Frontiers in Computing and Intelligent Systems
ISSN: 2832-6024 | Vol. 14, No. 1, 2025

Research on Airport Clearance Risk Assessment Based on Combination Weighting Method - Cloud Model

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Abstract: To address the problems existing in the current domestic airport clearance safety evaluation system, such as static indicator system, subjective weight allocation, and difficulty in dynamic adjustment, a three - level evaluation indicator system covering three modules, namely regulatory system guarantee, obstacle control, and operation monitoring, was constructed. Subjective opinions were collected through expert questionnaires, and the combination weighting method combining Analytic Hierarchy Process (AHP) and Entropy Weight Method (EWM) was used to quantify the importance of each indicator. The cloud model was introduced to model the uncertainty in the evaluation results, and a dynamic adjustment mechanism for risk levels and indicator thresholds was proposed. Taking a certain airport as a case study, the verification results show that this system can effectively identify high - risk indicators, clarify the boundaries of risk classification, and significantly improve the evaluation efficiency and operability.

Keywords: Airport Clearance Safety; Risk Assessment; Combination Weighting; Cloud Model.

1. Introduction

With the continuous advancement of the construction of "safe, green, smart and humanistic airports", more than 90% of hub airports have deployed runway foreign object monitoring systems and widely adopted emerging technologies such as drone inspections and three-dimensional laser scanning, which effectively supported the development of refined management of airspace safety. "ICAO Annex 14: Airports" [1]provides unified standards for obstacle restriction and airspace protection at airports, from geometric design to daily maintenance of airspace surfaces. "Procedures for Air Navigation Services - Aircraft Operations (PANS - OPS)" [2]provides technical requirements for obstacle avoidance based on flight performance in the design dimensions of approach and departure procedures. At the domestic level, "Regulations on the Safety Management of Civil Airport Operations" [3]clearly define the division of responsibilities of airports, local governments and civil aviation authorities in airspace protection, and incorporate the preparation, filing and airspace protection agreements of obstacle restriction charts into the statutory management process. With the continued emergence of new low-altitude threats, traditional static control models are no longer adequate. The number of registered drones nationwide has exceeded 1.2 million, electromagnetic interference incidents have increased by an average of 27% annually, and urban expansion has led to frequent violations of high-rise building regulations in cleared airspace. To address these challenges, the Civil Aviation Administration of China revised the "Management Measures for Cleared Airspace Protection at Transport Airports" in 2022, establishing a digital monitoring platform for cleared airspace areas. This upgrades risk prevention and control from a "passive handling" approach to an "active early warning" model, laying the institutional and technical foundation for building a dynamic and intelligent clear airspace risk assessment system. Therefore, this article will construct an airport clear airspace safety risk assessment system tailored to my country's national conditions, providing a theoretical basis and technical channels for improving the overall safety management level of my country's airports.

In recent years, domestic and foreign scholars have conducted extensive explorations on the theoretical methods and practical applications of clearance safety risk assessment, and have formed a variety of research methods and results. At present, GIS technology and spatial information technology are widely used in China, and airport clearance safety research has shown a diversified and sophisticated development momentum. Cheng Xiaokang et al. [4]used a three-dimensional GIS platform to construct an airport clearance restriction surface visualization model, which can intuitively display the spatial position and height of obstacles, laying a solid foundation for subsequent quantitative analysis. Shen Yingzheng et al. [5] designed an obstacle spatial information calculation method and developed a corresponding program, which effectively improved the timeliness and accuracy of obstacle data in the clearance protection area. Zhang Le and Qin Xianfeng [6]studied the planning and control of temporary obstacle heights, combined the measured data with the height limit surface model specified in the specification, and proposed a dynamic inspection and rapid response mechanism to effectively prevent construction and temporary facilities from invading the clearance restriction surface. In terms of multi-source detection and fusion, Chen Weishi et al. [7]systematically reviewed the multi-sensor detection technology for birds and drones, emphasizing that the existing single monitoring method is difficult to fully cover the new threats faced by low-altitude aircraft, and it is necessary to build a comprehensive monitoring system that integrates multiple modes such as radar, optics, and radio fingerprints. Wen Jun and Fan Zhixiang [8]used evolutionary game theory as an entry point to explore the game relationship and coordination mechanism between the main bodies of air clearance safety supervision, providing new insights for the establishment of a dynamic supervision model. Abroad, in terms of the construction of the airport air clearance safety risk assessment system, there is also a clear trend of interdisciplinary, multi-source data fusion and dynamic management. The integrated application of GIS platform and digital elevation model has become a necessary means of basic research. Nguyen and Do [9]proposed a GIS-based obstacle clearance assessment method, which uses spatial overlay analysis of the precision approach procedure restriction surface and existing terrain and buildings to achieve quantitative judgment of obstacle intrusion risk. Smith and Brown [10]then further integrated multi-sensor data (including ground LiDAR scans, airborne ADS-B trajectories, radar echoes, etc.) to construct a dynamic obstacle recognition model, achieving a transformation of obstacle detection from "post-event review" to "online continuous monitoring". In the monitoring of new low-altitude threats, Müller and Schubert [11]used machine learning algorithms to confirm the threat of bird strikes and drone activities in real time, and then linked the detection results with flight program design software to achieve advance warning of bird flocks or group drone activities. At the same time, risk quantification models and simulation evaluation methods are also maturing. Wang and Lee [12]used Monte Carlo simulation to conduct a large number of random simulations on the obstacle clearance margins and uncertainties corresponding to various airport approach and departure procedures, forming a risk level classification framework model based on probability distribution, which provides a scientific basis for the threshold definition of clearance evaluation indicators. Rossi and Bonomi [13]advocated combining airborne ADS-B trajectory data, three-dimensional terrain models and control procedure restriction surfaces to construct a "dynamic clearance risk field" model, using continuous risk field visualization to reveal the spatial propagation law of obstacle risks, bringing methodological innovation to comprehensive risk assessment across procedures and time periods.

In summary, while research both domestically and internationally has made significant progress in technological innovation and theoretical model development, existing indicator systems still face several shortcomings and challenges. First, indicators are redundant and missing. Some indicators (e.g., obstacle height) cover multiple evaluation dimensions, while emerging risks (e.g., drone activity and dynamic changes in the meteorological environment) lack targeted indicators. Second, weight assignment is highly subjective. Existing evaluation systems often rely on expert experience, which is susceptible to individual cognitive differences and results in objectively inappropriate evaluations. Finally, dynamic adaptability is insufficient. Existing systems often focus on static environments and struggle to reflect real-time risk changes in airspace areas. Therefore, this paper integrates the weighting results of the AHP and EWM methods and constructs a combined weighting model using a coupling function. A cloud model is introduced to calculate the membership and weighting of each risk indicator, thereby constructing an airport airspace safety risk assessment system based on multi-source information fusion and dynamic risk assessment. This system contributes to improving the theoretical framework of airport airspace safety and promoting the in-depth development of multidisciplinary aviation safety research.

2. Airport Clearance Safety Risk Assessment Index System

Table 1. Airport clearance safety risk assessment index system

First-level indicators	Secondary indicators	Level 3 indicators
Laws, regulations and management *guarantees*	Airport Obstacle Limitation Chart *D* 1	Does the obstacle restriction map conform to the actual plan? *C* 1
		Obstacle restriction map immediate filing *C* 2
	Airport Clearance Protection Agreement and Regulations *D* 2	Are the contents of the published specific management regulations for airport airspace protection complete? *C* 3
		Is there an airport airspace protection agreement *C* 4
Safeguards Control and Environmental Risk *Management*	Behavior that affects flight safety *D* 3	Smoke emission *C* 5
		Shooting range, explosives warehouse *C* 6
		Lights, signs, and objects that affect flight safety *C* 7
		Plants that affect the use of civil airport navigation aids *C* 8
		Burning to release smoke, fireworks, etc. *C* 9
		Places that attract birds and other animals *C* 10
	Precision approach runway area interference obstacles *D* 4	Fixed or moving objects within the approach plane *C* 11
		Fixed or moving objects within the inner transition surface *C* 12
		Fixed or moving object within the missed approach surface *C* 13
	New obstacle *D* 5 added to the takeoff and climb control area	Are there any new obstacles when leaving the airport in a straight line? *C* 14
		Whether there are new obstacles during designated altitude/turn departure *C* 15
		Are there any new obstacles on the multi-turn departure path? *C* 16
		Specify whether there are new obstacles when turning and leaving the TP *C* 17
	Are there any obstacles in the approach control area? *D* 6	Visual approach, are there any obstacles? *C* 18
		Are there obstacles during non-precision approach? *C* 19
		Is there any obstacle during precision approach? *C* 20
	Is there any obstacle in the missed approach segment? *D* 7	Is there any obstacle during the missed approach after the final approach? *C* 21
		Is there any obstacle during the missed approach in the precision segment? *C* 22
	Is there any obstacle in the side clearance area? *D* 8	Is there any obstacle on the transition surface? *C* 23
		Is there any obstacle on the inner horizontal surface? *C* 24
		Is there any obstacle on the conical surface? *C* 25
	Other obstacles or objects *D* 9	Objects not projecting above the approach surface but which adversely affect the performance of visual or non-visual aids *C* 26
		Objects that relevant departments believe will be harmful to aircraft operations within the activity area, inner horizontal surface or cone surface *C* 27
Operation monitoring and dynamic management *K*	Behavior that affects flight safety *D* 10	Clearance protection area inspections are conducted less than once a week *C* 28
		Inspection of barrier-free areas is conducted less than once a day *C* 29
	Precision approach runway area interference obstacles *D* 11	Inspection contents must comply with regulations *C* 30
		Is the inspection record complete? *C* 31
	New obstacle *D* 12 added to the takeoff and climb control area	Whether the location and height of new obstacles are reported to *C* 32 in a timely manner
		Is the airport clearance management file sound? *C* 33

Based on expert research and literature review, in order to achieve the systematization, standardization and operationalization of air clearance safety governance, the airport air clearance safety risk assessment index system is constructed according to the three-in-one logical path of "system design - on-site control - dynamic operation". It can be divided into three dimensions: laws and regulations and management guarantee, obstacle control and environmental risk management, and operation monitoring and dynamic management. Each dimension is composed of secondary indicators. Combining the current laws and regulations and the airport's modern governance requirements for air clearance risks that are "identifiable, assessable, controllable, and traceable" in a highly dynamic operating environment, 33 third-level evaluation indicators were finally determined, as shown in Table 1. The evaluation index system has a clear structure and rigorous logic. The three modules complement each other and jointly support the comprehensive assessment system of airport air clearance safety risks, realizing closed-loop management of the entire process from system construction, physical identification to dynamic operation and maintenance.

3. Empowerment of the Risk Assessment Indicator System

3.1. AHP - Analytical Hierarchy Process

In this study, AHP was used to assign weights to airport clearance safety risk assessment indicators. Specifically, by constructing a judgment matrix, conducting expert scoring, and performing consistency tests, the relative weights of each indicator in the evaluation system were calculated. This effectively solved the problem of diverse indicators and varying degrees of impact, ensuring the scientific and logical nature of the evaluation process. The specific implementation process is as follows:

(1) Construct the evaluation matrix, see formula (1):

$$A=(a_{ij})_{n\times n} \qquad i,j=1,2,\cdots,n \tag{1}$$

Where, n is the number of indicators; is the comparison result between indicator a_{ij} i and indicator j in the airport clearance system .

(2) Normalize the columns of the evaluation matrix, see formula (2):

$$\overline{a_{ij}}=\frac{a_{ij}}{\sum_{j=1}^{n}a_{ij}} \qquad i,j=1,2,\cdots,n \tag{2}$$

(3) The evaluation matrix is summed row by row, as shown in formula (3):

$$W_i=\sum_{j=1}^{n}\overline{a_{ij}} \qquad i=1,2,\cdots,n \tag{3}$$

(4) Normalize the row vector to obtain the AHP evaluation weight $\overline{W_i}$. See formula (4):

$$\overline{W_i}=\frac{W_i}{\sum_{i=1}^{n}W_i} \qquad i=1,2,\cdots,n \tag{4}$$

(5) Calculate the maximum characteristic root, see formula (5):

$$\lambda_{\max}=\sum_{i=1}^{n}\frac{(A\overline{W})_i}{n(\overline{W})_i} \tag{5}$$

(6) Calculate the consistency index and perform consistency test. See formula (6):

$$I_C=\frac{\Lambda_{\max}-n}{n-1} \tag{6}$$

3.2. EWM-Entropy Weight Method

EWM does not rely on subjective judgment and can effectively reflect the variation characteristics of the data itself. It has the advantages of strong objectivity and stable calculation results. In this study, the introduction of the entropy weight method can serve as a beneficial supplement to the AHP method, reducing the subjective image of AHP, improving the rationality of weight allocation and data-driven capabilities, and providing a more accurate weight basis for airport clearance safety risk assessment. The specific calculation process is as follows:

(1) Index normalization processing, see formula (7):

$$Y_{ij}=\frac{B_{ij}-(B_{ij})_{\min}}{(B_j)_{\max}-(B_j)_{\min}} \tag{7}$$

Where i is the evaluator number; j is the evaluation indicator number; is Y_{ij} the evaluation value of the B_{ij} *i -th evaluator* under the *j -th evaluation indicator* after normalization ; is the evaluation value of the *i -th evaluator* under the *j -th evaluation* indicator; $(B_{ij})_{\min}$ is the minimum value in the original data; $(B_j)_{\max}$ is the maximum value among the evaluation indicators in the $(B_j)_{\min}$*j- th row;* is the minimum value among the evaluation indicators in the *j -th row.*

(2) Calculation P_{ij} , see formula (8):

$$P_{ij}=\frac{Y_{ij}}{\sum_{i=1}^{m}Y_{ij}} \tag{8}$$

Where, P_{ij} is the proportion of the *i- th evaluator* under the *j -th indicator; m* is the number of evaluators.

(3) Calculate the index entropy value, see formula (9):

$$e_j=-\frac{1}{\ln m}\sum_{i=1}^{m}P_{ij}\ln P_{ij} \tag{9}$$

Where, e_j is the entropy value of the j-th evaluation index.

(4) The EWM entropy weight and EWM-weight under the computer field clearance safety evaluation index system.

$$H_j=\frac{1-e_j}{n-\sum_{j=1}^{n}e_j} \tag{10}$$

Where, H_j is the entropy weight of the j - th indicator; n is the number of indicators.

3.3. Portfolio Empowerment

In order to fully integrate the subjective information of expert judgment with the objective characteristics of data-driven, this paper uses the geometric mean normalization method to couple the weights obtained from AHP and EWM. This method can effectively reflect the consistency and coordination of subjective and objective evaluation results while keeping the sum of weights equal to 1, thereby improving the scientificity and credibility of risk assessment results [14]. The specific steps are as follows:

(1) The weights of each indicator are obtained by W_j

assigning weights using the AHP method, as shown in Table 2.

(2) The objective weights are determined by the EWM method to obtain the weights of each indicator H_j, as shown in Table 3.

Table 2. AHP calculation weights

index	Weight
C 1	0.115
C 2	0.047
C 3	0.019
C 4	0.042
C 5	0.026
C 6	0.012
C 7	0.005
C 8	0.022
C 9	0.012
C 10	0.004
C 11	0.001
C 12	0.009
C13	0.005
C14	0.070
C15	0.042
C16	0.024
C17	0.014
C18	0.130
C19	0.065
C20	0.032
C21	0.016
C22	0.050
C23	0.029
C24	0.017
C 25	0.010
C 26	0.045
C 27	0.022
C 28	0.011
C 29	0.039
C 30	0.013
C 31	0.050
C 32	0.033
C 33	0.040

(3) weights H_j of each indicator obtained in steps (1) and (2) are used W_j to calculate the comprehensive weight D_j, as shown in formula (11):

$$D_j = \frac{\sqrt{W_j H_j}}{\sum_{j=1}^{n} \sqrt{W_j H_j}} \tag{11}$$

Wherein, D_j is the comprehensive weight of the W_j *j- th indicator;* is the subjective weight of the H_j *j- th indicator* obtained by the AHP method ; is the objective weight of the *j-* th indicator obtained by the entropy weight method; $\sqrt{W_j H_j}$ represents the combined influence of subjective and objective weights represented by geometric mean .

The final comprehensive weight of each indicator is shown in Figure 1.

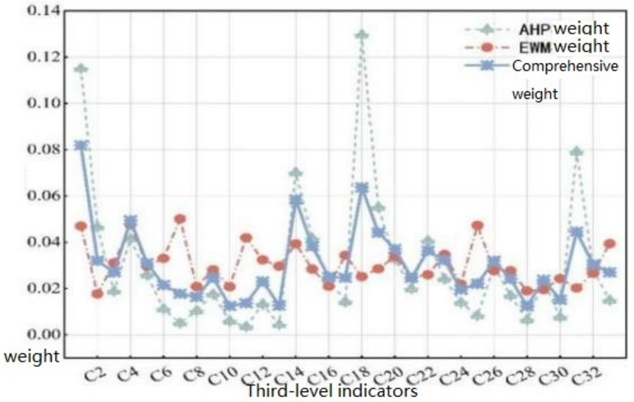

Figure 1. Comprehensive weight

Table 3. EWM calculation weight values

index	Weight
$C1$	0.047
$C2$	0.018
$C3$	0.031
$C4$	0.048
$C5$	0.030
$C6$	0.033
$C7$	0.050
$C8$	0.021
$C9$	0.028
$C10$	0.021
$C11$	0.042
$C12$	0.032
$C13$	0.030
$C14$	0.039
$C15$	0.028
$C16$	0.021
$C17$	0.034
$C18$	0.025
$C19$	0.029
$C20$	0.034
$C21$	0.025
$C22$	0.026
$C23$	0.035
$C24$	0.022
$C25$	0.047
C 26	0.028
C 27	0.028
C 28	0.019
C 29	0.020
C 30	0.024
C 31	0.020
C 32	0.027
C 33	0.039

4. Construction of Airport Clearance Risk Assessment Model Based on Cloud Model

4.1. Comprehensive Evaluation of Cloud Models

The cloud model is a mathematical tool that combines fuzzy mathematics with probability and statistics theory. It is suitable for describing complex systems where uncertainty and randomness coexist. Its core idea is to build a correlation mechanism between qualitative and quantitative factors, which can transform language evaluation results with fuzzy boundaries (such as "high risk" and "low risk") into computable numerical distributions, thereby achieving effective expression of uncertainty information [15].

The cloud model is primarily used to construct a comprehensive membership function for airport clearance safety risks, enabling the scientific classification and quantitative expression of fuzzy risk levels. The specific steps are as follows.

4.1.1. Determine the Standard Cloud

All three-level indicators in the airport clearance safety evaluation system and the final airport clearance safety level are mapped and risk graded. According to the risk grade classification standard, the evaluation results are divided into four grade intervals: high risk interval $[80,100]$, relatively high risk interval $[60,80)$, relatively low risk interval $[40,60)$, and low risk interval $[0,40)$.

Invite m industry experts to score n three-level evaluation indicators and obtain an $m \times n$ original evaluation matrix Z, as shown in formula (12):

$$Z = \begin{bmatrix} Z_{11} & \cdots & Z_{1n} \\ \vdots & \ddots & \vdots \\ Z_{m1} & \cdots & Z_{mn} \end{bmatrix} \tag{12}$$

Where, Z_{ij}represents ithe scoring result of the th expert on the th indicator j.

A standard cloud model is constructed based on the preset interval of risk level $C_v = (Ex_v, En_v, He_v)$. The calculation method is shown Ex_v in En_v equations (13) and (14) respectively:

$$Ex_v = \frac{x_{\max} + x_{\min}}{2} \tag{13}$$

$$En_v = \frac{x_{\max} - x_{\min}}{6} \tag{14}$$

Where, the expected value Ex_v is the median of the level interval . Entropy En_v represents the degree of fuzziness corresponding to the interval span .

The excess entropy He_v reflects the degree of discreteness of cloud droplets and is set to =0.1× in this paper He_v to control En_v the stability and transition of the cloud model.

Through the above calculations , a standard cloud diagram is drawn . The characteristic values of each risk level (expected value Ex , entropy En , and excess entropy He) are shown in Table 4.

Table 4. Standard cloud parameters

Risk Level	Lower limit	Upper limit	*Ex*	*En*	*He*
High risk	80	100	90	3.33	1.11
Higher risk	60	80	70	3.33	1.11
Lower risk	40	60	50	3.33	1.11
Low risk	0	40	20	6.67	2.22

The standard cloud diagram is shown in Figure 3 , which intuitively displays four risk levels : high risk (centered at 90 points, with a fluctuation of ±3.33 points), relatively high risk (centered at 70 points), relatively low risk (centered at 50 points), and low risk (centered at 20 points, with greater fluctuation). Through different color blocks and density areas, it not only highlights the core intervals of each level, but also reflects the overlap and gradient between adjacent levels, vividly depicting the uncertainty and hierarchical differences in clearance safety risk assessment.

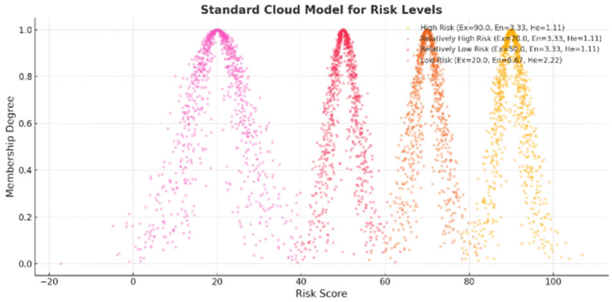

Figure 2. Standard cloud diagram

4.1.2. Calculating Indicator Cloud Parameters

Calculate the actual cloud model parameters corresponding to each evaluation index $C_j = (Ex_j, En_j, He_j)$. The calculation methods are shown Ex_j in En_j Equations (15) and (16) respectively:

$$Ex_j = \frac{\sum_{i=1}^{m} Z_{ij}}{m} \tag{15}$$

$$En_j = \sqrt{\frac{\pi}{2}} \cdot \frac{1}{m} \sum_{i=1}^{m} \left| Z_{ij} - Ex_j \right| \tag{16}$$

The variance of this indicator $S_j^{\,2}$ represents the dispersion of the scoring data, as shown in formula (17) :

$$S_j^{\,2} = \frac{1}{m-1} \sum_{i=1}^{m} (Z_{ij} - Ex_j)^2 \tag{17}$$

The final super entropy He_j calculation is shown in formula (18) :

$$He_j = \sqrt{S_j^{\,2} - En_j^{\,2}} \tag{18}$$

According to the indicator cloud computing, the evaluation cloud diagram of 33 third-level indicators is obtained, as shown in Figure 3.

4.1.3. Comprehensive Cloud

The comprehensive weights of each indicator obtained by the combined weighting method in the early stage are introduced into the model to construct the final comprehensive evaluation cloud. The weighted calculation formulas of comprehensive expectation, entropy and super entropy are shown in Equations (19) to (21) respectively:

$$Ex = \sum_{j=1}^{n} (Ex_j \cdot D_j) \tag{19}$$

$$En = \sum_{j=1}^{n} (En_j \cdot D_j) \tag{20}$$

$$He = \sum_{j=1}^{n} (He_j \cdot D_j) \tag{21}$$

According to equations (11)-(21) , the expected value, entropy value, and super entropy value of each third-level indicator are weighted and normalized with the combined weights obtained from the analytic hierarchy process and the entropy weight method. The numerical characteristics of the comprehensive cloud model are calculated as $Ex = 51.93$, $En = 4.31$, and $He = 2.40$. The resulting comprehensive cloud map is shown in Figure 4.

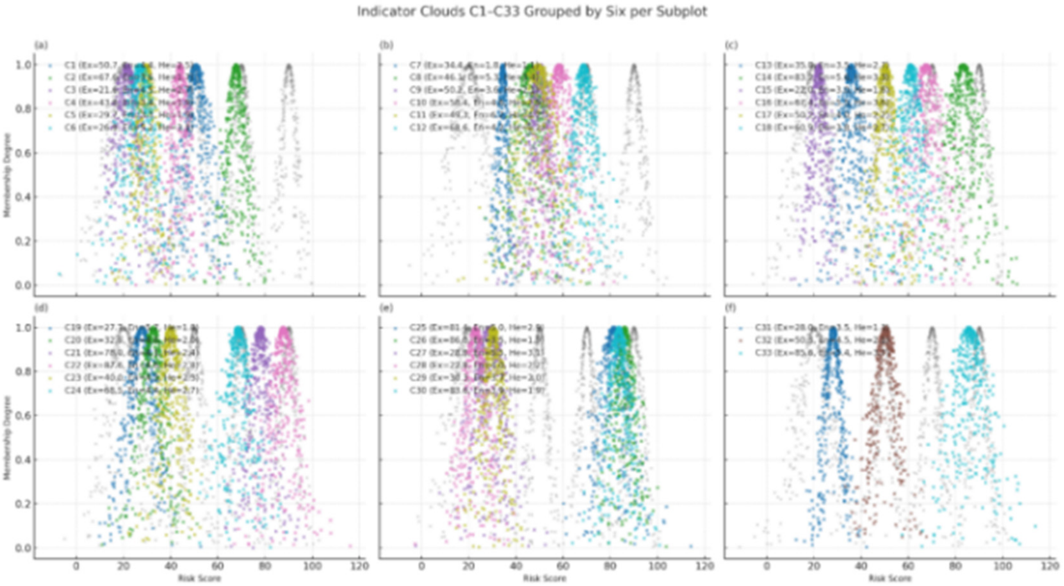

Figure 3. Three-level indicator evaluation cloud diagram

Figure 4. Comprehensive cloud diagram

4.2. Example Analysis

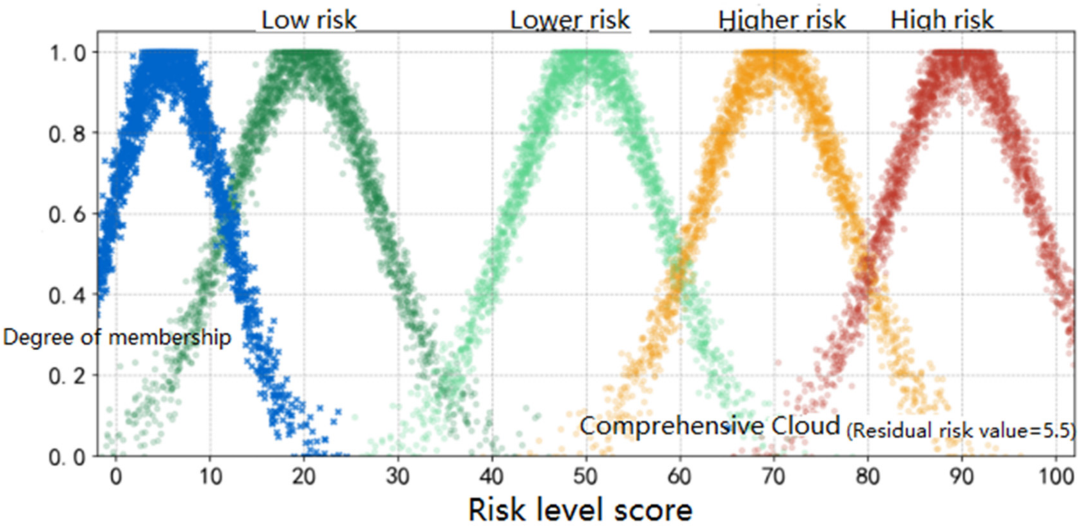

Figure 5. Cloud model risk level evaluation results

To verify the practicality and effectiveness of the constructed airport clearance risk assessment system, a case study of a Chinese airport was selected for analysis. This scoring system uses 33 third-level indicators determined in accordance with the "Airport Clearance Risk Assessment Index System." The geometric mean normalization method is used to W_j couple the subjective weights of the AHP with the objective weights of the entropy weight method to generate a comprehensive weight D_j.

According to the airport clearance risk assessment results, the overall score was 94.5, and the residual risk value calculated by the cloud model was 5.5. The cloud model risk level assessment results are shown in Figure 7. The figure shows the background distribution of the four-level standard cloud model (high risk, relatively high risk, relatively low risk, and low risk) with red, yellow, light green, and dark green cloud droplets. The red cloud droplets highlight the distribution of the comprehensive evaluation cloud. The expected value of the comprehensive cloud is around 5, which is right in the " low risk " zone, reflecting a high overall safety risk.

Fig. 5 Cloud Model Risk Level Evaluation Results

In summary, based on a comprehensive consideration of all three levels of indicators, the overall risk level of the airport's airspace environment is low, the safety situation is good, and the risk is within a controllable range. This chart not only demonstrates the credibility of the model's output, but also provides an intuitive basis for subsequent decision-making.

Although the overall risk is low, some shortcomings still exist. It is recommended that special cleaning or pruning operations be immediately organized for the two transition surface obstacles currently discovered to ensure that the height of the relevant areas meets the clearance limit standards. At the same time, a regular transition surface monitoring mechanism should be established, especially for areas with rapid vegetation growth and significant seasonal changes, to conduct periodic reviews to prevent recurrence of problems. In addition, the introduction of modern technologies such as drones and laser ranging in clearance inspections can be considered to improve recognition accuracy and response efficiency, thereby further strengthening the airport's dynamic clearance supervision capabilities and ensuring that risk management is forward-moved and the management loop is controllable.

5. Conclusion

(1) The airport clearance risk assessment method based on the cloud model can accurately identify the main risk sources in the airport's clearance area, such as super-high buildings and illegal drone flights. The assessment results are highly consistent with the on-site investigation.

(2) significantly improves the evaluation accuracy and has better indicator sensitivity and result stability.

(3) This method uses a visual risk cloud map to intuitively display the spatial distribution and level differences of each risk point, and provides airport operators with a number of specific management suggestions, including risk warning threshold setting and optimal allocation of prevention and control resources, which significantly improves the pertinence and effectiveness of airspace management.

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