Quality Assessment of Air Traffic Control System Proximity Control Service Process Based on Principal Component Analysis and Grey Comprehensive Analysis

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Abstract. Aiming at the operational process of air traffic control service, aiming at improving safety and efficiency, this paper analyses the main factors affecting the process of air traffic control service, chooses corresponding indicators, eliminates the indicators with correlation and information overlap by using principal component analysis, determines the key indicators system, and then uses grey comprehensive analysis method to analyze the quality indicators system of air traffic control service process. Through the evaluation, the number of conflict risks of the aircraft in the sector, the sorties flown simultaneously with the aircraft in the same area, the sorties flown simultaneously with the aircraft on the landing route, and the total time occupied by the aircraft on the runway have the most significant impact on the air traffic approach control. This is the case. Finally, the feasibility of this method is verified by an example analysis.

1. Introduction

Air traffic control operation unit is an important part of the air transport system, shouldering the important task of ensuring flight safety. The task of air traffic management is to effectively maintain and promote air traffic safety, maintain air traffic order and ensure smooth air traffic flow.

Cook Andrew et al. used complexity science to study performance evaluation and system design. Through an example of air traffic management, it is shown that complex network theory has higher applicability in performance evaluation than traditional technology [1]. Literature [2-5] studies the impact on air traffic control from the perspective of safety and efficiency. By introducing a linear programming model into the model, Jieguang He et al. proposed a decentralized coordination strategy, which divides air traffic control units into core units composed of multiple sub-units and coordinates the cooperation and competition among sub-units so as to achieve the goal of reducing the operation cost and increasing the efficiency of air traffic control units[6].

At present, experts at home and abroad have conducted in-depth research on the safety, efficiency, employee performance and operation quality of air traffic control system. Many evaluation models have been given, such as Jianping Zhang, Minghua Hu, Zhenya Wu and Ruiping Zhang. Taking Chengdu Terminal Control Area as an example, this paper aims at air traffic flow density, operation safety performance and operation efficiency. The general evaluation index system of rate performance and controllers' workload is adopted. The artificial intelligence evaluation method of BP (back propagation) network model is used to collect data and verify it. Finally, it is compared with the principal component analysis method to verify that the established BP network model can effectively evaluate the quality of
control operation [7]; Jianping Zhang and Minghua Hu, taking Chengdu terminal area as an example, set up a comprehensive evaluation index system through five aspects of traffic congestion, efficiency performance and workload. They used principal component analysis to evaluate the system. Finally, K-means clustering analysis was used to establish the quality evaluation of control operation based on principal component analysis. The method can be used to evaluate the operation quality of single runway terminal area control [8]. Yonggang Wang and Honglang Long, aiming at the performance appraisal characteristics of air traffic control units, draw the model framework of air traffic control unit scorecard, which pays attention to safety, efficiency, cost-effectiveness and other aspects, and carries out a comprehensive and objective evaluation of the performance of regional air traffic control units [9]. Mao Suqin calls on the quantification of safety performance of enterprises, and establishes a system for calculating and evaluating safety benefits of enterprises[10]. However, in the actual control process, the service quality of the control service process is not clearly evaluated. This paper determines to study the control service process.

Air Traffic Management System (ATMS) has the characteristics of complexity, dynamics and variability. There are often variability and uncertainty between its own factors and process service quality, and some factors are difficult to quantify. There is a high grey between factors and factors. Therefore, traditional methods are often difficult to achieve objectivity and science. The essential purpose of principal component analysis is to simplify and synthesize high-dimensional variables, objectively determine the weight of indicators, avoid the inaccurate influence of subjectivity, and then combined with grey comprehensive analysis to determine the degree of correlation between factors, and to improve and verify the results of principal component analysis. Comprehensive principal component analysis and grey comprehensive analysis to study the relationship between many factors in the control process can quickly find out the most influential variables, and scientifically and reasonably rank the impact of these variables on the quality of service in the control process, so as to control the service process of air traffic control units. Quality assessment provides a reliable evaluation method.

2. Basic theory

2.1. Principal Component Analysis

Principal Component Analysis (PCA) is a technique to simplify data sets in statistics. Through appropriate mathematical transformation, the principal components of new variables can be linearly combined with the original variables, and a few principal components which account for a large proportion of the total variation information are selected to analyze things [11].

Overall \( X = (x_1, x_2, \cdots, x_p)^T \), there is a p-dimensional random vector, each of which is an index of investigation. M samples were obtained, and a total of data was obtained. Most of the variations of P variables can be summarized by their respective K (less than p) comprehensive indicators. If the above situation is satisfied, the information in the K "comprehensive indicators" is as much as that in the original P variables, then the K "comprehensive indicators" can be used to replace the original P variables. In this way, M data of P variables are simplified to M data of K "comprehensive index"[12].

2.2. Grey comprehensive analysis method

The purpose of grey relational analysis is to find the important relationship among the factors of the system, and the grey relational degree is the basis of grey relational analysis[13]. The basic idea of the algorithm is to determine the tightness of the relations between the sequences according to the similarity of the geometric shapes of the curves of the behavior sequence[14]. The traditional mathematical statistics methods often require a large number of samples and a certain regularity in statistical analysis. But in practical research, it is often difficult to be satisfied, and the grey correlation degree makes up for this shortcoming. When using correlation degree to analyze data samples, the requirements are not so strict or irregular, and the results of quantitative and qualitative analysis are rarely inconsistent.

3. Evaluation model of quality of regulatory service process
The general idea of establishing the evaluation model of the quality of air traffic control service process is as follows: Firstly, the approach control process is selected as the research object, and the evaluation index system of the quality of the approach service process is established. Combined with the actual control data, the principal component analysis method is used to screen the indicators, eliminating the indicators with correlation and overlapping information. The principal component score of the selected indicators is screened out, and the selected indicators form a new index system. The grey correlation degree is obtained by using grey comprehensive analysis, and then the results of the principal component are verified, and the comprehensive evaluation of the quality of approaching service process is obtained.

3.1. Quality Evaluation Index System of Approach Control Service Process

Based on the operational process of air traffic control service, the system is divided into two dimensions: operational safety and operational efficiency, which include five key elements: security, capacity, efficiency, service and management. That is to say, we choose five indicators to reflect the quality characteristics of access control service process. If the time spent by the controllers in commanding an aircraft is taken as a reference, a starting indicator is established, and each allegation is denominated separately to represent it, as detailed in Table 1 below.

| Index coding | Indicator Meaning |
|--------------|-------------------|
| $x_1$        | The time spent by the controller in commanding the aircraft (s) |
| $x_2$        | Number of collisions (times) between the aircraft in the sector |
| $x_3$        | At the same time, the aircraft entered the airport sorties (times) |
| $x_4$        | Aircraft sorties flown simultaneously on this aircraft’s landing and landing routes (times) |
| $x_5$        | Aircraft sorties flying concurrently with this aircraft in a certain area (times) |
| $x_6$        | Time of flight (s) of the aircraft in a certain area |
| $x_7$        | This aircraft occupies all the runway time (s) |
| $x_8$        | Aircraft sorties leaving the airport at the same time (times) |

Based on the quality evaluation system of approach control service process, the principal component analysis method is used to select indicators from the original data, and then the grey comprehensive analysis method is used to rank the indicators and evaluate them at the same time.

3.2. Principal Component Analysis and Grey Comprehensive Analysis

3.2.1. Construction of raw data matrix. The time spent (s) by the controller in commanding the aircraft, the number of conflicts (times) in the sector, the number of aircraft sorties entering the airport at the same time, and the number of aircraft sorties flying at the same time on the landing route of the aircraft (times); Aircraft sorties flying simultaneously with the aircraft in a certain area (times); flight time (s) of the aircraft in a certain airspace; the aircraft occupies all the time (s) of the runway, and at the same time the aircraft leaves the airport (times).

Assuming that there are $N$ quality evaluation indicators for access control service process and $M$ indicators have been determined, the original data matrix can be constructed as $X = (x_{ij})_{nm}, i = 1, 2, \cdots n; j = 1, 2, \cdots m$. 
3.2.2. Standardized raw data. Because of the different dimensions and dimensions of indicators, in order to unify the dimensions between variables, it is necessary to standardize the original data [15]. Calculate the mean (denoted as $\bar{x}_i = \frac{1}{n+1} \sum_{j=1}^{n+1} x_{ij}$) and standard deviation of each variable (denoted as $s_i = \sqrt{\frac{1}{n} \sum_{j=1}^{n} (x_{ij} - \bar{x}_j)^2}$) for each variable.

$$\bar{x}_i = \frac{1}{n+1} \sum_{j=1}^{n+1} x_{ij}$$  \hspace{1cm} (1)

$$s_i = \sqrt{\frac{1}{n} \sum_{j=1}^{n} (x_{ij} - \bar{x}_j)^2}$$ \hspace{1cm} (2)

$$z_j = \frac{x_j - \bar{x}_j}{\sigma_j}$$ \hspace{1cm} (3)

Where, $i = 1, 2, \cdots m$, a new set of variables $z_1, z_2, \cdots z_m$ is finally obtained.

3.2.3. Computing the correlation coefficient matrix. The standardized data mean is 0 and the variance is 1. The covariance matrix of $m$ variables is the correlation coefficient matrix, that is $R = (r_{jk})_{mm}$, where $r_{jk}$ is the original variable $z_j$, $z_k$ coefficient of correlation.

$$r_{jk} = \frac{1}{n} \sum_{i=1}^{n} z_{ij} z_{ik} (j, k = 1, 2, \cdots m)$$ \hspace{1cm} (4)

3.2.4. Computing the eigenvalues and eigenvectors of the correlation coefficient matrix $R$.

3.2.5. Determination of Principal Components. $X$ can be obtained by finding the eigenvector corresponding to the largest eigenvalue $\lambda_1$ of $R$. Principal Component $I(i = 1, 2, \cdots m)$

$$y_{ji} = e_{i1}x_{j1} + e_{i2}x_{j2} + \cdots + e_{im}x_{jm}$$ \hspace{1cm} (5)

Contribution rate:

$$\frac{\lambda_i}{\sum_{i=1}^{m} \lambda_i} \quad (i = 1, 2, \cdots m)$$ \hspace{1cm} (6)

Accumulated contribution rate:

$$\frac{\sum_{k=1}^{k} \lambda_k}{\sum_{k=1}^{m} \lambda_k} \quad (k = 1, 2, \cdots m)$$ \hspace{1cm} (7)

If the contribution rate of the first $p$ principal component (the cumulative variance contribution rate of the $P$ eigenvalues) reaches 85%, it is considered that the first $p$ principal component contains all the information of the measurement indicators. This not only reduces the number of variables, but also facilitates the analysis of the actual problems of access control, the first $p$ principal component is selected:

$$F_1 = a_{11}X_1 + a_{12}X_2 + \cdots + a_{1p}X_p$$

$$F_2 = a_{21}X_1 + a_{22}X_2 + \cdots + a_{2p}X_p$$

$$\vdots$$

$$F_p = a_{p1}X_1 + a_{p2}X_2 + \cdots + a_{pp}X_p$$ \hspace{1cm} (8)
After obtaining the principal components, the data can be substituted to obtain the comprehensive score of each principal component:

\[ y_{ji} (j = 1,2, \cdots n+1; i = 1,2, \cdots p) \]  
\[ Y_j = \sum_{i=1}^{p} \frac{\lambda_i}{\sum_{k=1}^{m} \lambda_k} \times y_{ji} \]  

Based on the results of the above principal component analysis, the grey correlation degree is analyzed comprehensively.

3.2.6. Ranking of Grey Relevance Degree Step 1) The ideal quality evaluation index set of the new evaluation object is the best, then its comprehensive score \( Y_{n+1} \) is the largest, which is the ideal quality evaluation index score. According to the calculating method of grey relational degree, with \( Y_{n+1} \) as reference and \( Y_j (j = 1,2, \cdots n) \) as the object of comparison, the correlation number \( Y_j (j = 1,2, \cdots n) \) between \( Y_{n+1} \) score of each principal component and (ideal quality evaluation index) score is obtained by relational analysis method, that is:

\[ Y_j = \frac{\min_j [Y_{n+1} - Y_j] + \rho \max_j [Y_{n+1} - Y_j]}{[Y_{n+1} - Y_j] + \rho \max_j [Y_{n+1} - Y_j]} \]  

In this formula, \( \rho \in [0,1] \) takes \( \rho = 0.5 \) in general. Afterwards, the ranking of association degree is performed, i.e.

\[ \xi_j = \frac{1}{k} \sum_{j=1}^{k} y_j \]  

4. Sample analysis
The information of 12 flights recorded on November 18, 2018 was randomly extracted from the air traffic records of an air traffic control authority. SPSS22.0 was used for data analysis. Table 1 shows the original quality index system of ATC service process. Because of the dimension difference between each variable, the numerical variables are standardized and the Z scores of each variable are calculated. Details are shown in Table 2.

4.1. Elimination of overlapping information indicators based on principal component analysis Table 2 is the standardized data, Table 3 is the eigenvalue of each correlation matrix, and table 4 is the comprehensive score. Four principal components were extracted according to the principle of eigenvalue greater than 1. Then according to formula (8), the comprehensive score of comprehensive variable \( F_1, F_2, F_3, F_4 \) is obtained.

| \( F_1 \) | \( F_2 \) | \( F_3 \) | \( F_4 \) |
|----------|----------|----------|----------|
| 0.656x_1 - 0.612x_2 + 0.601x_3 + 0.660x_4 - 0.613x_5 + 0.452x_6 + 0.524x_7 - 0.180x_8 |
| 0.407x_1 - 0.336x_2 + 0.209x_3 - 0.547x_4 + 0.566x_5 + 0.791x_6 - 0.521x_7 - 0.111x_8 |
| -0.444x_1 - 0.142x_2 + 0.544x_3 + 0.045x_4 + 0.262x_5 + 0.121x_6 + 0.202x_7 + 0.847x_8 |
| 0.167x_1 + 0.588x_2 + 0.412x_3 - 0.201x_4 + 0.355x_5 - 0.003x_6 + 0.577x_7 - 0.314x_8 |

Table 2. Standardized data

| \( x_1 \) | \( x_2 \) | \( x_3 \) | \( x_4 \) | \( x_5 \) | \( x_6 \) | \( x_7 \) | \( x_8 \) |
|----------|----------|----------|----------|----------|----------|----------|----------|
| \( z(x_1) \) | \( z(x_2) \) | \( z(x_3) \) | \( z(x_4) \) | \( z(x_5) \) | \( z(x_6) \) | \( z(x_7) \) | \( z(x_8) \) |
which can be used to rank the factors that ultimately affect the quality of the near
the correlation degree of each principal component can be sorted by formula (11) as shown in Table 7,
By synthesizing these four principal components and weighting calculation, the final comprehensive
evaluation score can be expressed as:

\[ Y = 31.164\%F_1 + 22.105\%F_2 + 19.985\%F_3 + 15.259\%F_4 \]

Table 3. Eigenvalues of correlation matrices

| principal component | characteristic value | Contribution rate of variance /% | Cumulative variance contribution rate /% |
|---------------------|----------------------|----------------------------------|------------------------------------------|
| \( x_5 \)           | 2.501                | 31.164                           | 31.164                                   |
| \( x_2 \)           | 1.848                | 22.105                           | 53.269                                   |
| \( x_7 \)           | 1.357                | 16.985                           | 70.249                                   |
| \( x_4 \)           | 1.245                | 15.259                           | 85.508                                   |

Since the target is the cumulative contribution rate component greater than 85%, and combined with the principle of eigenvalue greater than 1, four principal components, namely \( x_2, x_4, x_5, x_7 \), are selected. By synthesizing these four principal components and weighting calculation, the final comprehensive evaluation score can be expressed as:

\[ Y = 31.164\%F_1 + 22.105\%F_2 + 19.985\%F_3 + 15.259\%F_4 \]

Table 4. Comprehensive score

| index | \( F_1 \) score | \( F_2 \) score | \( F_3 \) score | \( F_4 \) score | Comprehensive score |
|-------|----------------|----------------|----------------|----------------|---------------------|
| \( x_2 \)  | -6.1658       | -4.8743        | -2.1726        | 1.1876         | -3.2487             |
| \( x_4 \)  | -4.2875       | -2.9413        | 0.1541         | 2.9983         | -1.4899             |
| \( x_5 \)  | 1.1854        | 3.3872         | 5.3267         | 7.1264         | 3.2894              |
| \( x_7 \)  | 0.1357        | 2.3348         | 4.1764         | 5.8978         | 2.3089              |

Table 5. Selected key indicators

| Index coding | Indicator Meaning |
|--------------|-------------------|
| \( x_2 \)    | Number of collisions (times) between the aircraft in the sector |
| \( x_4 \)    | Aircraft sorties flying concurrently with this aircraft on the landing and landing routes (times) |
| \( x_5 \)    | Aircraft sorties flying concurrently with this aircraft in a certain area (times) |
| \( x_7 \)    | This aircraft occupies all the runway time (s) |

Minimum and maximum values are obtained by min and Max instructions. The correlation coefficients of each principal component can be calculated by formula (10) as shown in Table 6. Then, the correlation degree of each principal component can be sorted by formula (11) as shown in Table 7, which can be used to rank the factors that ultimately affect the quality of the near-regulatory service process.

Table 6. Correlation coefficients of principal components
### Table 7. Grey Relevance Degree of Factors Affecting Air Traffic Control Service Quality

| project | $x_2$ | $x_4$ | $x_5$ | $x_7$ |
|---------|-------|-------|-------|-------|
| content | 0.5197 | 0.3873 | 0.5314 | 0.4237 |
| sort    | 2     | 4     | 1     | 3     |

#### 4.2. Calculating Grey Relevance Degree

The key indexes selected are replaced by the index form $X'$ in the original matrix $X$ to form a new index system. As shown in Table 5, the grey correlation degree is calculated.

#### 5. Result analysis and conclusions

In this paper, the quality assessment method of the near-control service process of ATC system is studied. A general quality assessment model is proposed. By combining principal component analysis and grey comprehensive analysis, the important factors affecting the quality of the near-control service process of ATC system center on safety and efficiency are extracted. The severity of these factors affecting the quality of service process was studied and ranked scientifically and reasonably.

Through the example analysis, the comprehensive score of the index obtained by the principal component analysis method is basically the same as the correlation degree obtained by the grey comprehensive analysis method. It shows the number of collision risks of the aircraft in the sector during the process of approaching control service; the sorties flown simultaneously with the aircraft in the same area; the sorties flown simultaneously with the aircraft on the landing route; the aircraft occupies the runway for all the time during the process of ATC approaching control service. Quality has a very significant impact, and in the same airspace, aircraft sorties flying at the same time with the aircraft have the most significant impact. In the calculation process, the weight of all indicators is based on data, avoiding the use of analytic hierarchy process, expert scoring method mixed subjective factors, can more truly reflect the actual situation in access control. The feasibility and rationality of this method are illustrated by an example analysis. It provides a reliable evaluation method for the control quality of air traffic control units' access control service process.

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