Air Traffic Management Process Quality Assessment Model Based on Improved Fuzzy Matter Element Analysis

PAN Wei-jun, REN Jie, WANG Run-dong
Civil Aviation Flight University of China, Guanghan 10624, China
rogerfrozen@163.com

Abstract. In order to improve the service quality of the air traffic management system, the accurate air traffic management process quality assessment can identify the weak links in the process of interaction with the user, and timely make early warning, evaluation and feedback to avoid the risks of the air traffic control system. Based on the actual situation of air traffic control, the related factors affecting the quality of air traffic service process are analyzed. The process indicators covering the four aspects of human, machine, environment and management are selected and the fuzzy comprehensive evaluation model is established. Based on the improvement of the membership function. Finally, through the analysis and verification of the example, the result is in line with the actual situation of the operation of the air traffic control system, and provides a reference for improving the quality of air traffic control services.

1. Introduction
The rapid development of the civil aviation industry is inseparable from the protection of air traffic control (ATC), but with the rapid growth of flight traffic, air traffic generally exhibits high or ultra-high density operating conditions, good air traffic service quality for flights, crew, companies has a positive effect, which improves flight comfort and customer satisfaction. Therefore, ensuring the quality of air traffic control services has become the top priority of China's civil aviation construction. Civil aviation accident statistics show that the proportion of accidents caused by air traffic management is not large. Air traffic control-related accidents accounted for 4% of the total number of fatal accidents caused by accidents worldwide in 1980-2002[1]. However, if the air traffic control is the main cause of the accident, it will have serious and serious consequences, such as the 1977 Tenerife air crash. The International Civil Aviation Organization (ICAO) clearly states in Annex XI[2] that units providing air traffic control services should actively construct and implement a Safety Management System (SMS). Quality of service is an important part of the safety management system. It can reflect the quality of the operation of the air traffic control system and can identify and improve the weak links based on the evaluation results. Therefore, it is necessary to improve the operation level of the air traffic control system by evaluating the service quality of the air traffic control system.

Yuan Leping[3] based on fuzzy evaluation, establishes the evaluation factor set, evaluation set, determines the weight of each factor from the evaluation factor set to the evaluation set, and uses the unascertained number theory to calculate the probability of occurrence of danger, giving empty Pipeline safety risk assessment model; Zhang Jianping[4] used factor analysis method and fuzzy comprehensive evaluation method to study the quality factor of air traffic control, and analyzed the safety factor, flow factor and efficiency factor as the comprehensive evaluation terminal area. The basis for regulating the quality of operation and optimizing the operation strategy is provided; P Averty[5] designed a controller's psychological load estimation method, which is designed to take into account the additional load caused...
by objective traffic variables and subjective influences, including the severity of the conflict. And the time pressure of the solution. It is proposed that the controller workload estimate should be combined with objective task variables and subjective assessments related to it to study the potential risks caused by the controller workload. Wang Yanqing and Wu Weijie[6] used the LOGIT model to analyze the factors affecting the controller's mental deviation in an emergency, and determined that the controller's control work would be affected by psychological factors in an emergency; the literature[7] proposed a basis Probabilistic risk assessment of air traffic control and air traffic management methods, combined with the TOPAZ model, takes into account the intricate relationship between the various risk sources in the air traffic control system, proposes a dynamic color network model, thus solving the traditional risk assessment model. Risk assessment but ignoring the shortcomings of the interaction between the various components.

Yorck Hauss and Klaus Eyfert pointed out that air traffic has grown rapidly and increasingly in Western countries since the 1990s, and the impact of human factors on air traffic safety has led to situational awareness (Situation Awareness; SA) has become an important indicator to measure the quality of air traffic. The two experts also conducted a study of the event-based psychological representation of the controller[8]. Sven Ternov and Roland Akselsson built models and procedures based on aviation accidents and began an analysis of risk barriers for air traffic control systems, using this method to identify and identify sources of risk in an air traffic control environment in a complex system[9].

At present, there are many safety assessments for air traffic management, but there are few quantitative analysis of process service quality. How to change from qualitative analysis to quantitative research is an important topic in the future research of air traffic control. This paper selects the key indicators that reflect the quality of the control of the terminal area, and then collects the index data, and determines the five most important process indicators for evaluating the operational quality of the terminal area and two outcome indicators. The analytic hierarchy process is used to determine the weight of each index. Then, the fuzzy comprehensive evaluation method is used to evaluate the model. The improved normal distribution membership function is used to determine the value of each evaluation index. The classical domain of each level is valued, the current evaluation matrix of the sector is calculated, and the service quality of the current terminal area is rated according to the principle of maximum membership degree.

2. Establish a quality assessment model

In this paper, the process indicators are selected to determine the first-level indicators in five directions, namely equipment factors, control safety, control efficiency, workload, and meteorological factors; the above five indicators continue to subdivide the secondary indicators. Select the rate of accidents for the cause of the accident, and the rate of abnormality of the control cause is the result index[10]. See Table 1 for specific indicators.

| First-level | Second-level |
|-------------|--------------|
| Equipment factor $f_1$ | Equipment failure rate $f_{11}$ |
| | Equipment maintenance $f_{12}$ |
| | Key parts without accessories rate $f_{13}$ |
| Control efficiency $f_2$ | Flight normal rate $f_{21}$ |
| | Average flight delay time $f_{22}$ |
| | Flight departure rate $f_{23}$ |
| | Airport release rate $f_{24}$ |
Take-off average wake interval margin $f_{31}$

Control safety $f_3$

Landing average wake interval margin $f_{32}$

Conflict alarm frequency $f_{33}$

Number of instructions issued per unit time $f_{41}$

Workload $f_4$

Average length of ground and air calls $f_{42}$

Average duration of continuous work of controllers $f_{42}$

Weather forecast accuracy $f_{51}$

Aviation weather $f_5$

Report accuracy rate $f_{52}$

Safety accident $f_6$

10,000 sorties in controlled accident $f_{61}$

10,000 sorties in cases of abnormal control causes $f_{62}$

3. Analytic hierarchy process to determine indicator weights

Using AHP to establish index weights and construct judgment matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

Let the current level related factors be $A_1, \ldots, A_n$, and the related upper layer factor is $f$. For all factors, the two values are compared, and the value $a_{ij}$ is obtained. The definition and definition are shown in Table 2. $A = (a_{ij})_{m \times n}$ then $A$ is the judgment matrix of the factors $A_1, \ldots, A_n$ relative to the upper factor $f$. The maximum eigenvalue of $A$ is $\lambda_{\text{max}}$, and the normalized eigenvector belonging to $\lambda_{\text{max}}$ is $\omega = (\omega_1, \ldots, \omega_n)^T$, then $\omega_1, \ldots, \omega_n$ gives the factor $A_1, \ldots, A_n$ corresponds to the factor $f$.

Sort by importance level[11].

| Definition          | Explanation                                               |
|---------------------|-----------------------------------------------------------|
| 1 Equally important | Goal $i$ goal $j$ is equally important                    |
| 3 Slightly important| Target $i$ is slightly more important than goal $j$       |
| 5 Quite important   | Target $i$ is Quite more important than goal $j$          |
| 7 Obviously important| Target $i$ is Obviously more important than goal $j$     |
Absolutely important Target \( i \) is Absolutely more important than goal \( j \)

2, 4, 6, 8 In between

Since the 9-level grading makes the calculation process too cumbersome, this paper adopts the 5-level grading, that is, discards the evaluation of the 2, 4, 6, and 8 degrees. At the same time, a set of evaluation factors is established for the control results, and five levels of evaluation methods are used, which are good, pretty good, general, poor, and very poor, and are represented by \( M_1 \), \( M_2 \), \( M_3 \), \( M_4 \), and \( M_5 \), respectively.

4. Fuzzy comprehensive evaluation method evaluation model

4.1. Fuzzy comprehensive evaluation method evaluation model

By analyzing the weight of the underlying indicators on the upper-level indicators, the layers are progressive, and the proportion of the first-level indicators is introduced to evaluate the control process.

The fuzzy matter element is expressed as:

\[
R = \begin{bmatrix}
M \\
u(x)
\end{bmatrix}
\]

Where: \( R \) is a fuzzy matter element; \( M \) is a given thing, in this article, it is a five-level comment, which is \( M_j (j=1..5) \); \( f \) is the feature of thing \( M \), in this paper The index; \( u(x) \) is the fuzzy magnitude corresponding to the feature of the thing, that is, the membership degree. If \( m \) things are given, they have \( n \) features, namely \( f_i \) \((i=1\ldots n)\), and the corresponding fuzzy magnitudes are \( u_i(x_j) \), then \( R_{n\times m} \) is called \( n \)-dimensional fuzzy matter elements of \( m \) things.

\[
R_{n\times m} = \begin{bmatrix}
M_1 & M_2 & \cdots & M_i \\
\vdots & \vdots & \ddots & \vdots \\
\vdots & \vdots & \ddots & \vdots \\
\vdots & \vdots & \ddots & \vdots \\
u_i(x_1) & u_i(x_2) & \cdots & u_i(x_m)
\end{bmatrix}
\]

4.2. Evaluation step

Establish the fuzzy complex model

The fuzzy composite representation of the evaluation object:

\[
R_i = \begin{bmatrix}
f_i & f_{i1} & X_{i1} \\
f_{i2} & X_{i2} \\
\vdots & \vdots \\
f_{ip} & X_{ip}
\end{bmatrix}
\]

Where: \( f_i \) is the \( i \)-th level indicator \((i=1, 2, \ldots, n)\), \( n \) is the number of first-level indicators), since the number of first-level indicators in this paper is 5, so \( n=5 \); \( f_{ik} \) is the \( k \)-th second-level indicator under \( i \)-th first-level indicators \((where \ k=1, 2, \ldots, p, p \) is the number of secondary indicators); \( X_{ik} \) is the value of the secondary indicator.
Determining the classic domains of each level

Determining the range of values for each evaluation indicator for each level can be expressed by the following matter-element model:\[12\]:

\[
R(M) = \left[ \begin{array}{cccc}
M_1 & M_2 & \cdots & M_j \\
\frac{f_i}{a_{i1}}, \frac{b_{i1}}{a_{i1}} & \frac{b_{i1}}{a_{i1}} & \cdots & \frac{b_{i1}}{a_{i1}} \\
\vdots & \vdots & \ddots & \vdots \\
\frac{f_p}{a_{p1}}, \frac{b_{p1}}{a_{p1}} & \frac{b_{p1}}{a_{p1}} & \cdots & \frac{b_{p1}}{a_{p1}} \\
\end{array} \right]
\]

Where: \(M_j\) is the \(j\)-th rank (where \(j=1, 2, \ldots, m\)) \(m\) is the number of evaluation grades, \(a_{ pij}\) is the lower limit of the secondary indicator, and \(b_{ pij}\) is the upper limit of the secondary indicator. Therefore, the upper and lower limits of each rating of service quality are introduced in the subsequent calculations.

Determining the membership function matrix \(V\)

Membership is a measure of the size of the collocation between two things. The membership degree is determined by the membership function, and the membership degree and membership function are the basis of fuzzy mathematics\[13\]. Therefore, choosing the correct membership function is the basis for solving the practical problem by using fuzzy set theory. Combined with Wang Jifang\[14\], the definition of the membership function in fuzzy cybernetics is based on the normal distribution, so all the indicators are distributed.

\[
u_j(x_{ik}) = e^{-\left(\frac{x_{ik} - p}{q}\right)^2}
\]

where:

\[
p = \frac{|a_{jik} + b_{jik}|}{2}
\]
\[
q = \frac{|a_{jik} - b_{jik}|*\sqrt{2}}{2}
\]

Normalize the calculated \(u_j(x_{ik})\):

\[
u_j(x_{ik})' = \frac{u_j(x_{ik})}{\sum_{k=1}^{p} u_j(x_{ik})}
\]

Get the fuzzy composite matrix:

\[
R_{m* n}' = \left[ \begin{array}{cccc}
M_1 & M_2 & \cdots & M_j \\
\frac{u_1(x_{i1})'}{u_1(x_{i1})'} & \frac{u_1(x_{i1})'}{u_1(x_{i1})'} & \cdots & \frac{u_1(x_{i1})'}{u_1(x_{i1})'} \\
\vdots & \vdots & \ddots & \vdots \\
\frac{u_n(x_{i1})'}{u_n(x_{i1})'} & \frac{u_n(x_{i1})'}{u_n(x_{i1})'} & \cdots & \frac{u_n(x_{i1})'}{u_n(x_{i1})'} \\
\end{array} \right]
\]

Calculate the comprehensive evaluation results

Once the membership degree comprehensive evaluation matrix \(V\) is determined, the comprehensive evaluation result can be obtained, and the evaluation result of the same level indicator feature vector in the fuzzy degree is calculated as the membership degree:

\[
B = W \odot V = (b_1, b_2, \ldots, b_n)
\]
Here "⊙" is a synthetic operation, which can be taken as "+, ×", and this article takes "×".

5. Case Analysis
Select the recent data of an air traffic control bureau in East China and bring it into the model for calculation. For the survey of 20 first-line control experts, each expert is required to give the second-level index experience classic domain, and can not abstain. The value of qualitative indicators is obtained by expert scoring method. The value of quantitative indicators is obtained according to the statistical data of the unit. The range of values and actual values of the secondary indicators are shown in Table 3 [15].

| Second-level | M₁       | M₂       | M₃       | M₄       | M₅       | Actual value |
|--------------|----------|----------|----------|----------|----------|--------------|
| f₁₁          | [0.1, 0.3] | [0.3, 0.5] | [0.5, 1.0] | [1.0, 3.0] |          | 0.4          |
| f₁₂          | [95, 100]  | [85, 95]  | [70, 85]  | [60, 70]  | [60, 70]  | 91           |
| f₁₃          | [0.1, 0.3] | [0.3, 0.5] | [0.5, 1.0] | [1.0, 3.0] |          | 0.3          |
| f₂₁          | [95, 100]  | [85, 95]  | [70, 85]  | [60, 70]  | [60, 70]  | 89           |
| f₂₂          | [95, 100]  | [85, 95]  | [70, 85]  | [60, 70]  | [60, 70]  | 87           |
| f₂₃          | [95, 100]  | [85, 95]  | [70, 85]  | [60, 70]  | [60, 70]  | 86           |
| f₂₄          | [95, 100]  | [85, 95]  | [70, 85]  | [60, 70]  | [60, 70]  | 89           |
| f₃₁          | [95, 100]  | [85, 95]  | [70, 85]  | [60, 70]  | [60, 70]  | 86           |
| f₃₂          | [95, 100]  | [85, 95]  | [70, 85]  | [60, 70]  | [60, 70]  | 91           |
| f₃₃          | [95, 100]  | [85, 95]  | [70, 85]  | [60, 70]  | [60, 70]  | 73           |
| f₄₁          | [95, 100]  | [85, 95]  | [70, 85]  | [60, 70]  | [60, 70]  | 86           |
| f₄₂          | [95, 100]  | [85, 95]  | [70, 85]  | [60, 70]  | [60, 70]  | 89           |
| f₄₃          | [95, 100]  | [85, 95]  | [70, 85]  | [60, 70]  | [60, 70]  | 82           |
| f₅₁          | [90, 100]  | [80, 90]  | [70, 80]  | [60, 70]  | [60, 70]  | 89           |
| f₅₂          | [90, 100]  | [80, 90]  | [70, 80]  | [60, 70]  | [60, 70]  | 95           |
| f₆₁          | [0.01, 0.03] | [0.03, 0.05] | [0.05, 0.08] | [0.08, 0.1] |          | 0.03         |
| f₆₂          | [0.01, 0.03] | [0.03, 0.05] | [0.05, 0.08] | [0.08, 0.1] |          | 0.02         |

5.1. Index weight determination
Invite industry experts to conduct weight evaluations on each level of indicators, and conduct consistency tests on each expert's survey results to obtain first-level indicator weights:

\[ W = (0.105, 0.202, 0.202, 0.074, 0.020, 0.397) \]

Similarly, other secondary indicator weights are available:
$W_1=(0.121, 0.547, 0.332)$
$W_2=(0.231, 0.314, 0.343, 0.112)$
$W_3=(0.171, 0.587, 0.332)$
$W_4=(0.256, 0.443, 0.301)$
$W_5=(0.386, 0.614)$
$W_6=(0.667, 0.333)$

5.2. Index membership degree determination

Bring the result into the membership function and normalize it:

$R_1 = \begin{bmatrix}
0 & 0.028 & 0.897 & 0.053 & 0.022 \\
0 & 0.910 & 0.090 & 0 & 0 \\
0 & 0.475 & 0.475 & 0.018 & 0.032 \\
\end{bmatrix}$

$R_2 = \begin{bmatrix}
0 & 0.786 & 0.158 & 0 & 0.056 \\
0 & 0.654 & 0.276 & 0 & 0.070 \\
0 & 0.562 & 0.360 & 0 & 0.078 \\
0 & 0.786 & 0.158 & 0 & 0.056 \\
\end{bmatrix}$

$R_3 = \begin{bmatrix}
0 & 0.910 & 0.090 & 0 & 0 \\
0 & 0.562 & 0.360 & 0 & 0.078 \\
0 & 0 & 0.655 & 0.143 & 0.202 \\
\end{bmatrix}$

$R_4 = \begin{bmatrix}
0 & 0.562 & 0.360 & 0 & 0.078 \\
0 & 0.786 & 0.158 & 0 & 0.056 \\
0 & 0.041 & 0.959 & 0 & 0 \\
\end{bmatrix}$

$R_5 = \begin{bmatrix}
0 & 0.786 & 0.158 & 0 & 0.056 \\
0.499 & 0.499 & 0.002 & 0 & 0 \\
0.979 & 0.021 & 0 & 0 & 0 \\
\end{bmatrix}$

Comprehensive evaluation of the second level indicators

Multiplying the weights of the second-level indicators by the degree of membership can obtain the membership matrix of each level of indicators:

Available from B= W×V:

$B_1 = [0, 0.657, 0.316, 0.012, 0.015]$ 
$B_2 = [0, 0.668, 0.264, 0, 0.068]$ 
$B_3 = [0, 0.485, 0.385, 0.035, 0.095]$ 
$B_4 = [0, 0.504, 0.451, 0, 0.045]$ 
$B_5 = [0.306, 0.610, 0.062, 0, 0.022]$ 
$B_6 = [0.326, 0.340, 0.333, 0.001, 0]$ 

Comprehensive evaluation of the first level indicators

Multiplying the weight of the first-level index by the membership degree, the first-level indicator membership degree matrix can be obtained, that is, the service quality evaluation level of the unit can be obtained.
Evaluation conclusion

According to the principle of maximum membership, this unit evaluation level is M2 (better). This result is in line with the actual operation of the unit, which proves the reliability and effectiveness of the model. At the same time, it was found in the calculation process that the control safety score is low, so the unit needs to improve the quality of this part.

6. Conclusion

- Through calculation, the obtained regulatory quality assessment is consistent with the actual operation. For the control unit, it is possible to find out the problems and improvement directions of the unit in time.
- For first-line controllers, they can fully understand their own control skills, improve their control skills and control proficiency, and evade before risks occur.
- Through the safety assessment, we can understand the operation of each flight, improve the on-time rate of passengers and the travel experience of passengers.
- In the weight determination part, the expert research method is adopted, so the weight index has certain subjectivity. In the future, the model can be improved by improving the selection of weight indicators.

Acknowledgments

Thanks to the Civil Aviation East China Air Traffic Management Bureau 2018 Annual Science and Technology Project Plan (KJ1802)

Thanks to the 2018 Graduate Innovation Program of Civil Aviation Flight University of China(X2018-36)

References

[1] Eurocontrol Safety Regulation Commission Document (SRC DOC 2), ATM Contribution to Aircraft Accidents/ Incidents Review and Analysis of Historical Data [EB/OL], [2012-05-04]. http://www.eurocontrol.int/src/gallery/.../srcdoc2_e40_ri_web.pdf, 2005-5.

[2] ICAO. Annex 11 to the Convention on International Civil Aviation, 2001 Air Traffic Services [S]. Montreal: ICAO, 2001.

[3] Yuan Leping, Sun Ruishan and Cheng Yuan. Fuzzy Evaluation and Unascertained Mathematics Based Safety Risk Assessment in ATM System[J]. Journal of Civil Aviation University of China, 2006, 24 (4) :55-57

[4] Zhang Jianping, Yu Haiyang and Zou Guoliang. Research on evaluation factors for operation performance of air traffic control in terminal area[J]. Journal of Civil Aviation University of China, 2012, 30(3):18-21.

[5] Averty P, Collet C A, Athenes S, et al. Mental workload in air traffic control: an index constructed from field tests[J]. Aviation Space & Environmental Medicine, 2004, 75(4):333-341.

[6] Wang Yanqing. Analysis of Factors Influencing Air Traffic Controllers' Psychological Deviation under Emergency Condition[J]. China Safety Science Journal, 2012, 22(9):24.

[7] Blom H A P, Bakker G J, Blanker P J G, et al. Accident risk assessment for advanced ATM[J]. Air Transportation Systems Engineering Aiaa, 1999.

[8] Hauss Y, Eyferth K. Securing future ATM-concepts' safety by measuring situation awareness in ATC[J]. Aerospace Science & Technology, 2003, 7(6):417-427.

[9] Ternov S, Akselsson R. A method, DEB analysis, for proactive risk analysis applied to air traffic control[J]. Safety Science, 2004, 42(7):657-673.
[10] Zhang Jianping, Research on Quantitative Evaluation for Operation Performance of Air Traffic Control[D]. Nanjing: Nanjing University of Aeronautics and Astronautics, 2013

[11] Hu Yunquan 2012. Operational Research Tutorial. 4rd (Beijing: Tsinghua University Press)

[12] Han Yubin, Piao Chunzi. Research on safety performance assessment model of atc (Air Traffic Control) system[J]. Advances in Aeronautical Science and Engineering, 2016, 7(4):477-483

[13] Liu Kaidi, Pang Yanjun, Wu Heqin. The Problems in the Definition of Fuzzy Subordinative Degree[J]. SYSTEM ENGINEERING—THEORY & PRACTICE, 2000, 20(1):110-112.

[14] Wang Jifang, Lu Zhengding. The determine method of membership function in fuzzy control[J]. Henan Science, 2000, 18(4):348-351.

[15] Wang Tingchun, Sun Deqing, Yu Feifei, et al. Study on fuzzy comprehensive evaluation of safety management performance[J]. Journal of Safety Science & Technology, 2012, 08(3):185-188.