Risk assessment of heavy landing based on BWM and cloud model

Shi Jiahui^{1,a}, Xu Jihui^{2*,b}, Liu Tengfei³, Zhang Jing⁴, Zhu Pu⁵, Yang Chunlin⁶

¹Equipment Management and Unmanned Aerial Vehicle Engineering College Air Force Engineering University Xi'an, China

²Equipment Management and Unmanned Aerial Vehicle Engineering College Air Force Engineering University Xi'an, China

³Equipment Management and Unmanned Aerial Vehicle Engineering College Air Force Engineering University Xi'an, China

⁴Equipment Management and Unmanned Aerial Vehicle Engineering College Air Force Engineering University Xi'an, China

⁵Equipment Management and Unmanned Aerial Vehicle Engineering College Air Force Engineering University Xi'an, China

⁶Air Traffic Control and Navigation College Air Force Engineering University Xi'an, China

Abstract. Aiming at the systemic, ambiguity and randomness characteristics of the aircraft's heavy landing risk, this paper starts from the system perspective and proposes a risk assessment method based on the Best-Worst method (BWM) and cloud model. Aiming at the ambiguity and randomness of the information in the risk assessment, the cloud model is used to describe the language. In view of the difference in weights, combining BWM and cloud models for weighting. Finally, an example is given to verify the reasonableness and effectiveness of the model.

1 Introduction

Aircraft heavy landing risk refers to unsafe incidents that easily occur during the landing phase when the load exceeds the limit when the aircraft touches the ground, which may lead to accidents that cause damage to the aircraft body structure, and even serious flight accidents that cause damage to the aircraft. For heavy landing risk assessment, there are still the following problems: 1) Data processing lacks systematic and technical statistical analysis and research; 2) it is difficult to get rid of the limitations of the traditional expert empirical qualitative risk analysis and assessment model; 3) insufficient consideration of the large amount of ambiguity, randomness and cognitive uncertainty in the evaluation process. This paper proposes a risk assessment method based on BWM and cloud model.

2 Basic theory

2.1 BWM algorithm description

BWM is a new multi-factor evaluation method through a pairwise comparison matrix. The method steps mainly include the following steps.

- Define set $\{C_1, C_2, \dots, C_n\}$ to describe the subject of evaluation.
- Experts determine the factors B and W with the greatest and least impact and describe them as the best and worst factors.
- Determine the weight of the best factor B to other factors according to the prescribed scale, and get

the corresponding weight matrix $A_B = (a_{B1}, a_{B2}, \dots, a_{Bn})$. a_{Bn} is expressed as the degree of importance of the best factor B relative to the n th factor.

- Determine the weight of other factors for the worst factor W according to the prescribed scale, and get the corresponding weight matrix $A_W = (a_{1W}, a_{2W}, \dots, a_{nW})$. a_{Bn} is expressed as the degree of importance of the n th factor relative to the worst factor W .
- Describe the optimal weight set as $\{w_1, w_2, \dots, w_n\}$. The optimal weight set satisfies to minimize the maximum absolute difference of the set $\{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\}$. the problem is transformed into a nonlinear programming problem:

$$\min \tilde{z} s.t. \begin{cases} |w_B - a_{Bj}w_j| \leq \tilde{z} \\ |w_j - a_{jW}w_W| \leq \tilde{z} \\ \sum_{j=1}^n w_j = 1, w_j \geq 0; \text{ for all } j \end{cases} \quad (1)$$

Among them, w_B represents the weight of the best factor B . w_W represents the weight of the worst factor W . w_j represents the weight of the j th factor. a_{Bj} represents the importance of the best factor B to the j th factor and a_{jW} represents the j th factor to the worst factor W . $\tilde{z}$ represents the lowest allowable deviation.

^asjh415409531@163.com

^b*changan6018@163.com

The closer the $\tilde{z}$ value is to 0, the smaller the error of the result and the more reliable it is.

2.2 Cloud model algorithm description

The cloud model is a model method that can realize the conversion between qualitative concepts and quantitative indicators. Generally, three digital features of Expected value, Entropy and Hyper entropy are used to describe the concept as a whole.

Figure 1 Multi-dimensional cloud model diagram

The five comment sets included in Cloud Conversion are as follows: $S = \{s_0 = \text{low(L)}, s_1 = \text{moderately low(ML)}, s_2 = \text{moderate(M)}, s_3 = \text{moderately high(MH)}, s_4 = \text{high(H)}\}$.

$$\tilde{y}_0 = (Ex_0, En_0^2, He_0^2) = \left(X_{\min} + 3En_0^2, \frac{En_0^2}{0.618}, \frac{He_0^2}{0.618} \right) \quad (2)$$

$$\tilde{y}_1 = (Ex_1, En_1^2, He_1^2) = \left(\frac{Ex_2 - 0.382(Ex_2 - Ex_0)}{En_2^2}, \frac{He_2^2}{0.618} \right) \quad (3)$$

$$\tilde{y}_2 = (Ex_2, En_2^2, He_2^2) = \left(\frac{X_{\min} + X_{\max}}{2}, 0.382 \frac{X_{\min} - X_{\max}}{3(g+2)}, He_2^2 \right) \quad (4)$$

$$\tilde{y}_3 = (Ex_3, En_3^2, He_3^2) = \left(\frac{Ex_2 + 0.382(Ex_4 - Ex_2)}{En_2^2}, \frac{He_2^2}{0.618} \right) \quad (5)$$

$$\tilde{y}_4 = (Ex_4, En_4^2, He_4^2) = \left(X_{\max} - 3En_4^2, \frac{En_4^2}{0.618}, \frac{He_4^2}{0.618} \right) \quad (6)$$

3 Risk assessment of heavy landing based on BWM and cloud model

The environment of aviation flight is constantly changing, especially for military aircraft, which have the characteristics of diverse models and complex tasks. The execution of flight tasks is affected by the environment, pilot operations, and aircraft status. In each stage of flight, the landing stage is very easy to cause errors and even lead to serious flight accidents.

According to the operating environment, the landing kinematics of the aircraft is analyzed, and four parameters of ground speed, ground pitch angle, ground vertical acceleration and ground distance deviation are selected to

describe the results of the pilot's landing operation. This paper uses the key flight parameters as a benchmark for risk assessment and verification.

According to aircraft flight quality monitoring project specifications, operation manuals, training outlines and risk assessment procedures, the impact of risk factors is divided into 5 levels from I to V. The normalized values of the grading results are shown in Table 1.

Table1 Relative importance rating scale

Degree of influence	Code	Cloud digital characteristics		
		Ex	En^2	He^2
Equally important	I	1.000	0.333	0.052
Moderately important	II	3.472	0.206	0.032
important	III	5	0.127	0.020
Quite important	IV	6.528	0.206	0.032
Extremely important	V	9.000	0.333	0.052

3.1 Risk factor cloud weight determination

According to the language conversion in Table 1, the relative importance of the expert to the best factor relative to other risk factors can be represented by the cloud vector $\tilde{A}_B = \{\tilde{a}_{B1}, \tilde{a}_{B2}, \tilde{a}_{B3}, \tilde{a}_{B4}\}$, and $\tilde{a}_{Bj}$ represents the cloud representation of the importance of the best factor W relative to the risk factor.

Construct a nonlinear programming solution for the cloud weight of each risk factor according to Equation 1.

$$\min \tilde{z} \text{ s.t. } \begin{cases} \left| \frac{(Ex_B, En_B^2, He_B^2)}{(Ex_j, En_j^2, He_j^2)} - \tilde{a}_{Bj} \right| \leq (z_1, z_2, z_3) \\ \left| \frac{(Ex_j, En_j^2, He_j^2)}{(Ex_W, En_W^2, He_W^2)} - \tilde{a}_{jW} \right| \leq (z_1, z_2, z_3) \\ \sum_{j=1}^n Ex_j = 1, \text{ for all } j \\ Ex_j \geq 0, En_j^2 \geq 0, He_j^2 \geq 0 \\ z_1 \geq 0, z_2 \geq 0, z_3 \geq 0 \end{cases} \quad (7)$$

Among them, $\tilde{z} = (z_1, z_2, z_3)$. z_1, z_2, z_3 represent the minimum deviation allowable values corresponding to Ex_j, En_j^2, He_j^2 .

3.2 Expert weight determination and comprehensive evaluation

In the evaluation, each expert e evaluates the failure mode risk factors according to the scale. This paper constructs a 5-level scale for evaluation and converts it into a cloud parameter description. The scale is shown in Table 2.

Table2 Risk assessment scale

Probability of failure	Cloud digital characteristics		
	Ex	En^2	He^2
Extremely high(EH)	9.000	0.333	0.052
High(H)	6.528	0.206	0.032
Moderate(M)	5	0.127	0.020
Relatively low(RL)	3.472	0.206	0.032
Low(L)	1.000	0.333	0.052

The i th risk factor for the j th failure mode of expert l is transformed into a cloud vector $\tilde{X}_{ji}^k = (\tilde{x}_{ji}^1, \tilde{x}_{ji}^2, \dots, \tilde{x}_{ji}^k, \dots, \tilde{x}_{ji}^l)$. The evaluation weight w of the k th expert for the i th risk factor of the j th failure mode is as follow:

$$\begin{cases} w_{ji}^k = \lim \frac{\sum_{q=1}^l d_{ji}^{k,q}}{\sum_{p=1}^l \sum_{q=1}^l d_{ji}^{p,q}}, q \neq k, q \neq p, l \geq 2 \\ w_{ji}^k, l = 1 \end{cases} \quad (8)$$

Obtain the weight matrix $(w_{ji}^k)_{m \times n}$ of expert k for the n th risk factors of the m th failure modes.

$$W^k = \begin{bmatrix} w_{11}^k & w_{12}^k & \dots & w_{1n}^k \\ w_{21}^k & w_{22}^k & \dots & w_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ w_{m1}^k & w_{m2}^k & \dots & w_{mn}^k \end{bmatrix} \quad (9)$$

The comprehensive assessment of the m th risk factor of the n th failure mode by expert l is as follows.

$$\tilde{x}_{ji} = \sum_{k=1}^l w_{ji}^k * \tilde{x}_{ji}^k \quad (10)$$

After integrating all expert results, the cloud computing comprehensive evaluation matrix $\tilde{X}$ is obtained.

$$\tilde{X} = \begin{bmatrix} \sum_{k=1}^l w_{11}^k * \tilde{x}_{11}^k & \sum_{k=1}^l w_{12}^k * \tilde{x}_{12}^k & \dots & \sum_{k=1}^l w_{1n}^k * \tilde{x}_{1n}^k \\ \sum_{k=1}^l w_{21}^k * \tilde{x}_{21}^k & \sum_{k=1}^l w_{22}^k * \tilde{x}_{22}^k & \dots & \sum_{k=1}^l w_{2n}^k * \tilde{x}_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ \sum_{k=1}^l w_{m1}^k * \tilde{x}_{m1}^k & \sum_{k=1}^l w_{m2}^k * \tilde{x}_{m2}^k & \dots & \sum_{k=1}^l w_{mn}^k * \tilde{x}_{mn}^k \end{bmatrix} \quad (11)$$

3.3 Determine the risk level of heavy landing

The product of the evaluation results of each risk factor is the final risk evaluation result.

$$RPN^* = \prod_{i=1}^n F_i = \prod_{i=1}^n \left(\sum_{k=1}^l w_{ji}^k * \tilde{x}_{ji}^k \right) \quad (12)$$

$i = 1, 2, \dots, 7; j = 1, 2, \dots, m$

4 Case Analysis

The following takes a certain troop transport aircraft as an example, and conducts risk assessment on its landing data

through the above method.

4.1 Risk factor determination and empowerment

During the risk assessment process, three experts were invited to evaluate the risk factors of the failure mode and the relative importance of the risk factors. This article converts the expert evaluation results of each risk factor into cloud parameters, and describes the calculation of cloud weights for all risk factors.

$$W^* = \begin{matrix} (0.186, 0.0517, 0.0079) \\ (0.2217, 0.0563, 0.0086) \\ (0.1063, 0.0334, 0.0057) \\ (0.1537, 0.0329, 0.006) \end{matrix}$$

As shown in Table 3, the above weight determination method is used to determine the weight of each expert for all failure mode risk factors.

Table3 Expert weight of risk factors

	Ground speed deviation	Ground elevation deviation	Ground vertical acceleration	Ground distance deviation
1	0.5,0.5,0	1/3,1/3,1/3	0.17,0.45,0.41	0.0,5,0.5
2	0.41,0.16,0.41	0.10,0.36,0.44	0.0,5,0.5	0.5,0,0.5
3	0.41,0.41,0.16	0.5,0,0.5	0.5,0.5,0	0.5,0.5,0
4	0.40,0.40,0.18	0.18,0.41,0.33	0.5,0,0.5	0.39,0.10,0.21
5	0.5,0,0.5	0.5,0.5,0	0.5,0,0.5	0.5,0,0.5

4.2 Determination of the risk level of heavy landing

According to the comprehensive evaluation calculation expert's comprehensive evaluation results are shown in Table 4

Table4 Comprehensive assessment of risk factors

	Ground speed deviation	Ground elevation deviation	Ground vertical acceleration	Ground distance deviation
1	1.2142,0.1978,0.0629	1.9953,0.2807,0.0837	0.5315,0.0777,0.0267	0.7685,0.0904,0.0305
2	0.9300,0.1446,0.0454	1.3721,0.2217,0.0688	0.6796,0.0801,0.0265	1.0034,0.0917,0.0291

3	0.9300,0.157 8,0.0507	0.7697,0.128 0,0.0400	0.5315,0.078 4,0.0270	0.7685,0.112 9,0.0393
4	0.5745,0.150 9,0.0524	0.8002,0.189 9,0.0641	0.6939,0.063 7,0.0199	0.4499,0.099 3,0.0361
5	0.6458,0.104 4,0.0331	0.7697,0.180 2,0.0607	0.5315,0.049 6,0.0157	0.5336,0.076 2,0.0263

In order to verify the rationality and effectiveness of the model, the results of this paper are compared with the actual risk level, combined weighting cloud, and DS-cloud model evaluation results.

Table5 Heavy landing risk assessment results and comparison

Heavy landing risk level	Grade membership					Actual grade	Combination weighting normal cloud model	Cloud model-DS theory	Interactive multidimensional cloud model
	I	II	III	IV	V				
1	0.1332	0.4251	0.7741	0.9655	0.5694	IV	IV	IV	IV
2	0.4365	0.8859	0.9487	0.8841	0.3002	III	IV	III	III
3	0.8021	0.9871	0.7631	0.5037	0.1221	II	II	II	II
4	0.9238	0.9125	0.6003	0.3599	0.0765	I	I	I	I
5	0.8114	0.8848	0.5495	0.2111	0.0975	II	II	II	II

According to the results in Table 5, the results of the method in this paper are roughly the same as the actual grades, and are basically consistent with the prediction results of the cloud model-evidence theory. The combined weighted normal cloud model is biased in the second evaluation due to excessive randomness. This verifies that the application of the model in heavy landing risk assessment is reasonable, feasible and accurate.

5 CONCLUSION

Aiming at the ambiguity, randomness and uncertainty in the heavy landing risk, this paper proposes a risk assessment method based on BWM and cloud model, and combines examples to illustrate. The main work is as follows.

1) Taking into account the systemicity and availability of risk factors, select the ground speed deviation, ground elevation deviation, ground vertical acceleration and ground distance deviation as the influencing factors of the heavy landing risk classification, and determine the five risk classification levels and classification standards to construct Risk classification system.

2) The BWM model is combined with the cloud model to calculate the relative weights of different risk factors, and the description weights are more realistic.

3) The independence of expert weights is determined. The weights depend on each expert's relative assessment of the risk factors of each failure mode, which avoids the defect of the average expert weight and makes the assessment results more accurate and reliable.

Foundation item: National Natural Science Foundation of China (52074309); national social science foundation (19XGL029)

References

1. Hadi Badri Ahmadi, et al. Assessing the social

sustainability of supply chains using Best Worst Method[J]. Resources, Conservation & Recycling, 2017, 126: 99-106.

2. Jafar Rezaei. Best-worst multi-criteria decision-making method: Some properties and a linear model[J]. Omega, 2016, 64: 126-130.

3. Zikang Su, Chuntao Li, Honglun Wang. Barrier Lyapunov function-based robust flight control for the ultra-low altitude airdrop under airflow disturbances[J]. Aerospace Science And Technology, 2019, 84: 375-386.

4. Xinlong Li, Yan Ran, Genbao Zhang, et al. A failure mode and risk assessment method based on cloud model[J]. Journal of Intelligent Manufacturing, 2019, : 1-14.

5. WANG L, GUO S G, REN Y. Landing operation risk evaluation based on the normal cloud of the flight data[J]. Journal of Safety and Environment, 2019, 19(5): 1555-1561.

6. WEI B W, HUANG H P, XU Z K. Two-dimensional evaluation model of rock mass based on combination weighting and cloud model[J]. Chinese Journal of Rock Mechanics and Engineering, 2016, 35(S1): 3092-3099.

7. WANG L, SUN R S, WU C X. A flight QAR data based model for hard landing risk quantitative evaluation[J]. China Safety Science Journal, 2014, 24(2): 88-92.

8. JIAO, HUDSON J A. The fully-coupled model for rock engineering systems[J]. International Journal of Rock Mechanics & Mining Sciences & Geomechanics Abstracts, 1995, 32(5): 491-512.

9. Wang S C, Jia X S, Hu Q W, et al. Effectiveness evaluation for equipment maintenance support system based on normal grey cloud model[J]. Systems Engineering and Electronics, 2019, 41(07): 1576-1582.

10. PENG H G, ZHANG H Y, WANG J Q. An uncertain Z-number multicriteria group decision-making method

with cloud models[J].Information Sciences, 2019,501:136-154.

11. Sun X Y, ZHANG J Y,HAN G.Application of a grey cloud model in the identification of defects in bolt anchorage[J].INSIGHT,2019,61(8):465-471.