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Airport Bird-strike Risk Assessment Model with Grey Clustering Evaluation Method*

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Abstract — Bird strike, a common aviation accident, endangers aircrafts. A real-time bird-strike risk assessment system is a guarantee for airport safe management. This paper adapts grey clustering evaluation into a new real-time method with expert experience, Bird-strike risk assessment model (BRAM). Timeliness is a characteristic and bird-strike expert experience improves the effectiveness of BRAM. Bird-strike experts are invited to grade the importance of different risk indices, which are essential in BRAM. The inputs of the model are bird information and aircraft information. Afterwards, BRAM outputs bird-strike risk level timely and dynamically. Meanwhile, bird-strike management advices are also outputted in accordance with the risk level, and delivered to air traffic control of the airport.

Key words — Risk assessment, Grey clustering evaluation, Real-time, Bird strike.

I. Introduction

Bird strike is identified as a collision between birds and aircraft in this paper. Most collisions happen around airport[1]. It may keep collisions from happening, to assess the bird-strike risk and then to repel birds.

Many bird-strike risk analysis methods have been proposed, though they are not real-time. C.A. Tedrow analyzes bird-strike probability of some aircrafts and airports[2]. J. Allan proposes a widely used risk assessment method to grade the bird-strike risk[3]. Z. Wang utilizes integrated risk value of certain bird species via factor analysis to grade bird-strike risk[4]. R.A. Dolbeer develops the relationship between the height of flying-bird and the bird-strike risk[5]. The ignorance of bird information's variance results in the lack of timeliness in these methods.

Some nations have developed real-time bird-strike warning systems with radar systems, *e.g.* United States Avian Hazard Advisory System (USAHAS), Swiss/Dutch Radar Observation of Bird INtensities (ROBIN) system and German BIRDTAM system. These systems provide air-route bird-strike warnings which can be browsed online[6]. However, these systems cannot provide local bird information to a specific airport, so they fail to assist airport bird-strike management.

J. Wang and E.E. Herricks utilize X-band marine radar to detect birds around airport and calculate the risk for a runway. Though the method is real-time, it fails to rate risk and only consider risks of birds very close (120m) to a runway[7].

A new real-time Bird-strike risk assessment model (BRAM) is proposed in this paper which rests on grey clustering evaluation. After inputting bird information detected by radar system (data collected at Nanyang Jiangying Airport in this paper), and aircraft information (aircraft type and phase of flight) provided by air traffic control (aircraft information is simulated in this paper), BRAM outputs risk levels and bird-strike management advices. BRAM is distinguished from former researches in these characters: (1) real-time (risk level is outputted in 1s after bird being detected), (2) wider range detected (birds in the area extending three kilometers from a runway are considered), and (3) helpful in airport bird-strike management (bird-strike management advices can be given by the model).

II. Grey Clustering Evaluation

1. Application of grey theory in risk assessment

Some disadvantages of bird-strike reports are: (1) delayed bird-strike reports, (2) indistinct descriptions of bird strike, (3) confidentiality of original bird-strike reports, (4)s mall sample of bird strike (only a small scale bird-aircraft collisions were reported) and (5) impossibility to experiment[8]. All reasons above lead the data of bird-strike to be small-sample, data-lack, information-incomplete and experience-less. Deng[9] applied grey theory to address this kind of problem. With the development of this theory, it is utilized into risk assessment[10]. With improvements, grey theory can be applied into bird-strike risk assessment.

This paper develops grey clustering evaluation with Whitenization weight function (WWF) into bird-strike risk assessment. In BRAM, the values of different indices are rated into

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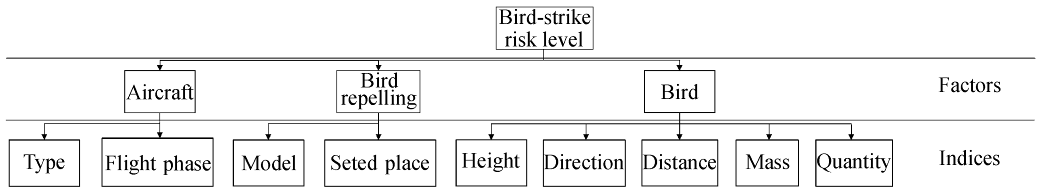

Fig. 1. Bird-strike factors and indices

several classifications (risk levels) according to whitenizated grey scales.

2. Bird-strike risk model

(1) Risk factors and indices

The bird-strike risk hierarchy is shown in Fig.1.

There are three factors including nine indices which affect bird-strike risk. Before assessment, importance of indices should be determined through Analytic hierarchy process (AHP). The importance of factors are determined first, and then of the indices.

The information of bird-repelling factor can be obtained from local airports. Yet in this paper, the bird-repelling information of Nanyang Jiangying Airport is not available. However, it will be considered when an airport employs equipments with BRAM in future.

The type index refers to the type of an aircraft. The flight phase index includes taxiing, take-off, climbing, descent, approach and landing. The height index means the altitude when the bird/flock is detected. The mass index is the average body weight of a bird species. The quantity index demonstrates the amount of birds in a flock.

Theoretically, the distance index refers to the distance between a bird/flock and an aircraft, but in this paper the distance index is defined as the distance between a bird/flock and runway center line. Because the bird speed can be ignored when comparing to the speed with which an aircraft takes off, approaches or lands.

The direction index describes the bird flying direction. In Fig.2, θ represents direction. The value range of θ is from 0 to 180°, 0 meaning that the bird heads against the runway, and 180° meaning that the bird direction is vertical to and the bird is flying away from the runway.

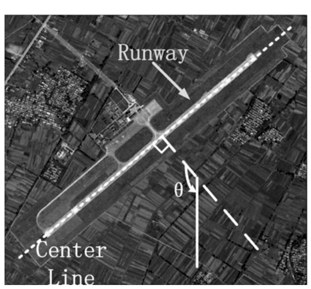

Fig. 2. Illustration of direction index

(2) The importance of indices

The importance of an index, a constant graded by experts, means an index's impact degree on risk. In this paper, four bird-strike experts are invited to give their opinions on importance of risk indices.

Firstly, the weight of each expert is defined through Eq.(1)[11], w_{pq} meaning the value of expert p, item q (Table 1). Expert weight is the influence of an expert. Weights of the four experts are 0.1840, 0.2040, 0.2985 and 0.3135.

$$R_i = \frac{\sum_{q=1}^{2} w_{pq}}{\sum_{p=1}^{n}\sum_{q=1}^{n} w_{pq}} \tag{1}$$

Table 1. Expert weight value

Item	Professional rank	Weight value	Working years	Weight Value
1	Senior	15	Above 30	10
2	Assoc. Senior	12	20 to 30	8
3	Intermediate	9	10 to 20	6
4	Junior	6	5 to 10	4
5	None	3	Below 5	2

Secondly, four experts grade the importance of every index by their own experience, and the importance is called rough importance.

Finally, rough importance of every index is weighted by expert weight defined in last step, and the refined importance η_j of index j is determined and will be used later.

(3) Center triangular WWFs

The function of WWF is to transform observed value to grey scale which represents degree that an index observed value attributes to grey classification k. A set of ideal grey scales of an index is standard, namely, the sum of all grey scales is 1. The center triangular WWFs (Fig.3) guarantee grey scale to be standard[12], thus in this paper, center triangular WWFs are used.

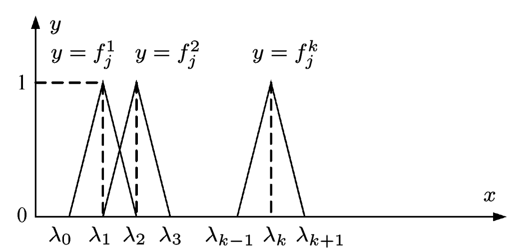

Fig. 3. Typical Center Triangular WWFs

λ_k is the center of grey classification k. The observed value x of index j is transformed to grey scale $f_j^k(x)$ through Eq.(2).

$$f_j^k(x) = \begin{cases} 0, & x \notin [\lambda_{k-1}, \lambda_{k+1}] \\ \dfrac{x-\lambda_{k-1}}{\lambda_k-\lambda_{k-1}}, & x \in (\lambda_{k-1}, \lambda_k] \\ \dfrac{\lambda_{k+1}-x}{\lambda_{k+1}-\lambda_k}, & x \in [\lambda_k, \lambda_{k+1}) \end{cases} \tag{2}$$

(4) BRAM

BRAM can be done in seven successive steps. Firstly, define grey classifications and centers; then define importance of indices; after this, grade Threat score (TS) of specific aircraft type and flight phase; next, establish center triangular WWFs; afterwards, calculate synthetic clustering coefficient vector; after this, figure out risk level; and finally, give bird-strike management advices.

(a) **Define grey classifications and centers**

Five grey classifications are related with five risk levels, and two more grey classification 0 and 6 are continued (for grey scale being standard mathematically), and the center λ_k of grey classification k is defined. Five basic grey classifications are VL, L, M, H and VH, related to risk levels very low, low, medium, high and very high.

Former researches[2,3,5,7,11] demonstrate the singularities of five bird indices and suggestions from bird-strike experts support them as well: ① Most of bird strikes happen at low altitude, ② a bird flying toward the runway is more dangerous than one flying away from, ③ a bird close to the runway is harmful, and ④ birds with greater mass or a larger flock enhance the consequence of a collision. Values being used in former researches are defined as the centers of index height, index distance and index mass, while of index direction and quantity are defined according to these singularities (Table 2).

Observed values between the center of classification VL and of VH, mainly affect the result of BRAM, so these two centers can be considered as endpoints. Therefore when an observed value exceeds the endpoints, the originally observed value x_{ori} is replaced by the endpoints Eq.(3), so that no observed value is ignored and that WWFs are uncomplicated.

$$x = \begin{cases} \min(\lambda_{VL}, \lambda_{VH}), & x_{ori} < \min(\lambda_{VL}, \lambda_{VH}) \\ x_{ori}, & \min(\lambda_{VL}, \lambda_{VH}) \le x_{ori} \\ & \le \max(\lambda_{VL}, \lambda_{VH}) \\ \max(\lambda_{VL}, \lambda_{VH}), & x_{ori} > \max(\lambda_{VL}, \lambda_{VH}) \end{cases} \tag{3}$$

(b) **Define importance of indices**

Importance of seven indices after expert grading are shown in Table 3.

Table 2. Centers of indices of bird factor

	λ_0	λ_{VL}	λ_L	λ_M	λ_H	λ_{VH}	λ_6
Height (m)	1500	1000	600	300	100	50	0
Direction (Deg)	180	150	120	90	60	30	0
Distance (m)	3000	2000	1000	500	100	0	N/A
Mass (g)*	N/A	0	50	300	600	1000	1800
Quantity**	N/A	0	1	5	10	15	20

*When mass is above 1000, the risk that a bird may cause is considered as VH. 1800 is a value to establish WWF. Average mass of some common bird species, swallow, pigeon, raven and pheasant are set as these centers.

**A flock with 15 birds is considered that will attribute to risk level VH apparently. 20 is a value to establish WWF. The intervals between centers are almost average.

Table 3. Importance of indices

Factor	Bird		Aircraft	
Indices	Height	0.0950	Type	0.0422
	Direction	0.0475	Flight phase	0.2639
	Distance	0.0475		
	Mass	0.2519		
	Quantity	0.2519		

(c) **Grade TS of specific aircraft type and flight phase**

The vulnerability of different aircraft types or an aircraft during different flight phases are diverse. TS is a substitution of observed value in expert experience method, when observed valued is hard to obtain. Because there is few researches on aircraft type or flight phase vulnerability in bird strike, expert experience can be utilized to grade the vulnerability.

As a regular index with observed value, centers of index aircraft type and index flight phase are defined (Table 4) before experts grading. During grading, four experts give their opinions, e.g. if an expert suggests the vulnerability is between L and M, he/she will grade a value between 3 and 4. After grading, TS of aircraft type and flight phase are weighted (Table 5 and 6). Some TS which are below 2 or above 6 will be replaced by 2 or 6.

Table 4. Centers of aircraft type & flight phase

Grey classification	0	VL	L	M	H	VH	6
λ_k	0	2	3	4	5	6	8

Table 5. TS of aircraft type

Type	Boeing 737	Airbus 320	Boeing 747	Airbus 330	EMB	CRJ
Threat score	3.149	3.235	1.851	2.298	5.201	5.298

Table 6. TS of flight phase

Flight phase	Taxiing	Take-off	Climbing	Descent	Approach	Landing
Threat score	1.000	6.179	4.985	3.701	5.522	2.433

(d) **Establish center triangular WWFs**

Theoretically, there are seven WWFs (five are for basic grey classifications and two for continued ones) of each index; however, after regularizing observed values through Eq.(3), all values are between λ_{VL} and λ_{VH}, so five center triangular WWFs for basic grey classifications mainly effect in BRAM. The function of two WWFs for continued grey classifications is to guarantee standardization of grey scales mathematically.

(e) **Calculate synthetic clustering coefficient vector**

The synthetic clustering coefficient vector of bird/flock i, can be calculated through Eq.(4), j representing the ordinal number of a risk index.

$$\boldsymbol{\sigma}_i = \left\{ \sigma_i^k = \sum_{j=1}^{7} f_j^k(x_{ij}) \cdot \eta_j, k = VL, L, M, H, VH \right\} \tag{4}$$

(f) **Figure out risk level of bird/flock i**

Every element of $\boldsymbol{\sigma}_i$ represents a bird/flock's memberships of different grey classifications. Hence, synthetic clustering risk value RV_i of bird/flock i is defined as Eq.(5) and in this paper $\boldsymbol{V}$ is selected as Eq.(6). The value range of RV_i is 1 through 5. Additionally, divide the value range equidistantly into five parts.

$$RV_i = \boldsymbol{\sigma}_i \bullet \boldsymbol{V} \tag{5}$$

$$\boldsymbol{V} = (1\ 2\ 3\ 4\ 5)^T \tag{6}$$

Therefore, the risk level RL_i of bird/flock i can be figured out through Eq.(7).

$$RL_i = \begin{cases} VL, & RV_i \in [1, 1.8) \\ L, & RV_i \in [1.8, 2.6) \\ M, & RV_i \in [2.6, 3.4) \\ H, & RV_i \in [3.4, 4.2) \\ VH, & RV_i \in [4.2, 5] \end{cases} \tag{7}$$

(g) **Give bird-strike management advices**

According to relevant risk level, the system provides different bird-strike management advices. Some advices will be introduced in Section IV.

III. Simulation and Analysis

For more efficiently illustrating BRAM, Nanyang Jiangying Airport is taken as an example. Birds/flocks information was collected with X-band marine radar operating at 9.4GHz[13] and further processed[14]. Seven typical birds/flocks are selected, which underline the characteristics of BRAM. The birds/flocks are show in Fig.4 (points), and their information is in Table 7. In addition, information of two aircrafts are simulated and also shown in Table 7. Risk levels (Table 8) are calculated through seven steps of BRAM as mentioned in Section II.

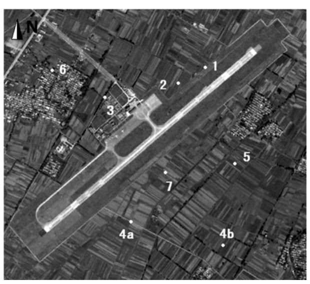

Fig. 4. Bird Information

Table 7. Bird Information* & aircraft information

No.	Height (m)	Direction (Deg)	Distance (m)	Mass (g)	Quantity	Type	Phase
1	51.2	45.38	151	280	1	737	Climb
2	24.9	27.25	179	23	2	737	Climb
3	31.3	133.22	563	23	8	737	Climb
4a	92.1	95.2	426	76	2	737	Climb
4b	95.9	103.7	1103	76	2	320	Descent
5	281	124.1	526	280	12	320	Descent
6	158.3	38.1	981	34	1	320	Descent
7	82.8	153.92	285	500	1	320	Descent

*The field research was Oct. 13th 2008 through Oct. 17th 2008.

The risk levels of Flock 3 and Flock 5 are H, while the risk levels of Bird 1, Bird 2, Bird 7 and Flock 4a are M, and Flock 4b and Bird 6 are L.

Bird mass, bird quantity and aircraft flight phase are the three most significant indices influencing on risk level, while other indices are less important.

Bird 7 is a typical example that great body mass effects risk level. Its body mass contributes to σ_7^H greatly and finally results in risk level M. Flock 5 explains all indices, especially quantity index and mass, cooperate to impact risk value and risk level, and with all indices' impacts the sum of σ_5^M, σ_5^H and σ_5^{VH} is 0.9296 almost equaling to 1, so the risk value RV_5 is 3.7424 and the risk level RL_5 is H.

Table 8. Synthetic clustering coefficient vector, risk value & risk level

No.	σ_i^{VL}	σ_i^L	σ_i^M	σ_i^H	σ_i^{VH}	RV_i	RL_i
1	0.2519	0.0262	0.3089	0.0317	0.3809	3.2622	M
2	0.3249	0.1788	0.0451	0.0444	0.4064	3.0275	M
3	0.157	0.1484	0.178	0.1574	0.3589	3.412	H
4a	0.1889	0.2964	0.1404	0.095	0.2789	2.9777	M
4b	0.1938	0.3571	0.1595	0.2781	0.0112	2.5549	L
5	0.0065	0.0636	0.3949	0.2495	0.2852	3.7424	H
6	0.3325	0.217	0.1411	0.2745	0.0385	2.4799	L
7	0.2994	0	0.2174	0.4502	0.0327	2.9159	M

Bird 1, Flock 2, Flock 3 and Flock 4a are impacting a climbing Boeing 737, which flight phase is vulnerable, so σ_1^{VH}, σ_2^{VH}, σ_3^{VH} and σ_{4a}^{VH} are great, improving their RV_i, leading their risk levels to be M and H.

The risk level of one bird/flock may change. Flock 4a and Flock 4b are the same flock but at different time. They are observed flying from one place to another, and their risk level alternated from M of Flock 4a to L of Flock 4b with the information (bird information and aircraft information) changing. With bird information calculated at distinct time, the model is able to provide dynamical bird-strike risk level.

For Bird 6, its indices are insignificant, so the risk level is just L.

IV. Management Advice

BRAM is designed not only to calculate bird-strike risk level, but also to deliver bird information and risk level with bird-strike management advice to airport air traffic control. The bird information, as mentioned in Section II and III, includes bird position (longitude and latitude), quantity, mass *etc.*, and bird-strike management advice corresponds to the risk level which is an output of BRAM. According to the regular airport bird-strike management methods[3], four kinds of optional advices are listed in Table 9. In practical application, local airports may adapt special actions according to their conditions.

Table 9. Bird-strike management advice

Risk level	Advices
VL (Very low)	No further action required
L (Low)	Keep watch over the bird/flock
M (Medium)	Repel bird/flock as soon as possible
H (High) & VH (Very high)	1. Suspend take-off and landing if necessary 2. Repel bird/flock as soon as possible

V. Conclusion

This paper proposes BRAM which rests on grey clustering evaluation method and expert experiences. The rated risk level is outputted from the model dynamically with timely updated bird information. Different bird-strike management advices correspond to different risk level, effectively assist the air traffic control to handle potential bird-strike hazard.

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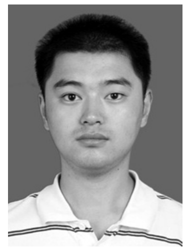

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