Airport Bird Strike Risk Assessment and Research

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Abstract. Bird strikes occur frequently at airports throughout the country, which poses a serious threat to flight safety. Birds have different risks to aircraft because of their different characteristics and habits. Principal component analysis was carried out based on bird survey data of Zhuhai Airport to optimize the bird strike risk evaluation index system. FCM algorithm combined with Xie-Beni effectiveness index is introduced to construct the evaluation model. The analysis results show that the 29 common bird species of Xinzheng Airport in accordance with different level of risk can be divided into 4 categories, the analysis results provide a basis for the airport bird strike prevention work, and this is a simple and effective bird strike risk assessment method.

1. Introduction

According to the "Bird Strike Aircraft Information Analysis Report" of Civil Aviation Administration, bird strike has become the first major type of accident symptoms in China for many years, which poses a great threat to the safety of civil aviation and brings huge economic losses to civil aviation transport enterprises, and has been widely concerned by civil aviation practitioners and researchers.

In recent years, bird strike research has shifted from simple bird survey, reduction of bird strike frequency and property loss to qualitative and quantitative analysis by multivariate statistical methods based on risk evaluation index. Many experts and research institutes at home and abroad have also carried out bird strike risk assessment research based on historical bird strike statistics, the probability of bird strikes in different bird species and aircraft types is obtained. Allan [1] proposed a bird strike risk assessment method based on the records of bird strikes at national and specific airports, which multiplied the probability and severity of bird strike. The probability is calculated from the frequency of different bird species in bird strike events at the same airport in the past five years, and the severity of impact depends on the degree of damage to aircraft caused by different bird species. Based on the statistics of 9 airports in Australia, Shaw [2] summarized the frequency of bird strikes in different bird species and different aircraft types. On the basis of three years' long-term investigation, Guangxi University has given a simple method to measure the risk of bird strike [3], and has given quantitative results on the risk evaluation index of different bird species. The U.S. bird avoidance model (USBAM) is based on bird statistics over the past 30 years. It gives bird distribution in different seasons and regions, and the bird strike risk is divided into nine grades. The database is updated every 3 to 5 years [4]. The"Civil Aviation Bird Strike Information Network" is established by China Academy of Civil Aviation Science and Technology, it provides suggestions and measures on the basis of data accumulation, and provides a platform for the sharing of bird information in civil aviation [5].
2. Establishment of bird collision risk evaluation index system

2.1. Preliminary selection of risk factors

There are many bird risk factors that affect aircraft safety, various research results have shown their own set of bird risk factors system. In order to objectively reflect the threat degree of each bird to aircraft and determine the priority of bird defense, bird strike risk assessment factors should be selected as comprehensively as possible. Therefore, our research group organizes experts from Guangzhou Civil Aviation College and Civil Aviation University of China as well as technical personnel from Zhuhai Airport, nine risk factors including body size, average activity height, movement frequency, encounter frequency, number of clusters, difficulty of prevention and control, flight agility, main activity time and main activity area are initially selected on the basis of 10 risk factors proposed by Carter and Rescue and 11 risk factors proposed by Dao-De YANG [6], and the flight status and type of aircraft are considered.

2.2. Determination of scoring criteria for qualitative indicators

Among the nine risk factors mentioned above, body size, movement frequency, flight agility, main activity time, difficulty prevention and control, and main activity area are qualitative indicators, which need to be quantified. In order to highlight the differences, these qualitative indicators are assigned according to the three levels of 10, 5 and 1, high scores represent high risk. According to expert’s opinion, the scoring criteria are shown in Table 1.

2.3. Principal component analysis

As everyone knows, the impact of each factor on the evaluation results will be reduced and the difficulty of calculation could be increased because of too many risk factors. On the other hand, too few risk factors will make the assessment results difficult to reflect the real situation and reduce the credibility. Therefore, principal component analysis method is used to determine the risk factor set with cumulative contribution rate of more than 85% as the index system of bird strike risk assessment. Based on the data of 27 dominant bird species in Zhuhai Airport Bird Survey in 2017, the principal component analysis results are shown in Table 2. It can be seen that the cumulative contribution rate of the first five principal components has reached 89.67%, more than 85% and nearly 90%, which basically reflects the information contained in the original data.

The load factors of the above five principal components are shown in Table 3. It can be seen that the first principal component has a strong positive correlation with two risk factors of mobile frequency and active area, the second principal component has a strong positive correlation with one risk factor of prevention and control difficulty, the third principal component has a strong positive correlation with one risk factor of activity area, the fourth principal component has a strong positive correlation with one risk factor of prevention and control difficulty, and the fifth principal component has a strong positive correlation with the two risk factors of average activity height and flight sensitivity. The comprehensive analysis results show that the five risk factors, mobile frequency, active area, difficulty of prevention and control, average activity height and flight sensitivity, can constitute a bird strike risk evaluation index system that correctly reflects the evaluation results.

3. Cluster analysis model

3.1. FCM algorithm

It is assumed that $X = \{x_1, x_2, \ldots, x_n\} \in R^d$ is a set of samples, each sample contains attribute indicators is marked as ‘s’ and $x_i = \{x_{i1}, x_{i2}, \ldots, x_{id}\}$, at the same time, the samples are divided into ‘c’ categories. The clustering problem is reduced by Bezdek to the following constrained nonlinear programming problems:
In formula (1), ‘m’ is the model coefficient and \( m > 1 \), \( U = u_{ij} \) is an \( c \times n \)-order fuzzy partition matrix, \( u_{ij} \) is the membership grade value of the sample \( x_j \) which belongs to category \( i \), and \( V = [v_1, v_2, \ldots, v_c] \) represents the cluster center vector.

The principle of FCM algorithm is to maximize the similarity between objects which are divided into the same class and minimize the similarity between different classes. The steps are as follows:

1. Let the clustering number ‘c’ be greater than 1 and less than \( n \) and the number of ambiguities ‘m’ be greater than or equal to 1 and less than \( +\infty \). Then, let \( \epsilon \) represent accuracy and let \( \epsilon > 0 \). It is assumed that ‘k’ represents iterations and let ‘k’ be equal to 0.

2. The value of \( U^{(k+1)} \) is calculated and make the number of iterations ‘k’ equal to ‘k+1’, the formula is as follows:

\[
u^{(k+1)}_j = \frac{1}{\sum_{i=1}^{c} \left( \frac{u_{ij}^{(k)}}{u_{ij}^{(k)}} \right)^{m-1}} \sum_{i=1}^{c} \left( \frac{u_{ij}^{(k)}}{u_{ij}^{(k)}} \right)^{m-1} \]

3. The value of \( V^{(k+1)} \) be calculated and make the number of iterations ‘k’ equal to ‘k+1’, the formula is as follows:

\[
u^{(k+1)}_i = \frac{1}{\sum_{j=1}^{n} \left( \frac{u_{ij}^{(k)}}{u_{ij}^{(k)}} \right)^m} \sum_{j=1}^{n} \left( \frac{u_{ij}^{(k)}}{u_{ij}^{(k)}} \right)^m x_j, \quad i = 1, 2, \ldots, c
\]

4. Repeat steps II and III until the termination conditions are met:

\[
\left\| V^{(k)} - V^{(k+1)} \right\| < \epsilon, \quad k \geq 1
\]

3.2. Effectiveness indicators

The number of clusters in FCM algorithm needs to be specified in advance, but the number of clusters is usually unknown in practice. Different clustering results can be obtained based on different number of clusters. Effectiveness index can be used to search for the best clustering number and get the best clustering result. FCM clustering algorithm has many validity indicators, some validity indicators are only related to the fuzzy membership degree, but not to the geometric structure of the data, which has some limitations. The validity index ‘ \( Xie-Beni \) ’ is used to search for the best clustering number in this paper, the fuzzy membership degree and data structure of the data are considered to improve the clustering accuracy. The calculation formula is as follows:
When the number of clusters is the best, the value of \( V_{XB} \) is the smallest, it is indicated that the effect of fuzzy clustering is the best. Let \( c^* \) denote the optimal number of clusters, in order to compute \( c^* \), all integers in the range of 2 to \( \sqrt{n} \) need to be searched and the optimal clustering number is obtained when the value of \( V_{XB} \) corresponding to each integer is the smallest.

4. Bird collision risk assessment model application

4.1. Xinzheng Airport bird survey

1. General situation of the airport

Xinzheng International Airport is located in the southeast of Zhengzhou, and 29.5km away from Zhengzhou downtown. The airport was built in 1997 with an aircraft movement area reference code of 4E. The runway of the airport is 3400m long and 60m wide. It is not only an important trunk transport airport in China, but also an alternate landing airport of Capital International Airport. The ecological environment of the airport and its surrounding areas is good, with beautiful scenery and a wide variety of animals and plants. In order to improve the comprehensive management level of bird strike prevention, reduce the incidence of bird strike disasters and ensure flight safety, in the summer and autumn of 2017, the research group was entrusted by the airport to conduct a comprehensive investigation on the ecological environment, birds and other animal and plant resources of the airport and its surrounding areas.

The terrain of the airport and surrounding areas is complex, with a large population, diverse natural landscapes, rich plant resources, and a large area of plantations and orchards. The ecology is good and suitable for bird habitats. There are a large number of wild plants related to bird food inside and outside the forest area, such as Glycine Soja, Rumex acetosa, Vicia amoem, Ziziphus jujuba var. spinosa etc. Outside the airport is a large area of farmland, the crops cultivated all year mainly include Hordeum vulgare, Zea mays cvnongda, Oryza sativa, Setaria viridis, Sorghun vulgare, Trapa dispinosa, various melons, fruits and vegetables, as well as Populus cathayana, AlSix sinica,S.matsudana, Vlmus pumila, Robiinia pseudacacia and other artificial plantations. Forestry and agricultural economy are relatively developed in this region, and birds are increasing year by year.

2. Investigation method

Based on the original bird survey data, the breeding and migration transit birds in the airport and surrounding areas are investigated in two stages: summer and autumn. The survey area extends 5 km from the periphery of the airport, and the sampling intensity of the survey route exceeds 20% of the total survey area. Investigators go along the selected survey routes, from inside to outside to radiate in different directions to reconnaissance, the bird species and number of birds in the area are counted in detail. In addition, the bird network laid in the airport area is also used to assist in the investigation and identification of captured birds. In order to obtain more accurate data, spot observation of key areas and random sampling review of some survey routes are conducted.

The state of bird resources in the survey is expressed in relative quantity scale. The conventional route statistics method is taken, the average hourly encounter rate is more than 5 species of the same species as the dominant species, 1~5 is only a common species, less than one is an occasional species. In the spring and autumn bird migration season, there are many species and large numbers of birds, and the relative number level is determined, the dominant species are more than 5% of the total number of individuals surveyed, the common species are 1%~5%, and the rare species are less than 1%.

3. Findings
After investigating and analyzing the bird resources in the airport and its surrounding areas, 11 orders, 36 families, 123 species and 6 subspecies of birds in the airport and its surrounding areas were obtained. Among these birds, *Phasianus lollhicus kiangsaensis* is a subspecies of Inner Mongolia, *Dendrocopos major japomicus*, *Ficedulum ugimaki* and *Fringilla coelebs coelebs* are new records of bird distribution in the airport and its surrounding areas. At the same time, *Anas Penelope* was first found to breed in the lotus root pond in the northeast corner of the airport. This bird is only found in Taiwan and parts of South Asia in China, and it is the first time to be found in mainland China.

Among 123 species of birds found in Xinzheng International Airport and its surrounding areas, there are 92 species of passeriformes birds, accounting for 74.7 % of all birds; there are 31 species of non-passeriformes birds, accounting for 35.3 % of all birds. There are 96 species of summer migratory birds and resident birds, which together form summer birds, accounting for 78 % of all birds. In the spring and autumn seasons, a large number of birds pass through the airport and the surrounding areas for rest and food. Therefore, the number of winter migratory birds is the lowest in the year, but the number of winter bird clusters is relatively large.

In China's animal geographical divisions, the airport and the surrounding area belong to the Oriental realm, and its bird flora composition also reflects the characteristics of this geographical area. Among them, 66 species (53.6%) of Oriental birds, 21 species (17.1%) of Palaearctic birds and 36 species (29.3%) of widespread birds were found. The proportion of birds in the Oriental realm is relatively large, which is comparatively consistent with that in Henan Province.

### 4.2. Data processing

In this survey of Xinzheng Airport, 29 species of common and dominant species were selected as sample matrices for cluster analysis as shown in Table 4. The five risk factors analyzed above are used as the feature vectors of the fuzzy clustering, and the five risk factors of each bird form a sample point, so that 29 cluster sample points can be obtained.

1. **Data normalization**

   Because the dimensions of bird strike risk factors are different, the dimension is eliminated by normalization. In this paper, the range method is used and the transformation formula is as follows:

   \[
   x^R_{ij} = \frac{x_{ij} - \min_{1 \leq i \leq n} x_{ij}}{\max_{1 \leq i \leq n} x_{ij} - \min_{1 \leq i \leq n} x_{ij}} \quad i = 1, 2, 3, 4, 5, \quad j = 1, 2, 3, 4, 5
   \]  

   In MATLAB software, the following procedures are executed to complete normalization:

   ```matlab
   for i=1:size(X,2)
   R(:,i)=(X(:,i)-min(X(:,i)))/(max(X(:,i))-min(X(:,i)));
   End
   ```

2. **Determination of the optimal cluster number**

   Given the cluster number ‘c’, the Xie–Beni validity index \( V_{XB} \) of ‘c’ is calculated. The value of ‘c’ corresponding to the smallest value of \( V_{XB} \) is chosen as the best clustering number ‘c’. When the risk of bird collision of 29 species is analyzed by fuzzy cluster analysis, the value range of cluster number is between 2 and 5. In MATLAB, the following program is executed to quickly search for the best number of clusters in each integer of 2 to 5:

   ```matlab
   VXB(1)=3000;
   for n=2:sqrt(size(R,1))
   [V,U,ob]=fcm(R,n);
   VXB(n)=min(ob)/(size(R,1)*min(pdist (V).^2));
   end
   [w,c]=min(VXB)
   VXB(1)=[]
   ```
The \textit{Xie–Beni} \(-\text{validity indices} \) corresponding to different values are obtained as shown in Table 5. As can be seen from Table 5, the value of validity index varies with different clustering numbers. When the clustering number \(c\) is 4, the value of \(V_{XB}\) is the smallest, and the optimal clustering number \(c^*\) is equal to 4. It can be seen that the best result is to divide 29 samples into four categories.

### 4.3. Clustering result analysis

The optimal classification method is determined according to the optimal clustering number, and 29 samples are clustered to get the membership matrix which is marked as ‘\(U\)’. Then, the maximum membership criterion is used to classify the samples, and each sample is assigned to a specific class to obtain the optimal clustering results. In MATLAB, the following program is executed to classify each sample in the sample set into a specific class:

\[
[V,U]=fcm(R,c);
[W,n]=max(U);
\]

The final classification results are detailed in Table 6. From the results, it can be seen that the first category represents very high risk of birds, the second category represents high risk of birds, the third category represents general risk of birds, and the fourth category represents low risk of birds.

Based on the above analysis results and the actual situation, \textit{Hirundo rustica} and \textit{Hirundo daurica} are good at flying in the air for a long time, and the activities are very frequent. They often cross the runway and have the greatest threat to the take-off and landing aircraft. They are the most important birds to be guarded against. Although the number of raptors such as \textit{Falco tinnunculus} and \textit{Nightjar} is small, they often hover in the air to find food because of the wide view in aircraft movement area. At the same time, they have a high flying height and prefer to prey at night to cause poor driving which also need to be taken attention. Birds such as \textit{Streptopelia turtur}, \textit{Upupa epops} and \textit{Lanius} are medium-sized and large in number. They like to forage in open areas on both sides of the runway and are difficult to drive away. Aircraft's strong suction during takeoff and landing is easy to cause accidents by sucking it into the engine. It also needs to be vigilant. Birds such as \textit{Heron}, \textit{Gallinula chloropus}, and \textit{Dicrurus macrocercus} are larger, but do not fly frequently, and activities are infrequent, which has less impact on flight safety. Although the number of \textit{Passer montanus} and \textit{Pica pica} is large, their flight is flexible and they are mostly active in villages and groves which are not harmful to the airport.

### 4.4. Prevention advice

In order to reduce the bird strike disaster, the airport authorities should focus on the prevention of bird strike on ecological environment management. By killing fish and shrimps and shellfish in the drainage ditch, reducing pavement surface gathered water, adding protective nets to the surrounding fish ponds, and filling the ponds, the wader can be reduced to live and feed in aircraft movement area and around the airport. The frequency of various raptors entering the airport can be reduced by killing small rodents. The population of carnivorous or omnivorous birds in the airport can be controlled by killing insects, earthworms and mosquitoes on a large scale. By replacing seedless grass seeds and clearing shrubs, the food sources of all kinds of phytophagous birds are cut off. At the same time, it is necessary to adopt targeted means of driving birds, the effect of bird driving could be improved by comprehensive using flame tracer and other various high-altitude bird-driving equipment, devices that drive birds by sound, such as gas cannon, imitating sound, etc., and trammel net installed on both sides of the runway.

### 5. Conclusion

According to the risk level of birds, bird prevention measures are taken for key bird species in order to effectively improve the control effect and control the risk of bird collision at airports. The risk assessment model of FCM cluster analysis combined with the \textit{Xie–Beni} \(-\text{validity index} \) is established. Based on the fuzzy membership degree of risk factors and the geometric structure of data, the evaluation index system is optimized by this model. Assessment and judgment are made by using the small sample data of the current annual bird survey. According to the risk classification of 29 common birds in
Xinzheng Airport, it can be seen that the clustering method based on PCA and FCM algorithm is scientific, effective and easy to implement. It has certain reference value for other airports.

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| Table 1. Scoring criteria for qualitative indicators of bird strike risk factor |
|-----------------------------------------------|
| **Risk factor** | Scoring criteria |
|-----------------------------------------------|
| Body size (weight) | 10 Points | 5 Points | 1 Point |
| ≥ 250g | 50g ~ 250g | ≤ 50g |
| Moving frequency | Long-term continuous flight | Intermittent or short flight | Very short or very few flight |
| Flight agility | Clumsy flight | Straight flight | Variable flight path |
| Activity time | Night or dusk | Daytime | Early morning |
| Active areas | Near the runway | Other areas in the aircraft movement area | Outside the airport |
| Difficulty of prevention and control | Hard to drive away | Appearance after driving | No appearance after driving |

| Table 2. Characteristic value, contribution value and cumulative contribution value of principal components |
|-----------------------------------------------|
| **Principal component** | Characteristic value | Contribution rate (%) | Cumulative contribution rate (%) |
|-----------------------------------------------|
| 1 | 3.6164 | 40.18 | 40.18 |
| 2 | 1.8292 | 20.32 | 60.4 |
| 3 | 1.3520 | 15.02 | 75.42 |
| 4 | 0.6765 | 7.52 | 82.94 |
| 5 | 0.6053 | 6.73 | 89.67 |
| 6 | 0.3338 | 3.71 | 93.38 |
| 7 | 0.2772 | 3.08 | 96.46 |
| 8 | 0.2024 | 2.25 | 98.71 |
| 9 | 0.1074 | 1.19 | 100 |
### Table 3. Load of principal component factor

| Risk factor                           | Principal component | 1         | 2         | 3         | 4         | 5         |
|---------------------------------------|---------------------|-----------|-----------|-----------|-----------|-----------|
| Encounter frequency                   |                     | 0.3838    | 0.2091    | -0.3342   | -0.3721   | -0.2569   |
| Number of clusters                    |                     | 0.3999    | 0.1570    | -0.3694   | -0.4116   | -0.0095   |
| Body size                             |                     | -0.2586   | -0.4520   | -0.3733   | -0.0136   | 0.2000    |
| Average activity height               |                     | 0.2584    | -0.4503   | -0.3041   | 0.0538    | 0.4827    |
| Moving frequency                      |                     | 0.4578    | -0.4503   | 0.1630    | 0.0907    | 0.2351    |
| Flight agility                        |                     | -0.3801   | 0.2135    | -0.3206   | -0.2545   | 0.4273    |
| Activity time                         |                     | 0.1036    | -0.6180   | -0.1193   | 0.0125    | -0.5345   |
| Active areas                          |                     | 0.4235    | -0.0786   | 0.3254    | 0.1305    | 0.3577    |
| Difficulty of prevention and control  |                     | 0.1229    | 0.3013    | -0.5201   | 0.7739    | -0.0973   |

### Table 4. Original sample data

| Specific name         | Moving frequency | Average activity height | Flight agility | Active areas | Difficulty of prevention and control |
|-----------------------|------------------|-------------------------|----------------|--------------|--------------------------------------|
| Podiceps ruficollis   | 1                | 0.4                     | 10             | 1            | 1                                    |
| Nycticorax nycticorax | 1                | 29                      | 5              | 5            | 5                                    |
| Ardea cinerea         | 1                | 25                      | 5              | 5            | 5                                    |
| A. purpurea           | 1                | 33                      | 5              | 5            | 5                                    |
| Gallinula chloropus   | 1                | 0.5                     | 10             | 5            | 1                                    |
| Rallus striatus       | 5                | 0.6                     | 5              | 5            | 1                                    |
| Streptopilia Orientalis | 5               | 6                       | 5              | 5            | 10                                   |
| C. canorus            | 5                | 3.4                     | 5              | 1            | 5                                    |
| C. poliephalus        | 10               | 4.3                     | 1              | 5            | 1                                    |
| Upupa epops           | 1                | 10                      | 5              | 1            | 10                                   |
| Hirundo rustica       | 10               | 16.5                    | 1              | 10           | 10                                   |
| H. daurica            | 10               | 29                      | 1              | 10           | 10                                   |
| Motacilla alba        | 5                | 6.2                     | 1              | 5            | 5                                    |
| Anthus novaeseelandiae| 5                | 1.4                     | 5              | 10           | 5                                    |
| P. sinensis           | 5                | 4.8                     | 5              | 1            | 10                                   |
| L. cristatus          | 5                | 4.5                     | 1              | 5            | 10                                   |
| Diru rmacrocercus     | 5                | 3.9                     | 1              | 1            | 10                                   |
| Sturnus cineraceus    | 5                | 2.6                     | 5              | 5            | 5                                    |
| Cyanopica cyana       | 5                | 6.8                     | 5              | 1            | 5                                    |
| Pica pica             | 5                | 6.8                     | 5              | 1            | 5                                    |
| Passer montanus       | 5                | 4.2                     | 1              | 1            | 5                                    |
| E. cooides            | 5                | 1.9                     | 5              | 5            | 10                                   |
| Anas Platyrhynchos    | 1                | 0.8                     | 10             | 1            | 1                                    |
| Falco tinnunculus     | 5                | 55                      | 5              | 10           | 10                                   |
| Coturnix coturnix     | 1                | 0.2                     | 10             | 5            | 1                                    |
| Gallinago gallinago   | 5                | 18.9                    | 1              | 5            | 5                                    |
| Caprimulgus indicus   | 5                | 32                      | 5              | 10           | 10                                   |
| Picus canus           | 5                | 2.2                     | 1              | 1            | 5                                    |
| Carduelis sinica      | 5                | 4                       | 5              | 5            | 5                                    |
Table 5. Cluster number and the Xie – Beni -index correspondence table

| c (Number of clusters) | 2     | 3     | 4     | 5     | 6     |
|------------------------|-------|-------|-------|-------|-------|
| Xie – Beni -index      | 1.6802| 1.7230| 0.5625| 0.6917| 0.8944|

Table 6. Xinzhueng Airport bird risk clustering results

| Category | Bird species included in the category |
|----------|---------------------------------------|
| 1        | Hirundo rustica, Hirundo daurica       |
| 2        | Streptopelia orientalis, Upupa epops, Caprimulgus indicus, Falco tinnunculus, Emberiza coides, Lanius cristatus, Anthus richardi, Pycnonotus sinensis |
| 3        | Gallirallus striatus, Gallinula chloropus, Cuculus canorus, Cuculus poliocephalus, Motacilla alba, Dicrurus macracercus, Sturnus cineraceus, Gallinago gallinago, Nycticorax nycticorax, Ardea cinerea, Ardea purpurea |
| 4        | Tachybaptus ruficollis, Anas platyrhynchos, Coturnix coturnix, Picus canus, Passer montanus, Pica pica, Carduelis sinica, Cyanopica cyanus |