Quality Assessment Model of Air Traffic Management Service Process Based on TFN-ANP

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Abstract. The ATM operation quality assessment model is the core component of the ATM process quality management. The existing model cannot accurately and completely describe the key indicators of performance in actual work due to the outdated concepts and strong subjectivity. After analyzing the characteristics of ATM process quality, we use TFN-ANP method to establish new assessment model. Each element in this model obtains its own weight and relevance to others. This method further reduces the subjectivity compared with the traditional assessment model. Finally, through the analysis of actual examples, the scientific and practicality of the new assessment model is indicated.

1. Introduction
Civil aviation is a national strategic industry. One of the main tasks of establishing a new era of civil aviation power is to comprehensively improve the quality of aviation services. High-quality civil aviation services are inseparable from the protection of Air Traffic management systems. Strengthening the quality management of service processes under the premise of ensuring air traffic safety and efficiency has become a new goal pursued by regulatory authorities today. The use of a more scientific and objective method to manage and evaluate the quality of Air Traffic management system services can further improve the quality of civil aviation services.

In recent years, both domestic and foreign efforts have been made to improve the operational quality of the Air Traffic management system. ICAO has put forward requirements for quality management work in intelligence and meteorological services; FAA has established a quality management system in the aviation safety field and achieved remarkable results; in October 2009, China introduced the operation of Air Traffic management system operation quality management system. Guide; January 2019, China Civil Aviation News reported that China's civil aviation is studying the establishment of a high-quality development index system for civil aviation \cite{1}.

At present, the research on the quality of Air Traffic management has the following results. In China, Pan Weijun established a risk assessment model for Air Traffic management based on fuzzy analytic hierarchy process \cite{2}; and proposed a control center effectiveness assessment method based on ADC performance assessment model \cite{3}; Lu Zongping established The quality assessment model of the control system based on principal component analysis and cluster analysis \cite{4}; and the quality assessment model of the control system based on the multi-level grey comprehensive assessment method \cite{5}; abroad, ICAO adopted the research of the Vismari’s team. The risk assessment method, which is combined with “absolute”, uses modeling, simulation, and inter-system quantitative methods to maximize the benefits of safety assessment \cite{6}. For the air traffic service process, there is still a lack of research in China.
The previous research can improve two points as follows: First, only the quality of operation is emphasized in the research and the difference between "operation" and "service process" is neglected. Based on the analysis of the differences between the two, this paper selects the key indicators [7], which is more in line with the actual situation of the control units and the daily work requirements of the control personnel, so that the indicator system can better meet the requirements of high quality Air Traffic management services. Second, in the past, when researchers selected the indicator elements, there were overlapping phenomena between the coverage of the indicators and a phenomenon that did not comprehensively and accurately reflect the actual working conditions [8]. This paper will adopt the network analytic hierarchy process (TFN-ANP) which introduces the triangular fuzzy number [9] to reduce the influence of subjective factors as much as possible to improve the assessment model [10].

2. TFN-ANP method

2.1. Analytic Network Process (ANP)

The ANP structure is mainly divided into a control layer and a network layer, as shown in figure 1. The control layer contains guidelines for target and problem decision-making. The network layer enumerates the elements contained under all control layers, and the elements interact with each other.

![Typical hierarchical structure of analytic network process](image)

In the ANP structure, the control layer contains elements $C_1, C_2, \ldots, C_m$. The network layer contains $m$ element sets $K_1, K_2, \ldots, K_m$, where $K_i$ contains elements $e_{i1}, e_{i2}, \ldots, e_{in}, (i = 1, 2, \ldots, n)$ . Analyze the interaction between the elements in the network layer. Take $C_s$ as the criterion, and use $e_{jl}, (l = 1, 2, \ldots, n_j)$ affected by the elements in $K_i$ as the secondary criterion, compare the elements in $K_i$ and construct the judgment matrix. Calculate the normalized weight ordering vector $w_i^{(j)} = (w_{i1}^{(j)}, w_{i2}^{(j)}, \ldots, w_{in}^{(j)})^T$ of the elements in $K_i$ with respect to the sub-criteria, and then obtain the weighting matrix $w_i^{(j)} = (w_{i1}^{(j)}, w_{i2}^{(j)}, \ldots, w_{ijn}^{(j)})^T$ of the influence of all elements in $K_i$ on the elements in $K_j$. Finally, a super-matrix under the $C_s$ criterion is obtained.

$$W = \begin{pmatrix}
W_{11} & \cdots & W_{1m} \\
\vdots & \ddots & \vdots \\
W_{n1} & \cdots & W_{nm}
\end{pmatrix}$$ (1)
The super-matrix \( W \) only considers the influence of a single element set on the sub-criteria, so the column vector of \( W \) is non-normalized. Using \( C_s \) as a criterion, the importance of the criteria \( K_i (i = 1, 2, ..., m) \) of each group of elements under \( C_s \) is compared, and the normalized weighted ordering vectors \( (a_{1j}, a_{2j}, ..., a_{mj})^T \) of other element sets are obtained. The resulting weighting matrix:

\[
A = \begin{pmatrix}
a_{11} & \cdots & a_{1m} \\
\vdots & \ddots & \vdots \\
a_{m1} & \cdots & a_{mn}
\end{pmatrix}
\]

The weighting matrix \( \overline{W} = (\overline{W}_{ij}) \), \( \overline{W}_{ij} = a_{ij}W_{ij}, (i, j = 1, 2, ..., m) \).

When \( k \to \infty \), the k-th root of \( \overline{W} \) is \( \overline{W}^k \) and the limit exists. At this time \( \overline{W}^\infty = \lim_{k \to \infty} \overline{W}^k \), the j-th column of \( \overline{W}^\infty \) is the limit relative ranking vector of each element in the network layer under \( C_s \) to the element \( j \), and the sorting vector reflects the interaction between the elements. The size of the degree.

2.2. Improve ANP with TFN

2.2.1. Triangular fuzzy number (TFN)

Suppose there is a domain \( P \), and \( T \) is the fuzzy number on \( P \). If the membership function \( \mu_T(x) \) of \( T \) such that \( P \to [0,1] \) can be expressed as equation (3), then \( T \) is called a triangular fuzzy number.

The triangular fuzzy number \( T \) can usually be expressed as \( (l, m, u) \), where \( 0 \leq l \leq m \leq u \).

\[
\mu_T(x) = \begin{cases} 
\frac{1}{m-l}x - \frac{l}{m-l} & x \in [l, m] \\
\frac{1}{m-u}x - \frac{u}{m-u} & x \in [m, u] \\
0 & x \in [-\infty, l] \cup [u, +\infty]
\end{cases}
\] (3)

2.2.2. Improvement measures

The subjectivity of the model can be reduced by applying the triangular fuzzy number to the judgment matrix construction process of the network analytic hierarchy process. The specific implementation method is divided into the following three steps:

Step 1, using TFN to construct a judgment matrix \( A \), wherein:

\[
M_{ij} = \frac{1}{T} \bigotimes (a_{ij}^1 + a_{ij}^2 + ... + a_{ij}^l), i = 1, 2, ..., n; j = 1, 2, ..., n \]

(4)

Step 2, calculating the comprehensive fuzzy value \( D_i^k \) of the element \( i \) in the element set \( K_k \) as the initial weight value:

\[
D_i^k = \sum_{j=1}^{n} M_{ij}^k \bigotimes (\sum_{j=1}^{n} \sum_{i=1}^{n} M_{ij}^k)^{-1}, i = 1, 2, ..., n
\]

(5)

Step 3, the obtained integrated fuzzy value is defuzzified. \( M_1(l_1, m_1, u_1) \) and \( M_2(l_2, m_2, u_2) \) are two triangular fuzzy numbers, assuming the probability of \( M_1 \geq M_2 \) is:

\[
p(M_1 \geq M_2) = \sup_{x, y} \left\{ \min[u_{M_1}(x), u_{M_2}(y)] \right\}
\]

(6)
\[
p(M_1 \geq M_2) = \mu(d) = \begin{cases} 
1 & m_1 \geq m_2 \\
\frac{l_2 - u_1}{(m_1 - u_1) - (u_2 - l_2)} & m_1 \leq m_2, u_1 \geq l_2 \\
0 & \text{other}
\end{cases} \tag{7}
\]

Suppose the probability that a fuzzy number is greater than the other \(K\) fuzzy numbers is
\[
p(M \geq M_1, M_2, \ldots, M_k) = \min p(M \geq M_i), i = 1, 2, \ldots, k \tag{8}
\]
Let \(z'(c_i) = \min p(M \geq M_i), i = 1, 2, \ldots, k\) get \(Z' = [z'(c_1), z'(c_2), \ldots, z'(c_n)]^T\), and normalize \(Z'\) to get the sorting vector \(Z = [z(c_1), z(c_2), \ldots, z(c_n)]^T\) needed to construct the super matrix.

3. ATC structure model for air traffic service process quality management

3.1. Establishing an air traffic management process quality management index system

After analyzing the previously established indicator system and listening to actual work requirements, the PDCA cycle [11] is used to refine management effectiveness based on the idea of quality management. Through this method, the second-level indicators of management effectiveness are finally classified into four categories: safety management, operation management, financial management and human resource management.

For safety management, it is mainly related to accidents in the control work. Therefore, the accident rate of accidents, the rate of comprehensive accidents, the rate of comprehensive air traffic accidents, the completeness of emergency management systems, and the proportion of full-time safety management personnel are regarded as three levels, index.

For operation management, it is mainly related to the normal operation of the daily work of the control unit. The implementation rate of important work tasks, the compliance rate of on-site inspection by management personnel, the productivity of all employees, and the annual growth rate of control support are regarded as three-level indicators.

For financial management, it is mainly related to the effectiveness of the control unit, and the financial management situation, the net growth rate of fixed assets and cost management are regarded as three-level indicators.

For human resources management, it is mainly related to the setting of controllers in various regions. The growth rate of controllers, the growth rate of communication and navigation monitors, the growth rate of aviation meteorological personnel, and the proportion of controllers are used as three-level indicators.

In summary, the regulatory effectiveness assessment index system in service process quality management is shown in Table 1.

| Secondary indicators | Third level indicators | Indicator definition |
|----------------------|------------------------|----------------------|
| Safety management \(U_1\) | \(U_{11}\): Accident rate | \(U_{11}\): The ratio of the number of accidents caused by external factors to the number of thousands of sorties |
| | \(U_{12}\): Comprehensive accident rate | \(U_{12}\): The ratio of accident symptoms to 10000 sorties |
| | \(U_{13}\): Integrated Air Traffic management error rate of 10,000 sorties | \(U_{13}\): The ratio of the number of accidents caused by control errors to the number of thousands of sorties |
3.2. Establishing ANP Model for Air Traffic Management Process Quality Management

After a comprehensive analysis of the interaction between the indicators at all levels in the index system, we established a network hierarchical structure model of quality management effectiveness assessment of air traffic control service process, as shown in Figure 2.

- \( U_{14} \): Completeness Rate of Emergency Management System
- \( U_{15} \): Proportion of full-time safety management personnel
- \( U_{21} \): Important Task Implementation Rate
- \( U_{22} \): On-site inspection compliance rate of managers
- \( U_{23} \): Total Labor Productivity
- \( U_{24} \): Annual growth rate of controlled and guaranteed sorties
- \( U_{31} \): Financial Funds Management
- \( U_{32} \): Net growth rate of fixed assets
- \( U_{33} \): cost control
- \( U_{41} \): Controller growth rate
- \( U_{42} \): Growth Rate of Communication Navigation Surveillance Personnel
- \( U_{43} \): Aviation Meteorological Personnel Growth Rate
- \( U_{44} \): Controller Ratio

\( U_{14} \): Ratio of existing emergency management systems to all emergency management systems needed
\( U_{15} \): Ratio of the number of full-time safety management personnel to the total number of front-line personnel
\( U_{21} \): Ratio of the number of important tasks completed to the total number of important tasks
\( U_{22} \): The ratio of the number of on-site inspection to the number of total inspection
\( U_{23} \): Ratio of control results (consecutive accident-free days, etc.) to labor consumption of personnel and equipment
\( U_{24} \): Annual control guarantees the ratio of sorties increment to total sorties
\( U_{31} \): Combination of budget execution rate, procurement plan execution rate, government fund budget execution rate and schedule fluctuation rate in budget execution
\( U_{32} \): Ratio of incremental net fixed assets to total fixed assets
\( U_{33} \): The integration of construction or renewal cost of control system and operation cost of control system
\( U_{41} \): Increased number of controllers (including tower controllers, approach controllers, regional controllers) as compared to the number of original controllers
\( U_{42} \): The ratio of the increased number of conductors to the original number of conductors
\( U_{43} \): The ratio of the increased number of meteorologists to the original number of meteorologists
\( U_{44} \): Ratio of the number of controllers at each level to the total number of controllers
4. Analysis case

4.1. Construct an unweighted initial Super-matrix

The 1~9 scale method is used to compare the factors of the quality management effectiveness model of the Air Traffic management service process of an Air Traffic management station in China according to the criteria, and the judgment matrix based on the triangular fuzzy number is established to represent the importance of the expert. Judging the decision, the weight of each index factor is obtained by defuzzification, and then the initial weighted Super-matrix is obtained. The domestic Air Traffic management industry experts are asked to compare the importance of each element in the above ANP model with the given fuzzy assessment method, and obtain the following fuzzy assessment matrix [12].

Table 2. Fuzzy assessment matrix

| Safety management as a benchmark | Safety Management S | Operation Management O | Financial Management F | Human Resource Management H |
|----------------------------------|--------------------|------------------------|------------------------|-----------------------------|
| Safety Management S              | [1,1,1]            | [1/3,1/2,1]            | [1/4,1/3,1/2]          | [1/4,1/3,1/3]               |
| Operation Management O           | [1,2,3]            | [1/2,1,1]              | [1/5,1/4,1/3]          | [1/4,1/3,1/2]               |
| Financial Management F           | [1,1,2]            | [1,1,1]                | [1/3,1/2,1/2]          | [1/3,1/2,1/2]               |
| Human Resource Management H      | [2,3,4]            | [2,2,3]                | [1,1,1]                | [1/3,1/2,1]                 |

Calculate and obtain the fuzzy judgment matrix F using equation (4):

\[
F = \begin{pmatrix}
(1,1,1) & (0.42,0.75,1.00) & (0.23,0.29,0.42) & (0.25,0.33,0.42) \\
(1.00,1.50,2.50) & (1,1,1) & (0.29,0.42,0.50) & (0.29,0.42,0.50) \\
(2.50,3.50,4.50) & (2.00,2.50,3.50) & (1,1,1) & (0.29,0.42,0.75) \\
(3.00,3.00,4.00) & (2.00,3.00,4.00) & (1.00,2.00,3.00) & (1,1,1)
\end{pmatrix}
\]

Using equation (5) to calculate the importance value of each criterion and other criteria, the initial weight can be obtained.
According to equations (6) to (8), the initial weights $D_{SS}$, $D_{SO}$, $D_{SF}$ and $D_{SH}$ are defuzzified and the results are normalized to obtain the weight vector

$$D_S = (0.35913, 0.35671, 0.13395, 0.15021)^T$$

$Z$ is the security management, operation management, and finance of the reference $U_I$. The normalized weight ordering vector of management and human resource management, from which $w^{(1)}_i = (0.35913, 0.35671, 0.13395, 0.15021)^T$ can be obtained. Similarly, calculating the weight vector based on each element in turn can obtain the weight matrix.

$$A = \begin{bmatrix} 0.35913 & 0.32882 & 0.36031 & 0.36683 \\ 0.35671 & 0.36776 & 0.34429 & 0.30712 \\ 0.13395 & 0.10990 & 0.12618 & 0.14195 \\ 0.15021 & 0.19352 & 0.16923 & 0.18410 \end{bmatrix}$$

By analogy, a two-level indicator unweighted Super-matrix can be obtained.

$$W = \begin{bmatrix} w_{11} & w_{12} & w_{13} & w_{14} \\ w_{21} & w_{22} & w_{23} & w_{24} \\ w_{31} & w_{32} & w_{33} & w_{34} \\ w_{41} & w_{42} & w_{43} & w_{44} \end{bmatrix}$$

### 4.2. Super-matrix Calculation

First, the second-order weighted Super-matrix $A$ is calculated according to the secondary index initial Super-matrix $W$ and the index weight matrix $W$, where $W = (W_{ij})$, $W_{ij} = a_{ij}$. Then calculate the infinite power of the weighted Super-matrix $W$, that is, the limit $W^\infty = \lim_{k \to \infty} W^k$, and the calculated matrix converges to a fixed value, which is the second-level index weight value. The specific results are shown in Table 4:

Due to space limitations, the specific matrix is not listed in the article, and the calculation process is implemented by Matlab and SuperDecisions software.

Then the above matrix is further calculated to obtain the weight value of each three-level index. The specific results are shown in Table 3:

| Second-level indicator labels | Comprehensive assessment weight |
|------------------------------|---------------------------------|
| Security management          | 0.41754                         |
| Operation Management         | 0.34778                         |
| Financial management         | 0.14974                         |
| Human Resources Management   | 0.08494                         |
Table 4. Third-level indicator weight value

| Target Layer       | Factor layer | Index Layer | Based on their respective secondary indicators | Comprehensive assessment weight |
|--------------------|--------------|-------------|-------------------------------------------------|---------------------------------|
|                     |              | $U_{11}$    | 0.30954                                         | 0.129247                        |
|                     |              | $U_{12}$    | 0.10775                                         | 0.044992                        |
| Security management | $U_1$        | $U_{13}$    | 0.11507                                         | 0.048048                        |
|                     |              | $U_{14}$    | 0.12253                                         | 0.05116                         |
|                     |              | $U_{15}$    | 0.3451                                          | 0.144094                        |
|                     |              | $U_{21}$    | 0.41766                                         | 0.145253                        |
| Control effectiveness| $U_2$        | $U_{22}$    | 0.35145                                         | 0.122225                        |
|                     |              | $U_{23}$    | 0.18287                                         | 0.063598                        |
|                     |              | $U_{24}$    | 0.04802                                         | 0.016701                        |
|                     |              | $U_{31}$    | 0.27047                                         | 0.040499                        |
| Financial management| $U_3$        | $U_{32}$    | 0.11264                                         | 0.016866                        |
|                     |              | $U_{33}$    | 0.6169                                          | 0.092373                        |
|                     |              | $U_{41}$    | 0.29294                                         | 0.024883                        |
| Human Resources Management | $U_4$ | $U_{42}$    | 0.22639                                         | 0.01923                         |
|                     |              | $U_{43}$    | 0.12388                                         | 0.010523                        |
|                     |              | $U_{44}$    | 0.35679                                         | 0.030307                        |

5. Analysis result

From Table 4, it can be seen that the accident rate of 10,000 sorties (0.129247), the proportion of full-time safety management personnel (0.144094), the implementation rate of important tasks (0.145253), and the rate of on-site inspection of managers (0.122225) are the main factors affecting the quality management efficiency of Air Traffic management service process. Through the overall analysis of the identified index elements and the AHP model of Air Traffic management service process quality assessment network, we can see that the index with higher weight has a larger impact on other service quality factors, which makes the low quality Air Traffic management service status transfer, thus reducing the overall level of Air Traffic management service.

6. Conclusion

Aiming at the new characteristics and requirements of quality management of Air Traffic management service process, this paper studies the model of quality assessment of Air Traffic management service process. TFN-ANP method is used to quantify the weight of each index in the model, and triangular fuzzy number network analytic hierarchy process is introduced to reduce the impact of the internal relations of each element in the model on the whole. The weight of each index is quantified. Practical examples show that the model can more accurately reflect the actual work situation and meet the needs of high-quality Air Traffic management services, and further reduce the subjectivity of the previous model, becoming more scientific and effective.

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