matrix is normalized to obtain a matrix where  $\bar{A} = |a_{ij}|$

$$\overline{a}_{ij} = \frac{a_{ij}}{\sum_{k=1}^n a_{kj}}; \quad (i, j, k=1,2,3,\dots,n) \quad (1)$$

Adding the elements of  $\overline{A}$  by row, we can get the vector  $\overline{W}_i$

$$\overline{W}_i = \sum_{j=1}^n \overline{a}_{ij}; \quad (i, j=1,2,3,\dots,n) \quad (2)$$

By normalized processing  $\overline{W}_i$ , the weights of the related elements of layer  $\overline{M}_i$  relative to layer M are obtained

$$W_i = \frac{\overline{W}_i}{\sum_{i=1}^n \overline{W}_i}; \quad (i, j=1,2,3,\dots,n) \quad (3)$$

Calculate the maximum eigenroot of the judgment matrix

$$\frac{\lambda_{\max} - n}{n - 1} \quad (4)$$

among  $(AW)_i$  represented as vector AW the i element.  
consistency index and consistency ratio:

$$C.I. = \lambda_{\max} = \sum_{i=1}^n \frac{(AW)_i}{nW_i} \quad (5)$$

In the above equation, n represents the order of the judgment matrix,  $\lambda_{\max}$  represents the maximum feature root. Among them, R.I. is the average random consistency index of the judgment matrix. R.I. values are shown in the table.

Table 3.2 Judgment Matrix Average Random Consistency Index

n	1	2	3	4	5	6	7	8	9	10
R.I.	0	0	0.51	0.89	1.12	1.25	1.36	1.42	1.46	1.49

If C.I./R.I.<0.10, it means that the consistency of the judgment matrix is acceptable, otherwise, it is necessary to re-compare the pairwise between each indicator, and then adjust the parameters of the level until the consistency test meets the requirements.

According to the above analysis, the comprehensive quality evaluation set of controllers can be divided into  $U = \{U_1, U_2, U_3\}$ , but  $U_1 = \{U_{11}, U_{12}, U_{13}, U_{14}, U_{15}\}$ ,  $U_2 = \{U_{21}, U_{22}, U_{23}, U_{24}, U_{25}\}$ ,  $U_3 = \{U_{31}, U_{32}, U_{33}, U_{34}, U_{35}\}$ . Judgment Book V represents a set of levels of influence on the controller's operational reliability:  $V = \{V_1, V_2, V_3, V_4, V_5\} = \{I, II, III, IV, V\}$ . The details are shown in Table 2.

Table 2 Importance classification table

Probability	Degree
I	Very important
II	Slightly important
III	Important
IV	Relatively important
V	Very unimportant

The ratio scale from 1 to 9 was used to obtain:

$$B_1 = \begin{bmatrix} 1 & 1/3 & 3 \\ 3 & 1 & 3 \\ 1/3 & 1/3 & 1 \end{bmatrix} B_2 = \begin{bmatrix} 1 & 1/4 & 2 \\ 4 & 1 & 5 \\ 1/2 & 1/3 & 1 \end{bmatrix} B_3 = \begin{bmatrix} 1 & 1/2 & 2 \\ 2 & 1 & 3 \\ 1/2 & 1/3 & 1 \end{bmatrix}$$

$$B_4 = \begin{bmatrix} 1 & 1/3 & 2 \\ 3 & 1 & 4 \\ 1/2 & 1/4 & 1 \end{bmatrix} B_5 = \begin{bmatrix} 1 & 1/2 & 3 \\ 2 & 1 & 5 \\ 1/3 & 1/5 & 1 \end{bmatrix}$$

The weight value is obtained by sum-product method, and the consistency test is carried out, C.I./R.I.<0.10, the weight meets the requirements, the weight matrix of the composite element is obtained by combining the weights obtained by 5 controllers:

$$R_1 = \begin{bmatrix} \cdot & M_1 & M_2 & M_3 \\ C_1 & 0.098 & 0.890 & 0.012 \\ C_2 & 0.024 & 0.970 & 0.006 \\ C_3 & 0.140 & 0.827 & 0.023 \\ C_4 & 0.045 & 0.818 & 0.137 \\ C_5 & 0.227 & 0.762 & 0.011 \end{bmatrix}$$

of which,  $C_1 C_2 C_3 C_4 C_5$  are  $\mu_1 \mu_2 \mu_3$  weight value determined by 5 active controllers.

Next, matter element analysis is used to determine the final weight matrix about  $U_1, U_2, U_3$ :

Determine the effective degree matrix of the indicator weights given by each serving controller  $R_v$ . By calculating the standard matter element  $R_{oj}$ , node domain matter element  $R_{pj}$ , the correlation function matrix can be obtained:

$$\text{of which, } R_{oj} = \begin{vmatrix} \cdot & M_1 & M_2 & M_3 \\ c_{oj} & d_1 & d_2 & d_3 \end{vmatrix} \quad R_{pj} = \begin{vmatrix} \cdot & M_1 & M_2 & M_3 \\ c_{pj} & (a_1, b_2) & (a_2, b_2) & (a_3, b_3) \end{vmatrix}$$

$$, d_j = \sqrt[n]{\prod_{i=1}^n a_{ij}} (i=1,2,3...n), a_j = \min a_{ij}, b_j = \max a_{ij} \quad (6)$$

$$R_o = \begin{bmatrix} 0.122 & 0.35 & 0.5 \\ 1 & 1 & 1 \\ 0.405 & 0.116 & 0.042 \\ 0.625 & 0.337 & 1 \\ 1 & 1 & 0.583 \end{bmatrix}$$

It can be obtained by calculation:  $K_1=0.972 K_2=3 K_3=0.563 K_4=1.962 K_5=2.583$

$R_v=(0.255, 0.083, 0.440, 0.126, 0.096)$  can be obtained.

Finally, the modified weight matrix is obtained:  $R_\omega = R_v \times R_1 = (0.025, 0.761, 0.083)$  can also find the weight matrix of  $U_{11}, U_{12}, U_{13}, U_{14}, U_{15}$   $R_\omega(U_1) = (0.265, 0.241, 0.275, 0.183, 0.063)$  the weight matrix of  $U_{21}, U_{22}, U_{23}, U_{24}, U_{25}$   $R_\omega(U_2) = (0.313, 0.192, 0.284, 0.142, 0.069)$ , the weight

matrix of  $U_{31}, U_{32}, U_{33}, U_{34}, U_{35}$   $R_{\omega}(U_3)=(0.142,0.346,0.034,0.263,0.215)$ .

Table 3 Classification evaluation table of core competence of controllers

Index	Weight	Judging element	Weight	Very important	Relatively important	Important	Normal	Not important
Cognitive ability $U_1$	0.025	Reactivity $U_{11}$	0.265	0.8	0.2	0	0	0
		Psychological quality $U_{12}$	0.214	0.6	0.2	0.2	0	0
		Logical judgment ability $U_{13}$	0.275	0.6	0.4	0	0	0
		Ability of attention distribution $U_{14}$	0.183	0.4	0.4	0.2	0	0
		Memory level $U_{15}$	0.063	0	0.2	0	0.4	0.
Technical ability $U_2$	0.761	Spatial thinking ability $U_{21}$	0.313	0.8	0.2	0	0	0
		Monitor flight dynamics $U_{22}$	0.192	0.6	0.4	0	0	0
		Flight conflict resolution capability $U_{23}$	0.284	0.8	0.2	0	0	0
		Provide flight intelligence capabilities $U_{24}$	0.142	0	0.4	0.4	0.2	0
		Coordination ability $U_{25}$	0.067	0	0.2	0.6	0.2	0
Emotional ability $U_3$	0.083	Interpersonal communication ability $U_{31}$	0.142	0.6	0.2	0.2	0	0
		Cooperation and coordination skill $U_{32}$	0.346	0.4	0.2	0	0	0
		Leadership and management skills $U_{33}$	0.034	0.2	0	0.4	0.2	0.
		Situational awareness skill $U_{34}$	0.263	0.6	0.4	0	0	0
		Decision-making skill $U_{35}$	0.215	0.8	0.2	0	0	0

### 3. Method

#### 3.1 Fuzzy transformation

The principle of fuzzy transformation is a comprehensive evaluation of the evaluation object by considering various factors related to it. By way of fuzzy operation of the fuzzy matrix of weight coefficient and fuzzy relation matrix, the membership matrix of comprehensive index to each evaluation grade can be finally obtained.[7-10]

Comprehensive evaluation of indicators of cognitive ability: Evaluation weight  $R_w(U_1)=(0.265,0.241,0.275,0.183,0.063)$ . The fuzzy relation matrix is:

$$N_1 = \begin{bmatrix} 0.8 & 0.2 & 0 & 0 & 0 \\ 0.6 & 0.2 & 0.2 & 0 & 0 \\ 0.6 & 0.4 & 0 & 0 & 0 \\ 0.4 & 0.4 & 0.2 & 0 & 0 \\ 0 & 0.2 & 0 & 0.4 & 0.4 \end{bmatrix}$$

The evaluation result set is calculated according to the fuzzy synthesis rule:  $D_1 = N_1 \times R_w(U_1)=(0.275, 0.275, 0.200, 0.063, 0.063)$ .  $D_1$  is normalized as  $(0.3141, 0.314, 0.228, 0.072, 0.072)$ . According to the principle of maximum membership degree of fuzzy mathematics, the largest value in  $D_1$  is 0.314. The membership degree of cognitive ability is 0.314.

Comprehensive evaluation of technical capability index: The evaluation weight is  $R_w(U_2)=(0.313, 0.192, 0.284, 0.142, 0.069)$ . The fuzzy relation matrix is:

$$N_2 = \begin{bmatrix} 0.8 & 0.2 & 0 & 0 & 0 \\ 0.6 & 0.4 & 0 & 0 & 0 \\ 0.8 & 0.2 & 0 & 0 & 0 \\ 0 & 0.4 & 0.4 & 0 & 0 \\ 0 & 0.2 & 0.6 & 0.2 & 0 \end{bmatrix}$$

$$D_2 = N_2 \times R_w(U_2)=(0.313, 0.200, 0.142, 0.142, 0).$$

It is normalized as  $(0.392, 0.250, 0.179, 0.179, 0)$ . According to the principle of maximum membership degree of fuzzy mathematics, the largest value in  $D_2$  is 0.392. The membership degree of technical quality is 0.392.

Affective ability index was evaluated comprehensively. The evaluation weight is:  $R_w(U_3)=(0.142, 0.346, 0.034, 0.263, 0.215)$ . The fuzzy relation matrix is:

$$N_3 = \begin{bmatrix} 0.6 & 0.2 & 0.2 & 0 & 0 \\ 0.4 & 0.4 & 0.2 & 0 & 0 \\ 0.2 & 0 & 0.4 & 0.2 & 0.2 \\ 0.6 & 0.4 & 0 & 0 & 0 \\ 0.8 & 0.2 & 0 & 0 & 0 \end{bmatrix}$$

$$D_3 = N_3 \times R_w(U_3)=(0.346, 0.346, 0.142, 0.034, 0.034).$$

It is normalized as (0.384,0.384,0.157,0.038,0.038). According to the principle of maximum membership degree of fuzzy mathematics, the largest value in  $D_3$  is 0.384. The membership degree of affective ability is 0.384.

### 3.2 Process of air traffic controller comprehensive ability evaluation

Analytic hierarchy process (AHP) calculates the weights of cognitive ability, technical ability and emotional ability. We need to choose C language as the program carrier to evaluate the comprehensive ability of a controller. The evaluation process is shown in the figure.1.

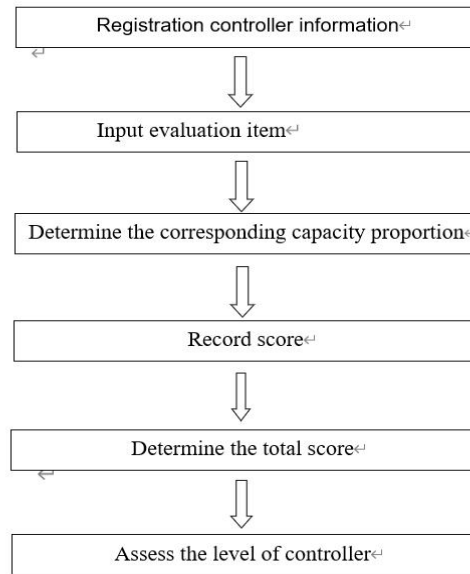


Figure 1 Flow chart of integrated capability assessment for controllers

The evaluation result of the controller comprehensive ability adopts the percentage system. Set 59 as Failing in the evaluation result standard, 60 to 79 as Passing, 80 to 90 as Good, and 90 or above as Excellent. In the design of the system, due to the particularity of the C language algorithm[11-13], one-point system is adopted for each ability evaluation. After using the percentage weighted average, the system algorithm will expand the value by 100 times, and the final comprehensive ability value will be expressed as a percentage system.

## 4. Experiment

We randomly selected a controller to evaluate the comprehensive ability. And the results are as follows.

Table 4: Various scores of cognitive ability

Ability category	Score	Weighted value
reactivity	0.8	0.265
Psychological quality	0.8	0.214
Logical analysis ability	0.8	0.275
Ability of attention distribution	0.9	0.183
Memory ability	0.8	0.063

According to the controller comprehensive ability evaluation process, the scores and ratios of the five abilities are input in turn, and the comprehensive score of the controller personal cognitive ability and the level of the personal cognitive ability will be obtained. The controller personal cognitive ability is 84.58 points, and the qualitative result is good. At the same time, we can get the corresponding comprehensive ability score according to the scores and weights of 10 indicators of technical ability and emotional ability. Finally, the membership degree of the three core

competencies determined by fuzzy transformation is used, and the final score and rating of the controller comprehensive ability evaluation are obtained through weighted calculation.

## 5. Conclusion

The comprehensive ability evaluation model of air traffic controllers based on fuzzy theory and multivariate evaluation method can effectively and quantitatively calculate the ability value. At the same time, this method can gather the advantages of various evaluation indexes to get a qualitative judgment. The combination of quantitative analysis and qualitative analysis is the advantage of this method to evaluate the comprehensive ability of controllers. In addition, this method can also be applied to the ability evaluation of other personnel in air traffic control system.

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