sustainability

MDPI

Article

Risk Assessment Model Based on Set Pair Analysis Applied to Airport Bird Strikes

Rui Wang [1], Qiang Zhao [1], Hui Sun [1,*], Xuedong Zhang [1] and Yuyue Wang [2]

[1] School of Electronic Information and Automation, Civil Aviation University of China, Tianjin 300300, China
[2] Tianjin Binhai International Airport Co., Ltd., Tianjin 300300, China
* Correspondence: h-sun@cauc.edu.cn

Abstract: In order to comprehensively evaluate the risk of bird strike at airports and effectively prevent the occurrence of bird strike events, this paper constructs the risk assessment index system of airport bird strike from five perspectives of "personnel-bird-equipment-environment-management". For the purpose of maximizing variances, the Analytic Hierarchy Process (AHP) and the entropy weight method are combined and used to obtain the comprehensive weights. The five-element connection number of Set Pair Analysis (SPA) is introduced to establish the identical-discrepancy-contrary airport bird strike risk assessment model, and the risk trend is analyzed according to the partial connection number for each order. The experiment results show that the combined weighting method can minimize the weight deviation and demonstrate good accuracy in determining the weights of indicators at all levels. The established airport bird strike risk assessment model can reasonably predict the risk trend, which is significant for airport personnel to carry out bird strike prevention works.

Keywords: bird strike; airport safety; set pair analysis; risk assessment

check for updates

Citation: Wang, R.; Zhao, Q.; Sun, H.; Zhang, X.; Wang, Y. Risk Assessment Model Based on Set Pair Analysis Applied to Airport Bird Strikes. *Sustainability* **2022**, *14*, 12877. https://doi.org/10.3390/su141912877

Academic Editors: T. Hikmet Karakoç, Selcuk Ekici, Ozgur Balli and Alper Dalkiran

Received: 11 September 2022
Accepted: 7 October 2022
Published: 9 October 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

"Bird strike" refers to the safety accidents caused by the collision between birds and aircrafts at high speed in the air [1]. Flight accidents caused by bird strike not only cause huge economic losses to life, property, and national economy, but also seriously threaten aviation safety. This is an international problem which has plagued the aviation industry for a long time [2,3]. Therefore, it is the key to the current bird strike risk assessment research when considering the scientific and comprehensive paths to assess the risks of bird strike at airports, and to ensure flight safety.

Domestic and foreign scholars have continuously carried out bird strike risk assessment research from new perspectives. Reference [4] summarized the collision frequency between different types of birds and aircrafts, and evaluated the bird strike risk based on the bird strike database system constructed by nine airports in Australia. Reference [5] analyzed a large number of bird strike events over years, obtained the potential correlation of bird strike events based on the FP-Growth data mining algorithm, and judged the factors that led to the occurrence of bird strike through historical data. Reference [6] developed the Generalized Linear Models (GLMs) with binomial distribution in order to further quantify the risk degree of the airport bird strike events. Reference [7] developed a collision avoidance algorithm through the bird strike advisory system, and studied the efficacy of the system for air traffic control. Reference [8] calculated the risk of bird strike by predicting tracks of birds and esteeming the severity of a collision. They also evaluated the impacts on the safety and capacity of an airport when implementing the bird strike advisory system. Reference [9] conducted an investigation regarding the birds' living and activity situation at an airport in North China, and constructed the ecological security pattern of high-risk birds by using landscape ecology theory. Reference [10] obtained the spatial

distribution of the birds' risk in different seasons by improving the feature importance assessment method, and found that the risk of bird strike has both seasonal and spatial differences. Reference [11] predicted the probability of bird strike through radar data from the US NEXRAD network. Reference [12] used the Geographically Weighted Regression (GWR) model, based on the least squares method, to evaluate the key factors of the density distribution of birds at an airport. This makes some contributions to the sustainable and safe development of the ecological environment near the airports. Reference [13] made a more reasonable prediction of bird strike risk factors based on Artificial Neural Network (ANN); however, this did not consider the special environmental impact factors of airports. Reference [14] used real-time bird status information from the airport bird detection radar to quantitatively analyze and calculate bird strike risks. However, this method is limited to specific bird detection radar equipment, without the universal characteristic. Reference [15] established a real-time bird strike risk assessment model based on associated factors, such as bird detection radar and flight data; however, the model was not dynamic, and the early established bird situation database was not considered. In addition, several common airport bird strike risk assessment methods also provide feasible ideas and methods for carrying out bird strike risk assessment according to the ecological works at airports and surrounding areas, mainly including the feature importance assessment method [16,17], grey fuzzy assessment method [18,19], and risk matrix assessment method [20,21].

Although domestic and foreign scholars have conducted relatively comprehensive research on bird strike risk assessments, furthermore, the mentioned methods can play a certain role in airport bird strike risk assessments. However, these cannot comprehensively evaluate certain and uncertain factors, and cannot make reasonable predictions on the risk trends. The set pair analysis method is a comprehensive analysis method to study the interaction between certainty and uncertainty of the system [22], which has been widely used in many fields, such as environmental assessment [23,24] and engineering technology [25,26]. The main contributions of this paper can be summarized as follows.

(1) From the perspective of "personnel-bird-equipment-environment-management", this paper established a risk assessment index system related to airport bird strike.
(2) A variance maximization-based combined weighting method is designed by coupling subjective and objective factors, and has better accuracy in determining the weights of indicators at all levels.
(3) Based on the SPA theory, the identical-discrepancy-contrary airport bird strike risk assessment model is established, and the risk trend of airport bird strike is predicted according to the partial connection numbers.

The rest of this paper is organized as follows. Section 2 describes the methods associated with set pair analysis. Section 3 proposes an airport bird strike risk assessment model. Section 4 presents a more detailed case study and results analysis. Finally, the conclusions are drawn in Section 5.

2. Materials and Methods

2.1. Set Pair Analysis and Connection Number

The set pair analysis method uses the connection number to effectively analyze the uncertainty factors in the system, whose core idea is to establish two sets with certain connections [27]. The characteristics of each set include terms identity, difference, and opposite. Take two sets as an example, shown in Figure 1.

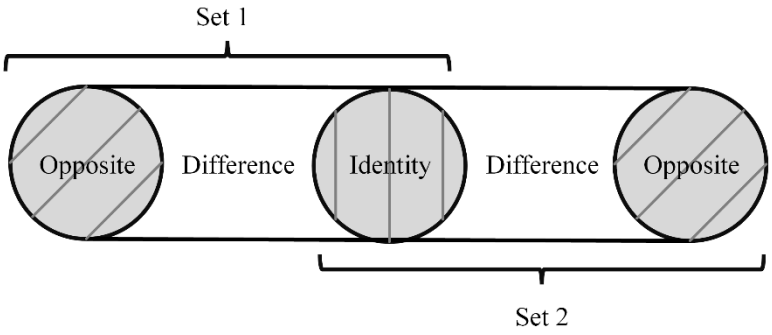


Figure 1. The scheme of set characteristics for two sets.

In order to meet the multi-level complex requirements of the practical problems, the connection number can be extended to different levels. The multi-element connection number equation is given by Equation (1).

$$\mu = a + b_1\tau_1 + b_2\tau_2 + \cdots + b_{t-2}\tau_{t-2} + c\eta \tag{1}$$

where μ is the connection number. a is the degree of identity, b_{t-2} are the degrees of difference, and c is the degree of opposite, which satisfies $a + b_1 + b_2 + \ldots + b_{t-2} + c = 1 (t \geq 3)$. The difference uncertainty coefficients are τ_{t-2} and $\tau_{t\text{-}2} \in [-1, 1]$ $(t \geq 3)$, and η is the opposite coefficient, which usually equals to –1.

When $t = 3$, the general expression for the connection number is shown as follows.

$$\mu = a + b_1\tau_1 + c\eta \tag{2}$$

When $t = 5$, the five-element connection number equation can be obtained as follows.

$$\mu = a + b_1\tau_1 + b_2\tau_2 + b_3\tau_3 + c\eta \tag{3}$$

2.2. Partial Connection Number

The partial connection numbers represent the trends of identities, differences, and opposites. When carrying out the risk assessments of bird strike at airports, the partial connection numbers of different orders can be introduced in order to analyze the trends of risks. The partial connection numbers of various orders are shown as follows [28].

The first-order partial connection number is

$$\partial\mu = \partial a + \tau_1\partial b_1 + \tau_2\partial b_2 + \tau_3\partial b_3 \tag{4}$$

where $\partial a = \frac{a}{a+b_1}, \partial b_1 = \frac{b_1}{b_1+b_2}, \partial b_2 = \frac{b_2}{b_2+b_3}, \partial b_3 = \frac{b_3}{b_3+c}$.

The second-order partial connection number is

$$\partial^2\mu = \partial(\partial\mu) = \partial^2 a + \tau_1\partial^2 b_1 + \tau_2\partial^2 b_2 \tag{5}$$

where $\partial^2 a = \frac{\partial a}{\partial a+\partial b_1}, \partial^2 b_1 = \frac{\partial b_1}{\partial b_1+\partial b_2}, \partial^2 b_2 = \frac{\partial b_2}{\partial b_2+\partial b_3}$.

The third-order partial connection number is

$$\partial^3\mu = \partial^2(\partial\mu) = \partial^3 a + \tau_1\partial^3 b_1 \tag{6}$$

where $\partial^3 a = \frac{\partial^2 a}{\partial^2 a+\partial^2 b_1}, \partial^3 b_1 = \frac{\partial^2 b_1}{\partial^2 b_1+\partial^2 b_2}$.

The fourth-order partial connection number is

$$\partial^4\mu = \partial^3(\partial\mu) = \partial^4 a \tag{7}$$

where $\partial^4 a = \frac{\partial^3 a}{\partial^3 a+\partial^3 b_1}$.

When $\partial^{\theta}\mu > 0$, it presents an upward trend, which indicates that the risk is decreasing. When $\partial^{\theta}\mu = 0$, it indicates that the risk is constant. When $\partial^{\theta}\mu < 0$, it presents a downward trend, which indicates that the risk is increasing.

3. Airport Bird Strike Risk Assessment Model

The airport bird strike risk assessment process is shown in Figure 2. The corresponding index system is constructed. The risk assessment process also includes the corresponding levels' divisions of the airport bird strike risks, the indicators' weights determination, the identical-discrepancy-contrary airport bird strike risk assessment model construction, and the situation and trend of the risk analysis.

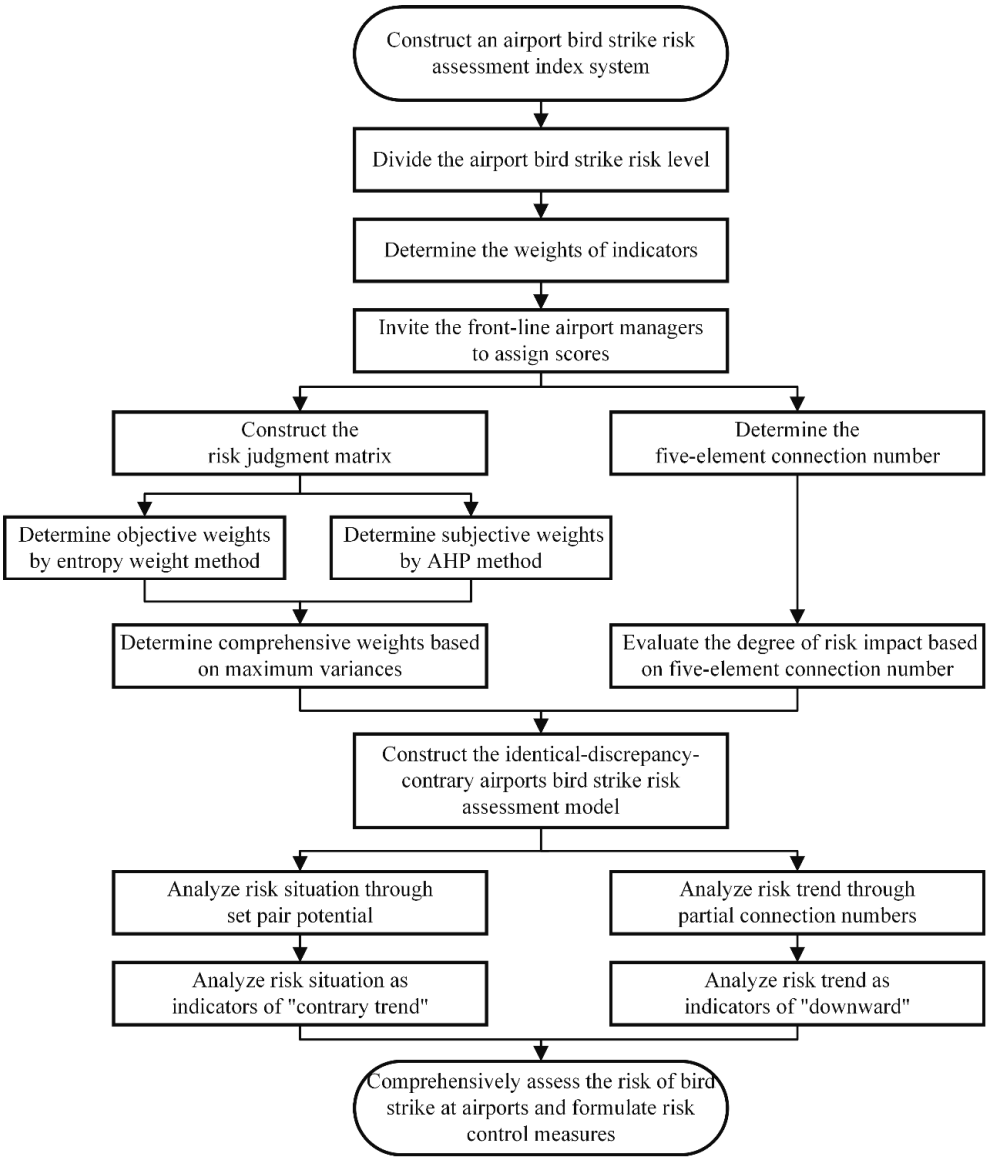


Figure 2. Flow chart for assessing airport bird strike risk.

3.1. Airport Bird Strike Risk Assessment Index System and Risk Classifications

As References [13,19,29] analyzed, the hierarchical structure of the airport bird strike risk assessment index system includes a target layer, criterion layer, and indicator layer, respectively. First, the ultimate target layer is the airport bird strike risk assessment. Second, the criterion layer includes five factors that affect the airport bird strike risks: personnel factors, bird factors, equipment factors, environmental factors, and management factors. Finally, the indicator layer is mainly refined based on the key points of the criterion layer.

A total of 22 secondary indicators with typical representatives are selected as shown in Figure 3.

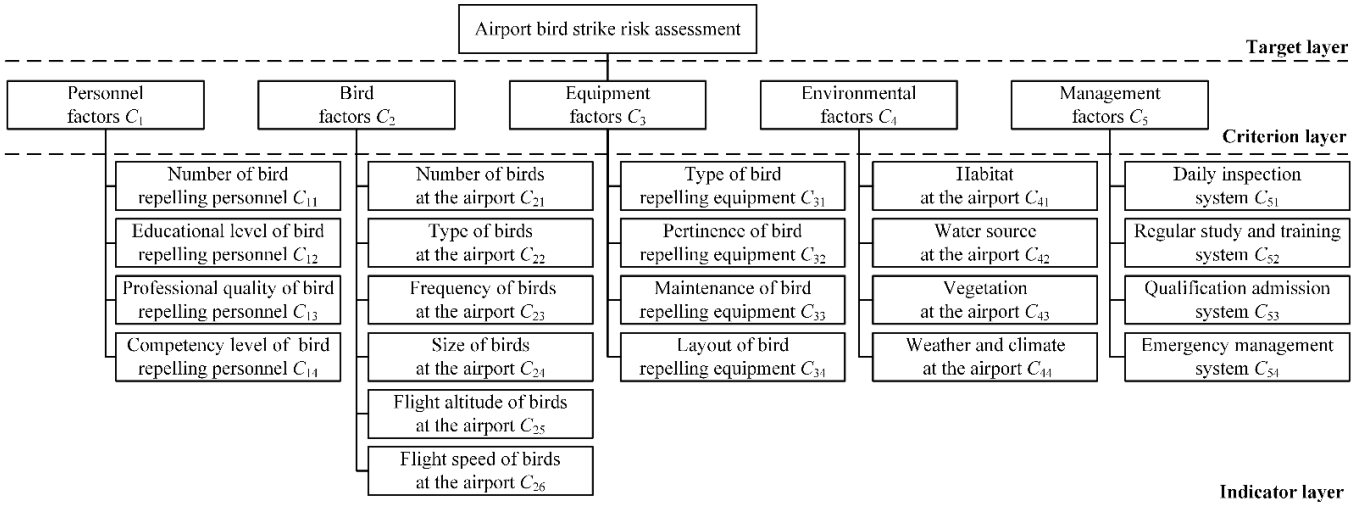


Figure 3. Airport bird strike risk assessment index system structure.

According to the "Guidelines for the Precaution of Common Birds in Civil Airports" (AC-140-CA-2010-1), "Measures for the Precaution of Bird Strike and Animal Intrusions in Transport Airports" (AP-140-CA-2022-02), "Guidelines for the Construction of Safety Management System (SMS) in Transport Airports" (AC-139/140-CA-2019-3), and "Catalogues of Dangerous Bird Species for the Precaution Bird Strike Aircrafts in Transport Airports" (AC-140-CA-2022-01), the airport bird strike risks are divided into 5 levels: Level I (lower), Level II (low), Level III (medium), Level IV (high), and Level V (higher) as shown in Table 1.

Table 1. Risk level evaluation standards for airport bird strike.

Risk Levels	Descriptions
Level I	Negligible, airport managers do not need to take risk control measures
Level II	Tolerable, airport managers do not need to take risk control measures, but need to pay attention
Level III	Acceptable, airport managers need to take appropriate risk control measures
Level IV	Partially acceptable, airport managers must take risk control measures
Level V	Unacceptable, airport managers must attach great importance and take risk control measures

3.2. Indicators' Weights Determination Method

The existing index weight calculation methods have their own advantages and disadvantages [30,31]. The entropy weight method is relatively objective. However, its application scope is limited [30]. The AHP method, as shown in Reference [31], cannot reflect the objectivity of the calculation results. Therefore, inspired by the maximum variance introduced in Reference [32], the methods mentioned above are combined to construct the linear programming model.

$$max \sum_{i=1}^{m} \sum_{j=1}^{v} (x_{ij} - \overline{x_{ij}})^2 W_j = max \sum_{i=1}^{m} \sum_{j=1}^{v} (x_{ij} - \overline{x_{ij}})^2 (\alpha U_j + \beta V_j) \quad (8)$$

where x_{ij} are the normalization results of the elements of the risk judgment matrix Z, which can be calculated by Equation (9), and $\overline{x_{ij}}$ is the arithmetic mean of x_{ij}, that is $\overline{x_{ij}} = \frac{1}{v} \sum_{j=1}^{v} x_{ij}$ $(i = 1, 2, \cdots m, j = 1, 2, \ldots v)$. The risk judgment matrix Z can be constructed by the nine-scale method as shown in Table 2. Both α and β are linear positive coefficients

that satisfy $\alpha^2 + \beta^2 = 1$; U_j are the objective weights determined by the entropy weight method and calculated by Equations (10) and (11); V_j are the subjective weights determined by AHP and calculated by Equations (12)–(14).

$$x_{ij} = \begin{cases} \frac{z_{ij}}{\sum_{i=1}^{m} z_{ij}} & z_{ij} \neq 0 \\ \frac{1+z_{ij}}{\sum_{i=1}^{m} (1+z_{ij})} & z_{ij} = 0 \end{cases} \quad (9)$$

Table 2. Scales and meanings of the nine-scale method.

Scales	Meanings
1	i is as important as j
3	i is slightly more important than j
5	i is more important than j
7	i is very much more important than j
9	i is more important than j
2, 4, 6, 8	The importance is in the middle of the 1, 3, 5, 7, 9 scales
reciprocal	If the importance relationship between i and j is z_{ij}, the importance relationship between j and i is $z_{ji} = 1/z_{ij}$.

The entropy weights H_j are determined by Equation (10).

$$H_j = -(\ln m)^{-1} \sum_{i=1}^{m} x_{ij} \times \ln(x_{ij}) \quad (10)$$

The objective weights U_j are calculated by Equation (11).

$$U_j = \frac{1 - H_j}{\sum_{j=1}^{v} (1 - H_j)} \quad (11)$$

A consistency test is carried out on the risk judgment matrix Z, and the consistency indicator is set as CI.

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (12)$$

where λ_{max} is the largest eigenvalue of the judgment matrix Z, and n is the order of the judgment matrix Z.

The consistency ratio CR is determined by Equation (13).

$$CR = \frac{CI}{RI} \quad (13)$$

The value of mean consistency index RI is determined by the different orders of the judgment matrix Z, as shown in Table 3. When $CR < 0.1$, the judgment matrix Z conforms to the consistency test and is regarded as a reasonable judgment matrix; otherwise, the judgment matrix Z needs to be adjusted.

Table 3. RI values under different orders.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49

The subjective weights V_j are calculated by Equation (14).

$$V_j = \frac{\left(\prod_{i=1}^{m} z_{ij}\right)^{\frac{1}{m}}}{\sum_{p=1}^{m}\left(\prod_{j=1}^{v} z_{pj}\right)^{\frac{1}{m}}} \tag{14}$$

Lagrangian function is constructed, as shown in Equation (15), to solve the optimization problem.

$$L(\alpha, \beta, \delta) = \sum_{i=1}^{m}\sum_{j=1}^{v}(x_{ij} - \overline{x_{ij}})^2(\alpha U_j + \beta V_j) + \delta(\alpha^2 + \beta^2 - 1) \tag{15}$$

where δ is the Lagrangian multiplier. The partial derivative of $L(\alpha, \beta, \delta)$ is calculated with respect to the linear coefficients α, β, and the multiplier δ, and it is set at 0 as shown in Equations (16)–(18).

$$\frac{\partial L(\alpha, \beta, \delta)}{\partial \alpha} = \sum_{i=1}^{m}\sum_{j=1}^{v}(x_{ij} - \overline{x_{ij}})^2 U_j + 2\delta\alpha = 0 \tag{16}$$

$$\frac{\partial L(\alpha, \beta, \delta)}{\partial \beta} = \sum_{i=1}^{m}\sum_{j=1}^{v}(x_{ij} - \overline{x_{ij}})^2 V_j + 2\delta\beta = 0 \tag{17}$$

$$\frac{\partial L(\alpha, \beta, \delta)}{\partial \delta} = \alpha^2 + \beta^2 - 1 = 0 \tag{18}$$

The linear coefficients α and β are expressed as follows.

$$\alpha = \frac{1}{\left[1 + \frac{\sum_{i=1}^{m}\sum_{j=1}^{v}\left(x_{ij} - \overline{x_{ij}}\right)^2 U_j}{\sum_{i=1}^{m}\sum_{j=1}^{v}\left(x_{ij} - \overline{x_{ij}}\right)^2 V_j}\right]^{0.5}} \tag{19}$$

$$\beta = \frac{1}{\left[1 + \frac{\sum_{i=1}^{m}\sum_{j=1}^{v}(x_{ij} - \overline{x_{ij}})^2 V_j}{\sum_{i=1}^{m}\sum_{j=1}^{v}(x_{ij} - \overline{x_{ij}})^2 U_j}\right]^{0.5}} \tag{20}$$

Equations (19) and (20) are substituted into Equation (8) to obtain $W_0 = (W_{01}, W_{02}, \ldots, W_{0v})$, and W_0 is normalized to obtain the final comprehensive weights matrix $W = (W_1, W_2, \ldots, W_v)$.

3.3. The Identical-Discrepancy-Contrary Airports Bird Strike Risk Assessment Model

After determining the comprehensive weights W of each indicator, Equation (21) is used in order to estimate the impact of each indicator on the airport bird strike risk assessment.

$$R_s = \frac{N_s}{N} \tag{21}$$

where R_s represents the risk degree of the evaluation indicator, N_s represents the number of experts who divide the indicator into the corresponding risk level s, and N is the total number of experts.

The identical-discrepancy-contrary airports bird strike risk assessment model is established.

$$\begin{aligned}\mu &= WRE^T \\ &= (W_1, W_2, \ldots, W_v)\begin{pmatrix} R_{11} & R_{12} & R_{13} & R_{14} & R_{15} \\ R_{21} & R_{22} & R_{23} & R_{24} & R_{25} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ R_{v1} & R_{v2} & R_{v3} & R_{v4} & R_{v5} \end{pmatrix}\begin{pmatrix} 1 \\ \tau_1 \\ \tau_2 \\ \tau_3 \\ \eta \end{pmatrix} \\ &= \sum_{k=1}^{v} W_k R_{k1} + \sum_{k=1}^{v} W_k R_{k2}\tau_1 + \sum_{k=1}^{v} W_k R_{k3}\tau_2 + \sum_{k=1}^{v} W_k R_{k4}\tau_3 + \sum_{k=1}^{v} w_k R_{k5}\eta \\ &= a + b_1\tau_1 + b_2\tau_2 + b_3\tau_3 + c\eta\end{aligned} \tag{22}$$

where W is the comprehensive weight coefficients matrix, R is the identical-discrepancy-contrary matrix, and E^T is the identical-discrepancy-contrary coefficients vector. The meaning of the specific parameters is shown in Table 4.

Table 4. Meaning of model parameters and the corresponding risk levels.

Parameters	Meanings	Risk Levels
$a = \sum_{k=1}^{v} w_k R_{k1}$	Same degree measure component	Level I
$b_1 = \sum_{k=1}^{v} w_k R_{k2}$	Partial measure component	Level II
$b_2 = \sum_{k=1}^{v} w_k R_{k3}$	Neutral measure component	Level III
$b_3 = \sum_{k=1}^{v} w_k R_{k4}$	Biased measure component	Level IV
$c = \sum_{k=1}^{v} w_k R_{k5}$	Opposite measure component	Level V

3.4. Set Pair Potential Analysis

To some extent, the set pair potential reflects the dynamic evolutionary trends of the two sets including the same, balanced, and contrary trends. The function is expressed by Equation (23).

$$SHI(\mu) = \frac{a}{c} \tag{23}$$

When the set pair potential value is greater than 1, it represents the "same trend", indicating that the risk of the assessment indicator is low. When the set pair potential is 1, it represents the "balanced trend", indicating that the risk of the assessment indicator is medium. When the set pair potential is less than 1, it represents the "contrary trend", indicating that the risk of the assessment indicator is high. Furthermore, the airport managers must take certain risk control measures to transmit the set pair potential to the "balanced trend" in order to achieve the "same trend". Table 5 shows the classifications of set pair potentials derived from Reference [33], which are associated with the set pair potential analysis in this paper.

Table 5. Classification of set pair potential.

Parameters Relationships	Potential Levels
$a > c, a < b_1, b_1 > b_2, b_2 < b_3, b_3 > c$	Same trend level 61
$a > c, a < b_1, b_1 < b_2, b_2 > b_3, b_3 > c$	Same trend level 73
$a < c, a > b_1, b_1 > b_2, b_2 < b_3, b_3 > c$	Contrary trend level 169
$a < c, a < b_1, b_1 > b_2, b_2 < b_3, b_3 > c$	Contrary trend level 223
$a < c, a < b_1, b_1 < b_2, b_2 < b_3, b_3 > c$	Contrary trend level 241

4. Case Study

Taking an airport in North China as an example, the airport managers coming from the flight area departments were invited to score the indicators. The airport is located in the northeastern part of the North China Plain and faces the Bohai Sea in the east. In addition, the airport is located in the East Asian–Australian Flyway, one of the word's nine major bird migration routes, which is an important stopover for the north–south migration of birds in China. The surrounding environment of the airport is mainly composed of large urban areas, villages, and farmland. The habitats in the airport flight area are mainly grasslands, buildings, boundary areas, ponds, and drainage channels. Twenty selected complete surveys were used to build the identical-discrepancy-contrary airports bird strike risk assessment model, which is designed according to the indicators as shown in Figure 3. SPSS (Statistical Product Service Solutions) was used to test the reliability of the survey data. The corresponding Cromabach Alpha coefficient is 0.925, which indicates that the reliability of the data is high. Furthermore, it is demonstrated that the airport bird strike risk index system established in this paper is reasonable.

4.1. Weights of Evaluation Indicators Calculation

Taking the criterion layer indicators C_1, C_2, C_3, C_4, and C_5 as examples, the scores of five experts are listed first. The objective weights U are calculated by Equations (10) and (11), while the subjective weights V are calculated by Equations (12)–(14). The linear coefficients' α and β values can be obtained by Equations (19) and (20), and the results are listed in Equation (24). Table 6 shows the results of the scoring of criterion layers and the weights calculation.

$$\alpha = 0.6536, \beta = 0.7568 \tag{24}$$

Table 6. Scoring and weights calculation results of criterion layers.

Criterion Layer	Expert A	Expert B	Expert C	Expert D	Expert E	Objective Weight U	Subjective Weight V	Comprehensive Weight W
C_1	1	2	2	1	2	0.2641	0.1321	0.1927
C_2	7	5	4	4	4	0.1659	0.2527	0.2119
C_3	3	2	3	3	3	0.1101	0.2094	0.1629
C_4	5	5	4	5	6	0.1925	0.2621	0.2292
C_5	2	3	2	3	1	0.2674	0.1489	0.2033

The weight values, as shown in Table 6, are plotted in Figure 4. Figure 4 shows that the values of comprehensive weights W are located between the objective weights U and the subjective weights V. This indicates that the designed combined weighting method weakens the deviation degree of some indicators of the entropy weight method. Furthermore, it reduces the subjective influence of the AHP method, so that the calculation results have better accuracy.

Similarly, the weights of each indicator are determined, and the results are shown in Table 7.

4.2. Risk Situations and Trends Analysis

The identical-discrepancy-contrary airports bird strike risk assessment model is constructed from Equation (22), with the weights of each indicator calculated above. The partial connection numbers for different orders are calculated by Equations (4)–(7). The set pair potential analysis results are shown in Tables 8 and 9.

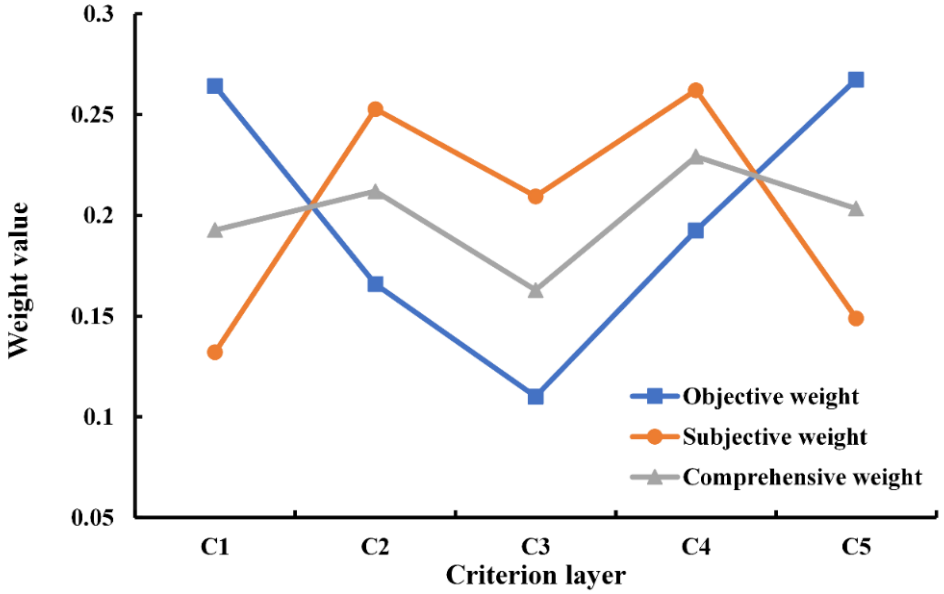


Figure 4. Comparison chart of three weight values for the criterion layers.

Table 7. Weights for each indicator.

Criterion Layer	Indicator Layer	Objective Weight *U*	Subjective Weight *V*	Comprehensive Weight *W*
C_1 (0.1927)	C_{11}	0.5770	0.1153	0.3292
	C_{12}	0.2400	0.1735	0.2043
	C_{13}	0.0729	0.3284	0.2100
	C_{14}	0.1102	0.3828	0.2565
C_2 (0.2119)	C_{21}	0.1854	0.1728	0.1786
	C_{22}	0.1879	0.1821	0.1848
	C_{23}	0.1975	0.1368	0.1649
	C_{24}	0.1104	0.1942	0.1554
	C_{25}	0.2007	0.1579	0.1777
	C_{26}	0.1181	0.1562	0.1385
C_3 (0.1629)	C_{31}	0.2561	0.1873	0.2192
	C_{32}	0.2782	0.2087	0.2409
	C_{33}	0.3316	0.2826	0.3053
	C_{34}	0.1341	0.3215	0.2346
C_4 (0.2292)	C_{41}	0.2982	0.2549	0.2750
	C_{42}	0.1975	0.2847	0.2443
	C_{43}	0.1455	0.2414	0.1970
	C_{44}	0.3588	0.2189	0.2838
C_5 (0.2033)	C_{51}	0.3604	0.2109	0.2802
	C_{52}	0.2058	0.2318	0.2198
	C_{53}	0.2352	0.2070	0.2201
	C_{54}	0.1986	0.3503	0.2800

Table 8. Five-element connection numbers and first-order partial connection numbers.

Criterion Layer	Indicator Layer	Five-Element Connection Number	Situation	First-Order Partial Connection Number	Trend
C_1 (0.1927)	C_{11}	$0.30 + 0.25\tau_1 + 0.20\tau_2 + 0.20\tau_3 + 0.05\eta$	Same	$0.55 + 0.56\tau_1 + 0.50\tau_2 + 0.80\tau_3$	Downward
	C_{12}	$0.25 + 0.20\tau_1 + 0.25\tau_2 + 0.15\tau_3 + 0.15\eta$	Same	$0.56 + 0.44\tau_1 + 0.63\tau_2 + 0.50\tau_3$	Upward
	C_{13}	$0.10 + 0.25\tau_1 + 0.30\tau_2 + 0.20\tau_3 + 0.15\eta$	Contrary	$0.29 + 0.45\tau_1 + 0.60\tau_2 + 0.57\tau_3$	Downward
	C_{14}	$0.00 + 0.25\tau_1 + 0.35\tau_2 + 0.30\tau_3 + 0.10\eta$	Contrary	$0.00 + 0.42\tau_1 + 0.54\tau_2 + 0.75\tau_3$	Downward
	Add up	$0.17 + 0.24\tau_1 + 0.27\tau_2 + 0.22\tau_3 + 0.10\eta$	Same	$0.41 + 0.47\tau_1 + 0.55\tau_2 + 0.69\tau_3$	Downward
C_2 (0.2119)	C_{21}	$0.00 + 0.10\tau_1 + 0.10\tau_2 + 0.35\tau_3 + 0.45\eta$	Contrary	$0.00 + 0.50\tau_1 + 0.22\tau_2 + 0.44\tau_3$	Downward
	C_{22}	$0.10 + 0.20\tau_1 + 0.30\tau_2 + 0.20\tau_3 + 0.20\eta$	Contrary	$0.33 + 0.40\tau_1 + 0.60\tau_2 + 0.50\tau_3$	Downward
	C_{23}	$0.00 + 0.15\tau_1 + 0.30\tau_2 + 0.30\tau_3 + 0.25\eta$	Contrary	$0.00 + 0.33\tau_1 + 0.50\tau_2 + 0.55\tau_3$	Downward
	C_{24}	$0.15 + 0.25\tau_1 + 0.20\tau_2 + 0.30\tau_3 + 0.10\eta$	Same	$0.38 + 0.56\tau_1 + 0.40\tau_2 + 0.75\tau_3$	Downward
	C_{25}	$0.15 + 0.30\tau_1 + 0.25\tau_2 + 0.15\tau_3 + 0.15\eta$	Balanced	$0.33 + 0.55\tau_1 + 0.63\tau_2 + 0.50\tau_3$	Downward
	C_{26}	$0.20 + 0.30\tau_1 + 0.15\tau_2 + 0.20\tau_3 + 0.15\eta$	Same	$0.40 + 0.67\tau_1 + 0.43\tau_2 + 0.57\tau_3$	Downward
	Add up	$0.10 + 0.21\tau_1 + 0.22\tau_2 + 0.25\tau_3 + 0.22\eta$	Contrary	$0.32 + 0.49\tau_1 + 0.47\tau_2 + 0.53\tau_3$	Downward
C_3 (0.1629)	C_{31}	$0.25 + 0.30\tau_1 + 0.05\tau_2 + 0.25\tau_3 + 0.15\eta$	Same	$0.45 + 0.86\tau_1 + 0.17\tau_2 + 0.63\tau_3$	Downward
	C_{32}	$0.25 + 0.15\tau_1 + 0.05\tau_2 + 0.30\tau_3 + 0.25\eta$	Balanced	$0.63 + 0.75\tau_1 + 0.14\tau_2 + 0.55\tau_3$	Upward
	C_{33}	$0.20 + 0.10\tau_1 + 0.15\tau_2 + 0.30\tau_3 + 0.25\eta$	Contrary	$0.67 + 0.40\tau_1 + 0.33\tau_2 + 0.55\tau_3$	Upward
	C_{34}	$0.05 + 0.15\tau_1 + 0.20\tau_2 + 0.30\tau_3 + 0.30\eta$	Contrary	$0.25 + 0.43\tau_1 + 0.40\tau_2 + 0.50\tau_3$	Downward
	Add up	$0.19 + 0.17\tau_1 + 0.12\tau_2 + 0.29\tau_3 + 0.24\eta$	Contrary	$0.53 + 0.59\tau_1 + 0.29\tau_2 + 0.55\tau_3$	Downward
C_4 (0.2292)	C_{41}	$0.00 + 0.55\tau_1 + 0.15\tau_2 + 0.20\tau_3 + 0.10\eta$	Contrary	$0.00 + 0.79\tau_1 + 0.43\tau_2 + 0.67\tau_3$	Downward
	C_{42}	$0.00 + 0.25\tau_1 + 0.30\tau_2 + 0.35\tau_3 + 0.10\eta$	Contrary	$0.00 + 0.45\tau_1 + 0.46\tau_2 + 0.78\tau_3$	Downward
	C_{43}	$0.20 + 0.30\tau_1 + 0.20\tau_2 + 0.10\tau_3 + 0.20\eta$	Balanced	$0.40 + 0.60\tau_1 + 0.67\tau_2 + 0.33\tau_3$	Upward
	C_{44}	$0.30 + 0.30\tau_1 + 0.10\tau_2 + 0.20\tau_3 + 0.10\eta$	Same	$0.50 + 0.75\tau_1 + 0.33\tau_2 + 0.67\tau_3$	Downward
	Add up	$0.13 + 0.36\tau_1 + 0.18\tau_2 + 0.22\tau_3 + 0.12\eta$	Same	$0.27 + 0.67\tau_1 + 0.45\tau_2 + 0.65\tau_3$	Downward
C_5 (0.2033)	C_{51}	$0.30 + 0.25\tau_1 + 0.15\tau_2 + 0.05\tau_3 + 0.25\eta$	Same	$0.55 + 0.63\tau_1 + 0.75\tau_2 + 0.17\tau_3$	Upward
	C_{52}	$0.10 + 0.30\tau_1 + 0.20\tau_2 + 0.30\tau_3 + 0.10\eta$	Balanced	$0.25 + 0.60\tau_1 + 0.40\tau_2 + 0.75\tau_3$	Downward
	C_{53}	$0.20 + 0.35\tau_1 + 0.05\tau_2 + 0.25\tau_3 + 0.15\eta$	Same	$0.36 + 0.88\tau_1 + 0.17\tau_2 + 0.63\tau_3$	Downward
	C_{54}	$0.00 + 0.05\tau_1 + 0.25\tau_2 + 0.45\tau_3 + 0.25\eta$	Contrary	$0.00 + 0.17\tau_1 + 0.36\tau_2 + 0.64\tau_3$	Downward
	Add up	$0.15 + 0.23\tau_1 + 0.17\tau_2 + 0.26\tau_3 + 0.20\eta$	Contrary	$0.39 + 0.58\tau_1 + 0.40\tau_2 + 0.57\tau_3$	Downward
Add up in total		$0.14 + 0.25\tau_1 + 0.19\tau_2 + 0.24\tau_3 + 0.17\eta$	Contrary	$0.37 + 0.56\tau_1 + 0.44\tau_2 + 0.59\tau_3$	Downward

Table 9. Partial connection numbers of the second, third, and fourth orders.

Criterion Layer	Indicator Layer	Second-Order	Trend	Third-Order	Trend	Fourth-Order	Trend
C_1 (0.1927)	C_{11}	$0.50 + 0.53\tau_1 + 0.38\tau_2$	Downward	$0.49 + 0.58\tau_1$	Downward	0.46	Upward
	C_{12}	$0.56 + 0.42\tau_1 + 0.56\tau_2$	Downward	$0.57 + 0.43\tau_1$	Upward	0.57	Upward
	C_{13}	$0.39 + 0.43\tau_1 + 0.51\tau_2$	Downward	$0.47 + 0.46\tau_1$	Upward	0.51	Upward
	C_{14}	$0.00 + 0.44\tau_1 + 0.42\tau_2$	Downward	$0.00 + 0.51\tau_1$	Downward	0.00	Constant
	Add up	$0.47 + 0.46\tau_1 + 0.44\tau_2$	Downward	$0.50 + 0.51\tau_1$	Downward	0.50	Upward
C_2 (0.2119)	C_{21}	$0.00 + 0.69\tau_1 + 0.34\tau_2$	Downward	$0.00 + 0.67\tau_1$	Downward	0.00	Constant
	C_{22}	$0.45 + 0.40\tau_1 + 0.55\tau_2$	Downward	$0.53 + 0.42\tau_1$	Upward	0.56	Upward
	C_{23}	$0.00 + 0.40\tau_1 + 0.48\tau_2$	Downward	$0.00 + 0.46\tau_1$	Downward	0.00	Constant
	C_{24}	$0.40 + 0.58\tau_1 + 0.35\tau_2$	Downward	$0.41 + 0.63\tau_1$	Downward	0.40	Upward
	C_{25}	$0.38 + 0.47\tau_1 + 0.56\tau_2$	Downward	$0.45 + 0.46\tau_1$	Downward	0.50	Upward
	C_{26}	$0.38 + 0.61\tau_1 + 0.43\tau_2$	Downward	$0.38 + 0.59\tau_1$	Downward	0.40	Upward
	Add up	$0.40 + 0.51\tau_1 + 0.47\tau_2$	Downward	$0.44 + 0.52\tau_1$	Downward	0.47	Upward
C_3 (0.1629)	C_{31}	$0.35 + 0.84\tau_1 + 0.21\tau_2$	Downward	$0.29 + 0.80\tau_1$	Downward	0.27	Upward
	C_{32}	$0.45 + 0.84\tau_1 + 0.21\tau_2$	Downward	$0.35 + 0.80\tau_1$	Downward	0.30	Upward
	C_{33}	$0.63 + 0.55\tau_1 + 0.38\tau_2$	Downward	$0.53 + 0.59\tau_1$	Downward	0.48	Upward
	C_{34}	$0.37 + 0.52\tau_1 + 0.44\tau_2$	Downward	$0.42 + 0.54\tau_1$	Downward	0.44	Upward
	Add up	$0.47 + 0.67\tau_1 + 0.35\tau_2$	Downward	$0.42 + 0.66\tau_1$	Downward	0.39	Upward
C_4 (0.2292)	C_{41}	$0.00 + 0.65\tau_1 + 0.39\tau_2$	Downward	$0.00 + 0.62\tau_1$	Downward	0.00	Constant
	C_{42}	$0.00 + 0.50\tau_1 + 0.37\tau_2$	Downward	$0.00 + 0.57\tau_1$	Downward	0.00	Constant
	C_{43}	$0.40 + 0.47\tau_1 + 0.67\tau_2$	Downward	$0.46 + 0.42\tau_1$	Upward	0.52	Upward
	C_{44}	$0.40 + 0.69\tau_1 + 0.33\tau_2$	Downward	$0.37 + 0.68\tau_1$	Downward	0.35	Upward
	Add up	$0.28 + 0.60\tau_1 + 0.41\tau_2$	Downward	$0.32 + 0.59\tau_1$	Downward	0.35	Upward
C_5 (0.2033)	C_{51}	$0.47 + 0.45\tau_1 + 0.82\tau_2$	Downward	$0.51 + 0.36\tau_1$	Upward	0.59	Upward
	C_{52}	$0.29 + 0.60\tau_1 + 0.35\tau_2$	Downward	$0.33 + 0.63\tau_1$	Downward	0.34	Upward
	C_{53}	$0.29 + 0.84\tau_1 + 0.21\tau_2$	Downward	$0.26 + 0.80\tau_1$	Downward	0.24	Upward
	C_{54}	$0.00 + 0.32\tau_1 + 0.36\tau_2$	Downward	$0.00 + 0.47\tau_1$	Downward	0.00	Constant
	Add up	$0.41 + 0.59\tau_1 + 0.41\tau_2$	Downward	$0.41 + 0.59\tau_1$	Downward	0.41	Upward
Add up in total		$0.40 + 0.56\tau_1 + 0.43\tau_2$	Downward	$0.41 + 0.57\tau_1$	Downward	0.42	Upward

4.3. Results Analysis

(1) Table 7 shows that the indicators "bird factors C_2" and "environmental factors C_4" have greater weights among the criterion layers, which have a higher degree of impact on the airport bird strike risk. The indicator layer indicators "number of bird-repelling personnel C_{11}", "types of birds at the airport C_{22}", "maintenance of bird-repelling

equipment C_{33}", "weather and climate at the airport C_{44}", and "daily inspection system C_{51}" have relatively large weights, indicating that these factors are important reasons for the occurrence of airport bird strike events.

(2) Table 8 shows that the five-element connection number of airport bird strike risk is $\mu = 0.14 + 0.25\tau_1 + 0.19\tau_2 + 0.24\tau_3 + 0.17\eta$, and its set pair potential calculated by Equation (23) is 0.82. It locates at contrary trend level 223, indicating that the risk is high. In addition, the risk situations of each criterion layer indicator are shown as follows. "personnel factors C_1" locates at same trend level 73, "bird factors C_2" locates at contrary trend level 241, "equipment factors C_3" locates at contrary trend level 169, "environmental factors C_4" locates at same trend level 61, and "management factors C_5" locates at contrary trend level 223. Among the 22 indicator layer indicators, 8 factors have the same trend, 4 factors have the balanced trend, and 10 factors have the contrary trend. The number of the contrary trend factors is slightly more than that of the same trend factors.

(3) Table 9 shows that the first, second, and third-order partial connection numbers all locate in a downward trend, indicating that the risk trend is increasing. The fourth-order partial connection number locates in an upward trend, indicating that the risk trend is decreasing. This demonstrates that the airport bird strike risk has a dynamic trend. Overall, the indicators can be divided into five types, as shown in Table 10, where "↑" indicates that the partial connection number locates in an upward trend, "↓" indicates that the partial connection number locates in a downward trend, and "—" indicates that the partial connection number locates in a constant state. It is worth noting that "competency level of bird-repelling personnel C_{14}", "number of birds at the airport C_{21}", "frequency of birds at the airport C_{23}", "habitat at the airport C_{41}", "water source at the airport C_{42}", and "emergency management system C_{54}" are strong contrary factors. Therefore, when dealing with bird strike at the airports, we should first pay attention to indicators C_{14}, C_{21}, C_{23}, C_{41}, C_{42}, and C_{54}, then indicators C_{11}, C_{24}, C_{25}, C_{26}, C_{31}, C_{34}, C_{44}, C_{52}, and C_{53}, then indicators C_{13}, C_{22}, C_{22}, C_{32}, and C_{33}, and finally, indicators C_{12}, C_{43}, and C_{51}.

Table 10. Risk classification of each indicator.

Type	Indicator	Partial Connection Number			
		First Order	Second Order	Third Order	Fourth Order
1	C_{12}, C_{43}, C_{51}	↑	↓	↑	↑
2	C_{32}, C_{33}	↑	↓	↓	↑
3	C_{13}, C_{22}	↓	↓	↑	↑
4	C_1, C_2, C_3, C_4, C_5, C_{11}, C_{24}, C_{25}, C_{26}, C_{31}, C_{34}, C_{44}, C_{52}, C_{53}	↓	↓	↓	↑
5	C_{14}, C_{21}, C_{23}, C_{41}, C_{42}, C_{54}	↓	↓	↓	-

(4) When considering the strong contrary factors mentioned above, the airport managers should build up the professional team, form a cooperation system between professional talents and experienced talents, set up a high-level bird strike prevention team, and carry out the bird-repelling work efficiently. In terms of equipment, the airport managers should strictly conduct regular inspections and maintenance of various types of bird-repelling equipment, and ensure the layout is prioritized in significant areas for bird strike prevention, such as runways, taxiways, and aircraft takeoff or landing directions. It is suggested that the linkage use of all kinds of bird-repelling equipment be strengthened, and that the bird-repelling work be carried out from multiple dimensions in terms of hearing, vision, smell, and physical interception. In addition, the airport managers should establish an emergency management system according to the characteristics of the local data and information on birds, and should also improve the other working mechanisms, such as airport bird information notifications, navigation notices, and flight dynamic adjustments. Furthermore, the airport managers ought to establish a coordination mechanism with the local governments and carry out management of the ecological environment around the airport, such as

bird habitats, water sources, and farming land. Therefore, the number and frequency of birds flying around the airport can also be reduced. As a result, the threat of bird strike to flight safety is reduced to some extent. In the end, the airport managers should prepare to prevent danger and focus on the factors for the contrary trend, so as to minimize the risk of airport bird strike.

5. Conclusions

There are many factors that influence bird strike events, but few previous studies have focused on certain and uncertain factors of bird strike risk. This paper evaluates airport bird strike risk based on the SPA model, from a fresh perspective. Guided by the SPA theory, this study analyzes the risk factors of airport bird strike, constructs an airport bird strike risk assessment index system from the perspective of "personnel-bird-equipment-environment-management", and establishes the identical-discrepancy-contrary airport bird strike risk assessment model. In addition, inspired by the maximum variance idea, an indicators' weights determination method is designed by coupling subjective and objective factors in order to calculate the weights of each indicator.

Taking an airport in North China as an example, the results of the study indicate that the proposed model in this paper can, on one hand, evaluate the risk of bird strike; on the other hand, it can analyze the risk trend of bird strike. Finally, it can achieve static and dynamic assessments for the risk of bird strike at airports. Furthermore, the method developed in this paper will be able to provide a data reference for airport managers to reduce the airport bird strike risk, which is significant for airport personnel to carry out bird strike prevention works.

In this study, the airport bird strike risk assessment index system only considers five factors; however, all kinds of detailed factors should also be taken into consideration. This will be improved in future research. Aiming at promoting sustainable development of airport security, we do hope that our approach can be applied to different case study airports.

Author Contributions: Conceptualization, R.W. and Q.Z.; methodology, R.W. and Q.Z.; software, Q.Z.; validation, R.W. Q.Z. and H.S.; formal analysis, Q.Z. and X.Z.; investigation, Q.Z., X.Z. and Y.W; resources, R.W.; data curation, X.Z. and Y.W.; writing—original draft preparation, R.W. and Q.Z.; writing—review and editing, R.W. and H.S.; visualization, Q.Z. and X.Z; supervision, R.W. and H.S.; project administration, R.W. and H.S.; funding acquisition, R.W. and H.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Civil Aviation University of China Graduate Research and Innovation Projects, grant number 2021YJS024.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Metz, I.C.; Ellerbroek, J.; Muhlhausen, T.; Kugler, D.; Hoekstra, J.M. The Bird Strike Challenge. *Aerospace* **2020**, *7*, 26. [CrossRef]
2. Wu, Q.; Tang, S.X.; Le, G. Study on ecological prevention and control of birdstrike accident disasters at the airports. *J. Saf. Sci. Technol.* **2006**, *1*, 40–44.
3. Ning, H.S.; Liu, W.M.; Li, J.; Zhao, X.R. Research on Radar Avian Detection for Aviation. *Acta Electron. Sin.* **2006**, *34*, 2232–2237.
4. Shaw, P.; McKee, J. Risk assessment: Quantifying aircraft and bird susceptibility to strike. In Proceedings of the 28th International Bird Strike Committee Meeting, Brasilia, Brazil, 24–28 November 2008.
5. Jia, M.; Shao, Q.; Zhang, J.S. Correlation analysis on the likely civil aviation bird strike events based on the FP-Growth algorithm. *J. Saf. Environ.* **2016**, *16*, 110–114. [CrossRef]
6. Coccon, F.; Zucchetta, M.; Bossi, G.; Borrotti, M.; Torricelli, P.; Franzoi, P. A Land-Use Perspective for Birdstrike Risk Assessment: The Attraction Risk Index. *PLoS ONE* **2015**, *10*, 16. [CrossRef]

7. Metz, I.C.; Ellerbroek, J.; Muhlhausen, T.; Kugler, D.; Kern, S.; Hoekstra, J.M. The Efficacy of Operational Bird Strike Prevention. *Aerospace* **2021**, *8*, 17. [CrossRef]
8. Metz, I.C.; Ellerbroek, J.; Muhlhausen, T.; Kugler, D.; Hoekstra, J.M. Analysis of Risk-Based Operational Bird Strike Prevention. *Aerospace* **2021**, *8*, 32. [CrossRef]
9. Rong, Y.Y.; Wang, C.Y.; Deng, W.; Peng, S.; Mao, G.Z.; Mo, X.Q. Landscape ecology approach to the prevention and control of airport bird strike. *Acta Ecol. Sin.* **2021**, *42*, 8939–8952. [CrossRef]
10. Shi, Z.F.; Zhou, Y.; Shao, Q. Risk assessment of bird strike based on airport environment and flight procedures. *Bull. Sci. Technol.* **2021**, *37*, 120–125. [CrossRef]
11. Nilsson, C.; La Sorte, F.A.; Dokter, A.; Horton, K.; Van Doren, B.M.; Kolodzinski, J.J.; Shamoun-Baranes, J.; Farnsworth, A. Bird strikes at commercial airports explained by citizen science and weather radar data. *J. Appl. Ecol.* **2021**, *58*, 2029–2039. [CrossRef]
12. Shao, Q.; Zhou, Y.; Zhu, P.; Ma, Y.; Shao, M.X. Key Factors Assessment on Bird Strike Density Distribution in Airport Habitats: Spatial Heterogeneity and Geographically Weighted Regression Model. *Sustainability* **2020**, *12*, 7235. [CrossRef]
13. Liu, G.G.; Yang, Y.M.; Liu, B.; Zhong, D.Y.; Yang, S.Q. Prediction model of the bird strike in the airport sphere by using the artificial neural network. *J. Saf. Environ.* **2020**, *20*, 416–422. [CrossRef]
14. Chen, W.S.; Wan, J.; Li, J. Bird strike risk assessment with airport avian radar data. *J. Beijing Univ. Aeronaut. Astronaut.* **2013**, *39*, 1431–1436. [CrossRef]
15. Lopez-Lago, M.; Casado, R.; Bermudez, A.; Serna, J. A predictive model for risk assessment on imminent bird strikes on airport areas. *Aerosp. Sci. Technol.* **2017**, *62*, 19–30. [CrossRef]
16. Wu, X.; Du, J.; Li, X.J.; Liao, W.B. Avian community structure and bird strike prevention measures at jiangbei airport in Chongqing. *Chin. J. Ecol.* **2015**, *34*, 2015–2024. [CrossRef]
17. Liu, Y.; Xu, H.R.; Yuan, H.; He, B.; Zhao, S.L.; Duo, L.A. Bird community structure and diversity at Tianjin binhai international airport. *Chin. J. Ecol.* **2017**, *36*, 740–746. [CrossRef]
18. Wang, J.K.; Ning, H.S.; Chen, W.S.; Li, J.; Wan, J.; He, W. Airport Bird-strike Risk Assessment Model with Grey Clustering Evaluation Method. *Chin. J. Electron.* **2012**, *21*, 409–413.
19. Qiao, L.; Zhang, L. Effectiveness evaluation of airport bird strike prevention system. *J. Civ. Aviat. Univ. China* **2014**, *34*, 55–58.
20. Allan, J. A heuristic risk assessment technique for birdstrike management at airports. *Risk Anal.* **2006**, *26*, 723–729. [CrossRef]
21. Hu, Y.Y.; Xing, P.; Yang, F.; Feng, G.; Yang, G.S.; Zhang, Z.W. A birdstrike risk assessment model and its application at Ordos Airport, China. *Sci. Rep.* **2020**, *10*, 7. [CrossRef]
22. Zhao, K.Q. Disposal and description of uncertainties based on the set pair analysis. *Inf. Control* **1995**, *3*, 162–166.
23. Wu, M.M.; Ge, W.; Li, Z.K.; Wu, Z.N.; Zhang, H.X.; Li, J.J.; Pan, Y.P. Improved Set Pair Analysis and Its Application to Environmental Impact Evaluation of Dam Break. *Water* **2019**, *11*, 821. [CrossRef]
24. Zou, Q.; Zhou, J.Z.; Zhou, C.; Song, L.X.; Guo, J. Comprehensive flood risk assessment based on set pair analysis-variable fuzzy sets model and fuzzy AHP. *Stoch. Environ. Res. Risk Assess.* **2013**, *27*, 525–546. [CrossRef]
25. Yan, F.; Xu, K.L. A set pair analysis based layer of protection analysis and its application in quantitative risk assessment. *J. Loss Prev. Process Ind.* **2018**, *55*, 313–319. [CrossRef]
26. Yue, R.T.; Han, M. Diagnosis of safety operation state for ATC position based on four diagnostic methods. *China Saf. Sci. J.* **2021**, *31*, 52–59. [CrossRef]
27. Kumar, K.; Garg, H. Connection number of set pair analysis based TOPSIS method on intuitionistic fuzzy sets and their application to decision making. *Appl. Intell.* **2018**, *48*, 2112–2119. [CrossRef]
28. Shi, Z.J.; Wang, H.W.; Wang, X. Risk state evaluation of aviation maintenance based on multiple connection number set pair analysis. *Syst. Eng. Electron.* **2016**, *38*, 588–594.
29. Li, X.J.; Zhou, C.Q.; Du, J.; Huang, Y.; Ming, X.B.; Wu, X.; Zheng, J.P. Characteristics of bird strike and prevention system building in airport. *Sichuan. J. Zool.* **2018**, *37*, 22–29.
30. Xu, H.S.; Ma, C.; Lian, J.J.; Xu, K.; Chaima, E. Urban flooding risk assessment based on an integrated k-means cluster algorithm and improved entropy weight method in the region of Haikou, China. *J. Hydrol.* **2018**, *563*, 975–986. [CrossRef]
31. Lyu, H.M.; Zhou, W.H.; Shen, S.L.; Zhou, A.N. Inundation risk assessment of metro system using AHP and TFN-AHP in Shenzhen. *Sust. Cities Soc.* **2020**, *56*, 14. [CrossRef]
32. Sun, Y.; Bao, X.Z. A new combination weighting method and its application based on maximizing deviations. *Chin. J. Manag. Sci.* **2011**, *19*, 141–148. [CrossRef]
33. Chen, K.; Cheng, Q.R.; Pan, W.J. Evaluation of the operation risk level with the small and medium sized airports based on the set pair analysis. *J. Saf. Environ.* **2019**, *19*, 743–753. [CrossRef]