Research on Multi-Temporal Safety Assessment of Approach Control System Based on Multi-Level Extensibility Evaluation Method

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Abstract. Improving the safety of the approach control system is important for flight safety. Through the analysis of the risk in the operation process of the approach control system, the risk factor set is constructed by using the fault tree analysis method. Then, on this basis, the evaluation index system of its operation safety is established, and the weight is determined by using the fuzzy order relation analysis method. Finally, the multi-level safety evaluation model is constructed by using the extensibility method, and given the formula for calculating security assessment over multiple time periods of the day. Taking the operation of Qingdao air traffic control station as an example, the operation safety is evaluated and calculated, the results of the assessment are given, and the suggestions for improving the operation safety of the control system in recent years are given.

1.Introduction

There are many research results on the safety assessment of air traffic control systems at home and abroad. In 2005, Pasquini et al. built a safety assessment application based on the interaction of the operating environment, taking into account the ATC operating environment[1] . In 2006, Massimo first proposed a safety assessment method for air traffic control systems that integrates technical, organizational, and cost factors[2] . In 2010, Bingxiang Zhang et al. proposed an evidence-based safety assessment model for air traffic control systems based on the safety standards of air traffic control systems and their subsystems[3] . In 2018, Lan Ma et al. proposed an air traffic safety risk modeling and assessment method based on rough sets and BP neural networks[4] . In 2019, Tao Wang et al. proposed a safety assessment method for air traffic control based on fuzzy matter- element analysis and combinatorial weighting[5] . In 2022, Jiawen Tanget al. conducted a safety risk assessment of an air traffic control (ATC) system based on game theory and cloud material element analysis[6] . Yu Li et al. constructed a quantitative assessment model of air traffic control safety for night operation in plateau airports based on the set pair analysis theory[7] .

In China, in 2009, Du Hongbing and Wang Xueli used principal component analysis (PCA) to process index data and establish a comprehensive evaluation model for control safety[8] . In 2010, Du Hongbing et al. established an ATC safety risk assessment model based on Fuzzy-ANP based on the characteristics of the interaction of air traffic control safety risk factors[9] . In 2013, Zhang Zhaoning et al. proposed to use a process method to establish a safety assessment model, which can conduct a safety risk assessment of the whole or part of the control system[10] . In 2016, Zhang et al. established a risk assessment model for air traffic control operation based on the fuzzy analytic hierarchy process and combined with the cloud model[11] . Wu Tao and Yang Changqi proposed a security assessment model based on rough set fuzzy neural network[12] . In 2017, Zhang Zhaoning et al. established a risk assessment index system by analyzing the risk factors in the operation of the control system under hazardous weather[13] . In 2018, Yao Dengkai et al. used the fuzzy Petric net algorithm to assess the safety risk of an air traffic controller[14] . In 2021, Tang et al. considered the ambiguity and randomness of various factors affecting the safe operation and support capability of air traffic control, and constructed a cloud model evaluation model to evaluate the safe operation support capability of air traffic control[15] .

The above safety assessment model research includes a variety of technical means based on computer applications, comprehensive technology, fuzzy mathematics, Petri net, neural network and so on. These methods can comprehensively consider the operating environment, risk factors and safety standards of the ATC system, and provide theoretical and methodological support for improving the safety of the ATC system. However, there are some limitations in considering the factors affecting safety risks. Second, it is difficult to ensure the objectivity of the evaluation results due to the influence of the ambiguity of the participants ' thinking in the evaluation process, which needs to be further improved.

Different from the previous work research, this paper analyzes the operation process of the approach control system, uses the fault tree analysis method to construct the risk factor set, obtains the more comprehensive risk factors, and then establishes the safety evaluation index system. Then, considering the influence of the ambiguity of the participants ' thinking in the process of evaluation, the triangular fuzzy number is introduced, and the weight of each index in the index system is determined by the fuzzy order relation method. Finally, a safety level evaluation model of approach control system based on multi-level extended evaluation method is established.

2.Security risk factors for the operation of the approach control system

Fault tree analysis (FTA) is a method that uses logical reasoning to identify and evaluate the risk factors of various information systems. It draws a tree diagram of the possible accident conditions and possible impact results in a given information system and operation according to a certain order and relationship[16] .It can identify and evaluate the risk of various systems, not only can analyze the direct cause of the accident, but also can reveal the potential cause of the accident. This helps organizers and managers to understand the deep-seated mechanism of the accident and develop effective prevention and response strategies.

The approach control system is a dynamic and complex system. The influence of potential risk factors on the safe operation of the system is uncertain and random. The approach control process is a transitional process connecting tower control and area control. It bears the responsibility of aircraft air sequencing and preventing aircraft from colliding with obstacles. Fault tree analysis is a method for system safety analysis, which can be applied to the safety assessment of approach control system. The following are the general steps to construct the fault tree of the factors affecting the operation safety of the approach control system :

1.Determine the research object : determine the specific approach control system or subsystem to be analyzed by fault tree analysis.

2.Identifying the top event : Identifying the final adverse outcome that may lead to an accident or failure.

3.Determine the basic event : Identify the basic events that cause the top event to occur. These basic events are usually specific operational errors, equipment failures, etc.

4.Fault tree construction : Use logic gates (such as ' and ' gate and ' or ' gate) to combine basic events to form a logical path leading to the occurrence of top events.

Based on the fault tree theory, the unsafe operation of the approach control system is taken as the top event. According to the relevant investigation report of the air traffic control unsafe event and through expert analysis, the reasons for the unsafe operation of the approach control system are mainly divided into three categories, namely, the system disposal level reason, the controller workload reason and the operating environment reason. It is used as the intermediate event of the fault tree, and the logical relationship between the first layer is expressed by OR gate. On this basis, the secondary indicators that lead to unsafe events are further summarized, and the basic events of the fault tree are obtained. The fault tree of the factors affecting the operation safety of the approach control system is shown in figure 1 below.

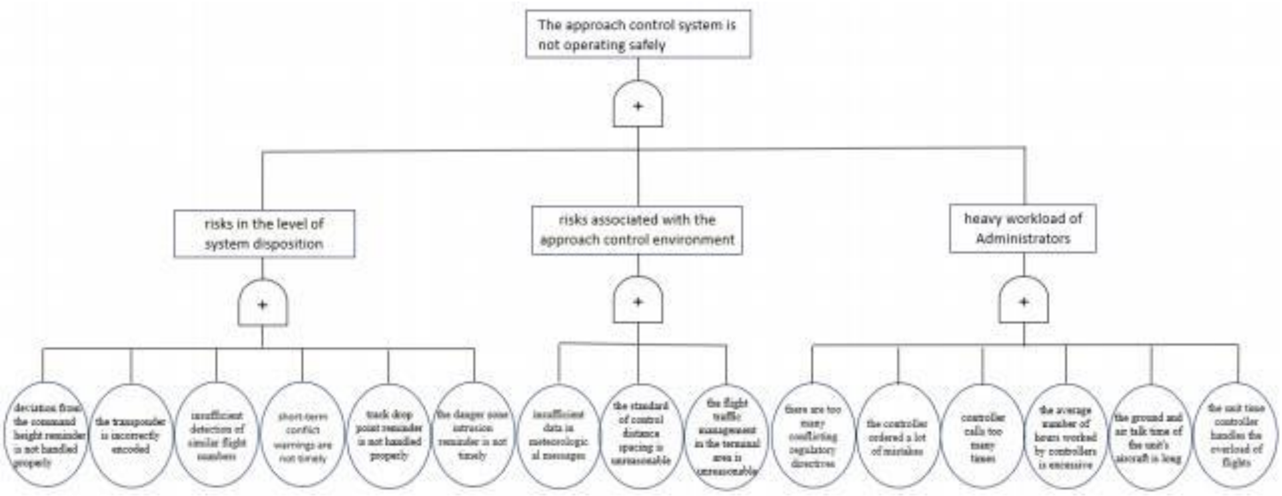

Figure.1. Accident tree of influencing factors for the operation safety

The risk factors of the system disposal level include insufficient detection of similar flight numbers, improper handling of track drop point reminders, untimely short-term conflict alarms, improper handling of deviation command height reminders, untimely reminders of intrusion in dangerous areas, and incorrect transponder coding. And risk factors of the workload of the controller include excessive number of calls by controllers, excessive average working hours of controllers, excessive number of flights handled by controllers per unit time, excessive time of ground and air calls per unit aircraft, and excessive correction and conflict of control instructions. Approach control environment risk factors include unreasonable control distance interval standards, unreasonable flight flow management in terminal areas, and insufficient meteorological message data.

3.A safety evaluation index system for the approach control system

According to the risk factors obtained by the accident tree analysis method, the safety evaluation index system was shown in Table 1 below.

Table 1: Safety evaluation index system of approach control system

1st level index	2nd level index	Unit
System disposition level B_1	x_{11} Number of similar flight number detections x_{12} Handle the number of track drop reminders x_{13} The number of short-term conflict alerts	times/hour times/hour times/hour

	x_{14} Handle the number of times the height of the deviation instruction is reminded	times/hour
	x_{15} Handle the number of hazard zone intrusion alerts	times/hour
	x_{16} Handle the number of low-altitude reminders	times/hour
	x_{17} The number of times the transponder code was correct	times/hour
Controller workload B_2	x_{21} Number of controllers' calls	times/hour
	x_{22} The average number of hours worked by a controller	minute
	x_{23} The number of flights handled by controllers per unit of time	sorties/hour
	x_{24} Aircraft air-ground airtime of the controller unit	minute
	x_{25} The number of times the controller ordered the error to be corrected	times/hour
	x_{26} The number of regulatory directive conflicts	times/hour
Approach control environment B_3	x_{31} Control distance spacing	kilometer
	x_{32} Terminal area flight traffic	sorties/hour
	x_{33} Weather messages	none

3.1 Index dimensionless processing. In order to eliminate the differences in the dimension and value range of the secondary indicators and facilitate the calculation, the indicators are processed without dimension according to Formula (1) (2).

The normalization of the security level increases with the increase of the index value, as shown in Eq. (1), and the normalization of the security level decreases with the increase of the index value, as shown in Eq. (2).

$$b_{ij} = \frac{x_{ij} - min(x_{ij})}{max(x_{ij}) - min(x_{ij})} \tag{1}$$

$$b_{ij} = \frac{max(x_{ij}) - x_{ij}}{max(x_{ij}) - min(x_{ij})} \tag{2}$$

Among them, b_{ij} is the normalized value of the index x_{ij} , $i = 1,2,3; j = 1,2,\ldots,7$. After dimensionless processing, the range of the values of each evaluation index was $[0,1]$.

4.Safety evaluation model for approach control system

According to the constructed safety evaluation index system of the approach control system, the fuzzy order relationship analysis method is used to determine the weights, and finally the evaluation model constructed by extensibility is used to realize the multi-level extensibility evaluation of the safety of the approach control system.

4.1 The fuzzy order relationship analysis method determines the weights. 4.1.1 Determine the order relationship. For an evaluation objective, if the c_i of the evaluation index is more important than or equal to the c_j of the evaluation index, it is recorded as $c_i > c_j$. Ranking the evaluation indicators in order of importance from high to low, we can get a relation, which is recorded as:

$$\widetilde{c_1} > \widetilde{c_2} > \cdots > \widetilde{c_N} \tag{3}$$

Among them, N is the total number of evaluation indicators.

4.1.2 Comparative judgment of relative importance. For any two adjacent indicators, it is assumed that the ratio of the c_{n-1} and the degree of importance of the c_n (also called the importance scale) of the two adjacent indicators of the evaluation objective is r_n, $n = 2,3,\ldots,N-1,N$. For details about the values of r_n, see Table 2 below.

Table 2: Importance scale

Importance scale r_n	Illustrate
1.0	Indicator $\widetilde{c_{n-1}}$ and $\widetilde{c_n}$ are equally important
1.2	Indicator $\widetilde{c_{n-1}}$ is slightly more important than $\widetilde{c_n}$
1.4	Indicator $\widetilde{c_{n-1}}$ is significantly more important than $\widetilde{c_n}$
1.6	Indicator $\widetilde{c_{n-1}}$ is more important than $\widetilde{c_n}$
1.8	Indicator $\widetilde{c_{n-1}}$ is extremely more important than $\widetilde{c_n}$

However, the ambiguity of human judgment is not taken into account, so this paper introduces a trigonometric fuzzy number to give a comparative judgment of the relative importance between $\widetilde{c_{n-1}}$ and$\widetilde{c_n}$.

4.1.3 Triangular fuzzy number representation. Assuming that p experts are involved in the judgment of the importance scale of the evaluation index, the r_n in equation (4) is expressed by a trigonometric fuzzy number, $r_n = (L_{ij}, M_{ij}, U_{ij})$, where $1 \leq i \leq N$, $1 \leq j \leq p$, L_{ij}, M_{ij}, and U_{ij} are the most conservative, probable, and satisfactory judgments of the j-th experts on the i-th importance scale, respectively.

4.1.4 Calculation of the weight factor. According to the operation rules of trigonometric fuzzy numbers, the calculation of $\sum_{n=2}^{N} \prod_{i=n}^{N} r_i$ is also a trigonometric fuzzy number, and the weighted average method is used to deblur the trigonometric fuzzy number, and the accurate evaluation value of the importance scale i is obtained:

$$f_i = \frac{(L_{ij} + 4M_{ij} + U_{ij})}{6} \tag{4}$$

After obtaining the clear values of the importance scale between the indicators, the weight coefficients of the r_n expressions (5) and substituting the clear values f_i into the ordinal relationship analysis method to obtain the weight coefficients (6) and (7) respectively.

$$r_n = \frac{\omega_{n-1}}{\omega_n} \tag{5}$$

$$\omega_n = \left(1 + \sum_{n=2}^{N} \prod_{i=n}^{N} r_i\right) \tag{6}$$

$$\omega_{n-1} = r_n \omega_n \tag{7}$$

4.2 Establish model of multi-level extensibility evaluation. The theoretical basis of the multi-level extensibility evaluation method is the extensible set theory, which integrates qualitative and quantitative perspectives to solve complex incompatibility problems, and its core is the matter-element theory, which is a ternary combination composed of things, features, and the quantities of things about the features [25].

4.2.1 Determine between classic and node domains. Let R represent the matter element, denoted as $R = (N, C, V)$, according to the characteristics of each influencing factor and the size of the security degree of the evaluated thing, different security levels are divided, and the security level domain $N, N = \{N_1, N_1, \dots, N_m\}$ is constructed, where m represents the number of security levels. C is the set of evaluation factors, $C = \{c_1, c_2, \dots, c_l\}$, where l is the number of evaluation factors. Then its classic and node fields are:

$$R_j = [N_j, C, V_j] = \begin{pmatrix} N & c_1 & V_{1j} =< a_{j1}, b_{j1} > \\ \square & c_2 & V_{2j} =< a_{j2}, b_{j2} > \\ \square & \vdots & \vdots \\ \square & c_l & V_{lj} =< a_{jl}, b_{jl} > \end{pmatrix} \tag{8}$$

$$R_N = [N, C, V_N] = \begin{pmatrix} N & c_1 & V_{1N} =< a_{N1}, b_{N1} > \\ \square & c_2 & V_{2N} =< a_{N2}, b_{N2} > \\ \square & \vdots & \vdots \\ \square & c_l & V_{lN} =< a_{Nl}, b_{Nl} > \end{pmatrix} \tag{9}$$

In Eq. (8), V_j is the range of values given by the evaluation factor set C with respect to the safety level N_j , and a_{jl} and b_{jl} are the lower and upper limits of the index c_l in the $j, j = 1,2, \ldots, m$, i.e., the classical domain of the N_j ;and in Eq. (9), the V_N is the range of the given values of the evaluation factor set C for all safety levels N, and the a_{Nl} and b_{Nl} are the lower and upper limits of the index c_l in all security levels,i.e., the nodes of N, respectively.

4.2.2 Determine the element to be evaluated. For the evaluation object, the data obtained from the actual survey are expressed in R_i:

$$R_i = \begin{bmatrix} U_i & c_{i1} & v_{i1} \\ \square & c_{i2} & v_{i2} \\ \square & \vdots & \vdots \\ \square & c_{ip} & v_{ip} \end{bmatrix} \tag{10}$$

where the U_i represents the i-th 1st level index to be evaluated, c_{ik} is the k-th 2nd level index to be evaluated of the i-th 1st level index, and the v_{ik} is the magnitude of the v_{ip} about the c_{ik}, that is, the $k(k = 1,2, \ldots, p)$,the specific evaluation values of the indicators based on the analysis of relevant standards and actual conditions.

4.2.3 Calculate relevance. The correlation function of the second-level index of the safety evaluation of the approach control system c_{ik} on the safety level N_j was established, so as to determine the correlation degree of the k-th 2nd level index on the risk level N_j in the i-th 1st level index $k_j(c_{ik})$.

$$k_j(c_{ik}) = \begin{cases} \frac{\rho(v_{ik}, V_j)}{\rho(v_{ik}, V_N) - \rho(v_{ik}, V_j)}, & v_{ik} \notin V_j \\ \frac{-\rho(v_{ik}, V_j)}{|V_j|}, & v_{ik} \in V_j \end{cases} \tag{11}$$

$$\rho(v_{ik}, V_j) = \left| V_{ik} - \frac{a_{ji} + b_{ji}}{2} \right| - \frac{b_{ji} - a_{ji}}{2} \tag{12}$$

$$\rho(v_{ik}, V_u) = \left| V_{ik} - \frac{a_{Ni} + b_{Ni}}{2} \right| - \frac{b_{Ni} - a_{Ni}}{2} \tag{13}$$

$$V_j = |a_{ji} - b_{ji}| \tag{14}$$

$k_j(c_{ik})$ is the correlation degree of the k-th 2nd level index about the safety level $j(j = 1,2, \ldots, m)$ in the i-th 1st level index.

4.2.4 The relevance of the security level of the first-level indicators. The correlation matrix of the 1st level index to each security level $k(c_i)$ is equal to the weight vector $\omega_i = \omega_{ik}$ multiplied by the correlation matrix of the 2nd level index to each security level $k_j(c_{ik})$.

$$k(c_i) = [\omega_{i1}, \omega_{i2}, \cdots \omega_{ip}] \cdot \begin{pmatrix} k_1(c_{i1}) & k_2(c_{i1}) & \cdots & k_m(c_{i1}) \\ k_1(c_{i2}) & k_2(c_{i2}) & \cdots & k_m(c_{i2}) \\ \vdots & \vdots & \cdots & \vdots \\ k_1(c_{ip}) & k_2(c_{ip}) & \cdots & k_m(c_{ip}) \end{pmatrix} = k_j(c_i) \tag{15}$$

4.2.5 Relevance of the operational safety level of the approach control system. The correlation matrix $K(N)$ of the operation of the approach control system to each safety level is equal to the weight vector of the 1st level index $\omega =$ （ω_j） multiplied by the correlation degree of the 1st level index to each safety level $K(C) = k(c_i)$.

$$k(N) = [\omega_1, \omega_2, \cdots \omega_n] \cdot \begin{pmatrix} k_1(b_1) & k_2(b_1) & \cdots & k_m(b_1) \\ k_1(b_2) & k_2(b_2) & \cdots & k_m(b_2) \\ \vdots & \vdots & \cdots & \vdots \\ k_1(b_n) & k_2(b_n) & \cdots & k_m(b_n) \end{pmatrix} = k_j(N) \tag{16}$$

4.2.6 Determine the level of security. According to the principle of maximum membership, the safety risk level corresponding to the maximum value of the correlation degree in the correlation matrix $k(N)$ of the operation safety of the approach control system for each safety level is its safety risk level, and if it meets the $k_{j0}(N) = \underset{j=\{1,2,\cdots m\}}{max}\,(k_j(N))$,the safety level of the object N is called the level j_0.

$$\bar{k}_j(N) = \frac{k_j(N) - \min_j k_j(N)}{\max_j k_j(N) - \min_j k_j(N)} \tag{17}$$

$$j^* = \frac{\sum_{i=1}^m j \cdot \bar{k}_j(N)}{\sum_{i=1}^m \bar{k}_j(N)} \tag{18}$$

$\bar{k}_j(N)$ is the dimensionless evaluation level after the extreme treatment, and j^* is the variable eigen-value of the security level of the target layer, that is, the degree of the security level.

4.2.7 The approach control system safety value formula is obtained. The characteristic value of the safety level is normalized and the approach safety value S_j is defined, and the calculation formula is expressed as follows:

$$S_j = \frac{(5 - j^*)}{5} \times 100\% \tag{19}$$

In the formula, the S_j are sorted according to the size of the approach, and the safety level of the approach control system is compared for different time periods, and the larger the S_j, the higher the safety.

4.3 Formula for calculating the weighted average operational safety value of daily flights. Since the operation of the approach control system is a cycle every day, the time range for the evaluation of the secondary indicators is a day. Considering the idle period and busy period of operation, the time from 08:00 to 22:00 in a day is divided into periods. Each hour is a period. The secondary indicators are evaluated in different periods, so that the security of each day can be evaluated.

First, perform a safety evaluation for each hour period, which is obtained from the previous formula. Then the safety evaluation value of the approach control system for one day is given, which is the weighted average safety value of the flight movements on that day.

Assume that the weighted average safety value of daily flight movements is E_p, and the safety level is represented by E_p. The calculation formula is as follows: the hourly flight flow is multiplied by the ratio of the corresponding safety value to the total flight flow.

$$E_p = \frac{F_i * E_i}{\sum F_i} \tag{20}$$

In the formula, F_i represents the average hourly traffic corresponding to the i period, and E_i represents the safety value corresponding to the i period.

The detailed evaluation process is shown in Figure 2.

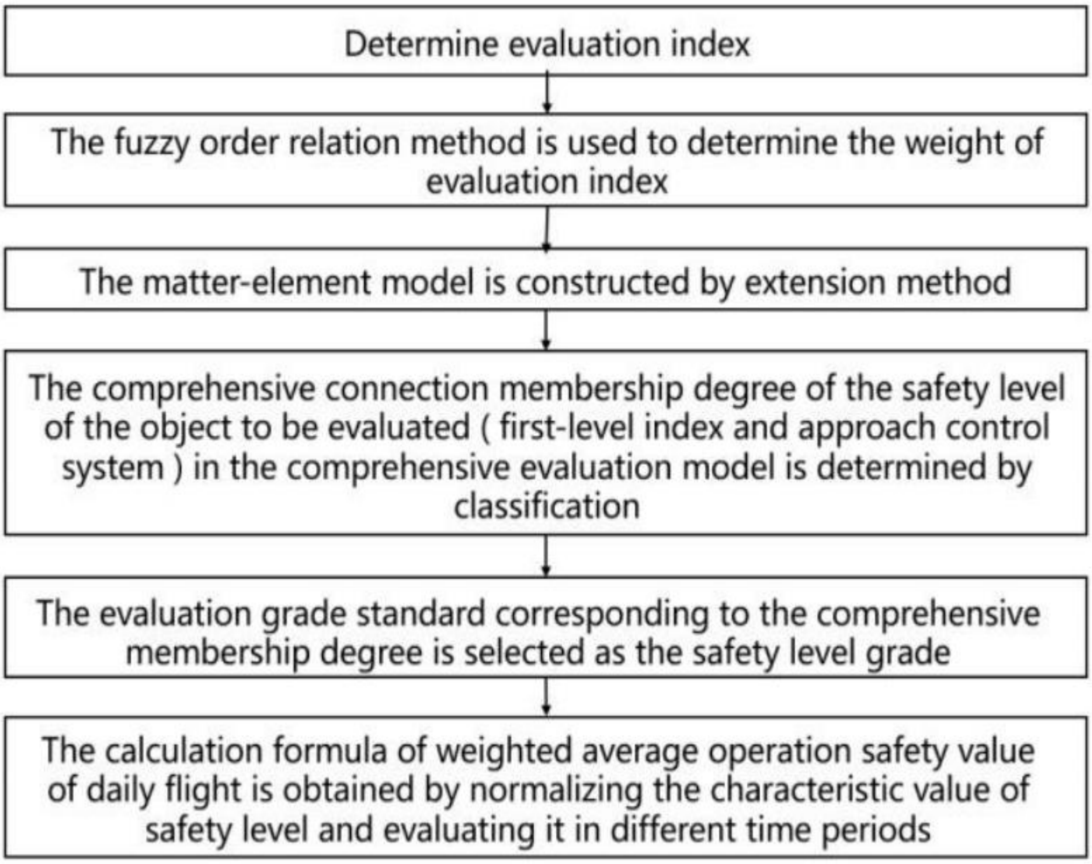

Figure.2. Technology roadmap

5.Example analysis

The operation of the approach control system of Qingdao air traffic control station is selected to verify the validity and feasibility of the model. The main responsibilities of Qingdao Air Traffic Control Station include coordinating and controlling aircraft routes, flight take-off and landing and air traffic in the jurisdiction to ensure flight safety and efficiency.

5.1 Determine the safety level classification standards for secondary evaluation indicators. According to the safety evaluation index system of the approach control system, for each index, it is divided into five levels according to the safety level : very good (K1), good (K2), general(K3), poor (K4), very poor (K5), collect data and carry out calculation and evaluation. The specific data of each index in each period of 5 days are collected from the Qingdao approach control system, and the questionnaire is made to provide this part of the data and the safety level classification schedule for experts to refer to and discuss. Through the analysis of the collected index data and expert opinions, the classification criteria of each evaluation index level can be obtained, as shown in Table 3.

Table 3: Classification criteria for safety evaluation of approach control systems

1st level index	2nd level index	Security level				
		Very good K1	Better K2	average K3	Poor K4	Very poor K5
System disposition	x_{11}	[10,8]	[8,6]	[6,4]	[4,2]	[0,2]
	x_{12}	[10,8]	[8,6]	[6,4]	[4,2]	[0,2]
	x_{13}	[10,8]	[8,6]	[6,4]	[4,2]	[0,2]
	x_{14}	[10,8]	[8,6]	[6,4]	[4,2]	[0,2]

level	x_{15}	[10,8]	[8,6]	[6,4]	[4,2]	[0,2]
	x_{16}	[10,8]	[8,6]	[6,4]	[4,2]	[0,2]
	x_{17}	[10,8]	[8,6]	[6,4]	[4,2]	[0,2]
Controller workload	x_{21}	[6,8]	[8,10]	[10,12]	[12,14]	[14,16]
	x_{22}	[25,30]	[30,35]	[35,40]	[40,45]	[45,60]
	x_{23}	[50,45]	[45,40]	[40,35]	[35,30]	[30,25]
	x_{24}	[5,10]	[10,15]	[15,20]	[20,25]	[25,30]
	x_{25}	[4,6]	[6,8]	[8,10]	[10,12]	[12,15]
	x_{26}	[4,6]	[6,8]	[8,10]	[10,12]	[12,15]
Approach control environment	x_{31}	[20,22]	[22,24]	[24,26]	[26,28]	[28,30]
	x_{32}	[50,60]	[60,70]	[70,80]	[80,90]	[90,100]
	x_{33}	[10,8]	[8,6]	[6,4]	[4,2]	[0,2]

5.2 Determine the weight of indicators at each level. According to the fuzzy order relationship analysis method, the values of the secondary indicators are first standardized according to equations (1) and (2). Then, combined with Table 2, the importance scale of the secondary indicators was obtained by the experts'scores r_n. Then, the r_n is expressed by the trigonometric fuzzy number, and the trigonometric fuzzy number is deblurred by the weighted average method of Eq. (4) to obtain the accurate evaluation value of the importance scale f_i. The weights of the r_n expressions (5) and the clear values f_i are substituted into the equations (6) and (7) of the ordinal relationship analysis method, and their weight coefficients are obtained, respectively. Determine the weight of the safety evaluation indicators for the approach control system.

The weight values of the secondary indicators $x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}, x_{17}$ are 0.09, 0.11, 0.16, 0.19, 0.15, 0.13, 0.17 respectively, and the weight values of the primary indicator, the system disposition level, are 0.298. The weight values of the secondary indicators $x_{21}, x_{22}, x_{23}, x_{24}, x_{25}, x_{26}$ are 0.18, 0.14, 0.23, 0.13, 0.17, 0.15 respectively, and the weight values of the primary indicator, the controller workload, are 0.431. The weight values of the secondary indicators x_{31}, x_{32}, x_{33} are 0.39, 0.28, 0.33 respectively, and the weight values of the primary indicator, the approach control environment, are 0.271.

5.3 Safety assessment results and analysis of approach control system operation. According to the established safety evaluation model of the approach control system, the secondary indicators of the Qingdao approach control system on atypical day in each period of the day were first collected. Taking the Qingdao approach control system as an example, the matter element R is established, and its classic domain R_j , node domain R_N and the matter element to be evaluated R_i are determined. Combined with the integrated weights of indicators at each layer in Table 4 and the determined matter elements to be evaluated, the correlation degree is calculated with reference to formulas (11)-(14). Carry out multi-level extension evaluation with reference to formulas (15) and (16) to obtain the correlation between indicators and each security level. According to the principle of maximum correlation, the safety levels of various operating indicators of the Qingdao approach control system can be obtained from equations (17) and (18), and substituted into equation (19) to obtain the safety values of each safety level. Then, according to Equation (20), the safety evaluation value of the approach control system for one day is given, which is the weighted average safety value of the flight movements on that day. Determine and calculate the 8:00-22:00 safety value for the typical daily average Qingdao approach, as shown in Table 4, and make the safety value change trend chart, as shown in Figure 3.

Table 4 Safety evaluation values for approach control systems

Time period	The value of the approach control safety evaluation index and the results of the safety value of each period																	
	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{31}	x_{32}	x_{33}	Number of flights	safety value
8:00-9:00	8	6	7	7	6	7	6	7	25	46	5	6	9	21	65	7	47	89.52%
9:00-10:00	6	6	7	9	7	8	6	7	26	45	8	6	7	20	70	8	46	89.55%
10:00-11:00	8	8	6	7	7	7	7	8	26	42	6	7	7	22	72	8	35	89.97%
11:00-12:00	5	4	8	9	8	8	6	7	27	46	10	7	8	22	63	7	43	89.73%
12:00-13:00	6	6	8	6	8	6	8	10	29	42	9	8	6	21	60	9	41	89.80%
13:00-14:00	7	7	7	8	6	7	7	9	28	48	8	6	6	20	82	8	53	89.58%
14:00-15:00	8	5	8	8	7	7	6	9	29	48	5	6	7	21	71	9	51	89.57%
15:00-16:00	8	6	8	7	6	7	6	7	26	42	6	6	9	20	66	7	42	89.63%
16:00-17:00	6	8	7	7	7	7	6	7	28	45	6	8	7	22	67	7	36	89.75%
17:00-18:00	8	6	6	9	6	8	6	7	28	40	5	6	7	21	72	8	39	89.42%
18:00-19:00	6	6	8	9	7	8	8	10	27	44	8	6	7	20	63	8	34	89.75%
19:00-20:00	5	4	7	8	8	7	7	8	29	40	10	7	6	22	82	8	51	89.71%
20:00-21:00	8	5	8	6	8	7	7	9	28	42	9	6	8	21	72	9	52	89.53%
21:00-22:00	7	7	7	8	6	6	6	9	29	48	7	7	6	20	70	9	53	89.78%

Figure.3. The safety value change trend at 8：00-22：00

Through the analysis of the change trend of the safety value in Fig.3 and the analysis of the data of each index in Table 4, it can be seen that (1) due to the relatively low number of reminders for processing the deviation from the instruction height and the low number of correct transponder coding, the safety value from 8：00 to 9：00 is at a low level, second only to 17：00 to 18：00. In addition, the number of flights handled by the controller and the low accuracy of meteorological reports are also the main reasons for the low safety value from 8 to 9 o 'clock. (2) With the increase of the number of similar flight number detection, the number of processing track drop point reminders, and the decrease of the number of flights and the number of control instruction conflicts, the safety value increases, and reaches the maximum at 10 o 'clock. (3) From 10：00 to 11：00, the average working hours of controllers are the lowest among the whole, and the control distance interval is the largest, which is also the reason why the safety value (89.97%) is the largest throughout the day. (4) Starting from 11：00, the number of similar flight number detection and processing track drop point reminders is reduced, and the controller 's working hours and the number of processed flights are increased, resulting in a gradual decrease in the safety value. (5) It is worth noting that between 12：00 and 13：00, the terminal area flight flow is the lowest on the day, and the accuracy of meteorological reports is the highest, which makes the safety value rise. (6) Between 14：00 and 17：00, the reason for the slow rise of the safety value is that the number of power-down reminders in the processing track increases, the number of controller calls and the flight flow in the terminal area decrease. (7) From 17：00 to 18：00, the number of low-altitude reminders and the correct number of transponder codes are the lowest throughout the day, and the controller 's working hours and terminal area flight traffic are large. These are undoubtedly the reasons for the lowest safety value of the day (89.42%). (8) Between 19 : 00 and 20 : 00, although the number of flights in the terminal area, the length of controller 's working hours and the time of land and air calls that are not conducive to the safety value are the largest throughout the day, the number of intrusion reminders in the dangerous area and the control distance interval are the largest on the same day. At the same time, the number of flights handled by the controller and the number of command conflicts are the lowest on the same day. The combined effect of these factors leads to the safety value of the time period at a medium level.

From the discussion and analysis of controllers and experts, it can be seen that the results are in line with the actual situation and verify the effectiveness of the model. The model can be used to see the safety of the approach control system in each period of the day. When the safety assessment value is found to be low, precautions can be taken in time to solve the quantitative representation of the real-time safety level during the operation of the approach control system. The model can be used to identify safety problems, and the assessment results can effectively analyze the safe operation of the approach control system every day, which is helpful for safety development.

According to the analysis and discussion of the results, the corresponding suggestions for improving the operation safety of the control system are given as follows : for the work part of the controller, the training and assessment of the controller can be strengthened, the control operation can be standardized and regularized, and the workload of the controller caused by the unreasonable and unskilled control work can be reduced scientifically ; carry out flow control on flight flow to prevent aircraft flow from exceeding capacity, leaving capacity margin ; aiming at the harsh airspace environment, multiple simulation exercises are carried out to simulate scenarios such as large flow and airspace restrictions, so as to improve the system 's compressive capacity. At the same time, the supervision of the site should be strengthened, and the error subject should be reminded in time.

6.Conclusion

By analyzing the risks during the operation of the approach control system, this paper establishes an evaluation index system for the operation safety of the approach control system, uses the fuzzy sequential relationship analysis method to determine the weight, and constructs a multi-level safety evaluation model for the approach control system. And combined with the actual operation of the approach control system of Qingdao Air Traffic Control Station, the typical daily safety assessment of Qingdao's approach control system from 8:00 to 22:00 shows that the highest daily safety value of the approach control system is 89.97%, weighted by the number of daily flights. The average safety value is 89.66%. The effectiveness of the safety evaluation model is verified, and an effective solution is proposed for the safe operation of the control system.

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