Risk assessment of heavy landing based on BWM and cloud model

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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 \( \{C_1, C_2, \ldots, C_n\} \) 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 \( A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn}) \) where \( a_{Bn} \) 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 \( A_W = (a_{W1}, a_{W2}, \ldots, a_{Wn}) \) where \( a_{Wn} \) is expressed as the degree of importance of the \( n \)th factor relative to the worst factor \( W \).
- Describe the optimal weight set as \( \{w_1, w_2, \ldots, w_n\} \). The optimal weight set satisfies to minimize the maximum absolute difference of the set \( \{w_B - a_{Bj}w_j, w_j - a_{Wj}w_W\} \). The problem is transformed into a nonlinear programming problem:

\[
\min \bar{z} \text{ s.t. } \begin{cases} 
|w_B - a_{Bj}w_j| \leq \bar{z} \\
|w_j - a_{Wj}w_W| \leq \bar{z} \\
\sum_{j=1}^{n} w_j = 1, w_j \geq 0; \text{ for all } j 
\end{cases}
\]

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 \( a_{Wj} \) represents the importance of the \( J \)th factor to the worst factor \( W \). \( \bar{z} \) represents the lowest allowable deviation.
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.

$$\tilde{y}_0 = (E_{x_0}, En^{e_0}, He^{e_0}) = \left( \frac{X_{\max} + 3E_{n} + En^{e_0}}{0.618}, \frac{He^{e_0}}{0.618} \right)$$  \hspace{1cm} (2)

$$\tilde{y}_i = (E_{x_i}, En^{e_i}, He^{e_i}) = \left( \frac{E_{x_i} - 0.382(E_{x_i} - E_{x_0})}{En^{e_i} - He^{e_i}} \right)$$  \hspace{1cm} (3)

$$\tilde{y}_2 = (E_{x_2}, En^{e_2}, He^{e_2}) = \left( \frac{X_{\max} + X_{\min}}{2 \times 0.382 X_{\max} - X_{\min}} \right)$$  \hspace{1cm} (4)

$$\tilde{y}_3 = (E_{x_3}, En^{e_3}, He^{e_3}) = \left( \frac{E_{x_3} + 0.382(E_{x_3} - E_{x_0})}{En^{e_3} + He^{e_3}} \right)$$  \hspace{1cm} (5)

$$\tilde{y}_4 = (E_{x_4}, En^{e_4}, He^{e_4}) = \left( \frac{X_{\min} - 3E_{n} + En^{e_4}}{0.618}, \frac{He^{e_4}}{0.618} \right)$$  \hspace{1cm} (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.

### 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 $\tilde{a}_b = [\tilde{a}_{b1}, \tilde{a}_{b2}, \tilde{a}_{b3}, \tilde{a}_{b4}, \tilde{a}_{b5}]$, 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.

$$\min \tilde{z}(\tilde{x}) \left[ \begin{array}{c} \tilde{E}_{x_1}, \tilde{E}_{n_1}, \tilde{He}_{e_1} \\ \tilde{E}_{x_2}, \tilde{E}_{n_2}, \tilde{He}_{e_2} \\ \tilde{E}_{x_3}, \tilde{E}_{n_3}, \tilde{He}_{e_3} \\ \tilde{E}_{x_4}, \tilde{E}_{n_4}, \tilde{He}_{e_4} \end{array} \right] \leq \tilde{z} = (z_1, z_2, z_3)$$

$$\sum_{j=1}^{n} E_{x_j} = 1, \text{ for all } j$$

$$E_{x_j} \geq 0, En^{e_j} \geq 0, He^{e_j} \geq 0$$

Among them, $\tilde{z} = (z_1, z_2, z_3)$ represent the minimum deviation allowable values corresponding to $E_{x_j}, En^{e_j}, He^{e_j}$.

### 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.
The kinematics of the aircraft is analyzed, and four parameters are considered for pilot operations, and aircraft status. In each stage of flight, expert evaluation is required, especially for military aircraft, which have the largest amount of data. The present paper uses the key flight parameters as a benchmark for further discussion.

## 3.3 Determine the risk level of heavy landing

The ith risk factor for the jth failure mode of expert l is transformed into a cloud vector \( \mathbf{x}_{j}^{i} = (x_{j1}^{i}, x_{j2}^{i}, \ldots, x_{jg}^{i}) \). The evaluation weight \( w_{j} \) of the kth expert for the ith risk factor of the jth failure mode is as follows:

\[
\begin{align*}
    w_{j} & = \lim_{n \to \infty} \frac{\sum_{p=q}^{n} a_{p}^{i} x_{j}^{p}}{\sum_{p=q}^{n} \sum_{q}^{n} a_{p}^{i} x_{j}^{q}}, q \neq k, q \neq p, l \geq 2
\end{align*}
\]

(8)

Obtain the weight matrix \( (w_{j})\) of expert k for the nth risk factors of the mth failure modes.

\[
W_{k} = \begin{bmatrix}
    w_{11}^{k} & w_{12}^{k} & \cdots & w_{1m}^{k} \\
    w_{21}^{k} & w_{22}^{k} & \cdots & w_{2m}^{k} \\
    \vdots & \vdots & \ddots & \vdots \\
    w_{m1}^{k} & w_{m2}^{k} & \cdots & w_{mk}^{k}
\end{bmatrix}
\]

(9)

The comprehensive assessment of the mth risk factor of the nth failure mode by expert l is as follows:

\[
\widetilde{x}_{j} = \sum_{k=1}^{l} w_{j} \mathbf{x}_{j}^{k}
\]

(10)

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

\[
\tilde{X} = \begin{bmatrix}
    \sum_{i=1}^{7} w_{i1}^{*} x_{i1}^{*} & \sum_{i=1}^{7} w_{i2}^{*} x_{i2}^{*} & \cdots & \sum_{i=1}^{7} w_{im}^{*} x_{im}^{*} \\
    \sum_{i=1}^{7} w_{i1}^{*} x_{i2}^{*} & \sum_{i=1}^{7} w_{i2}^{*} x_{i2}^{*} & \cdots & \sum_{i=1}^{7} w_{im}^{*} x_{im}^{*} \\
    \vdots & \vdots & \ddots & \vdots \\
    \sum_{i=1}^{7} w_{i1}^{*} x_{im}^{*} & \sum_{i=1}^{7} w_{i2}^{*} x_{im}^{*} & \cdots & \sum_{i=1}^{7} w_{im}^{*} x_{im}^{*}
\end{bmatrix}
\]

(11)

### 3.3.1 Determine the risk level of heavy landing

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

\[
RPN = \prod_{i=1}^{7} E_{i} = \prod_{i=1}^{7} \left( \sum_{j=1}^{m} w_{j} \mathbf{x}_{j}^{k} \right)
\]

(12)

## 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.

\[
W = (0.2217, 0.0563, 0.0086, 0.1063, 0.0334, 0.0057, 0.1537, 0.0329, 0.006)
\]

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.

### 4.2 Determination of the risk level of heavy landing

According to the comprehensive evaluation calculation, the risk assessment results are shown in Table 4.

| Cloud digital characteristics | Ex | En | He |
|------------------------------|----|----|----|
| 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 |

### Table 2 Risk assessment scale

| Probability of failure | Ex | En | He |
|------------------------|----|----|----|
| 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 |

### Table 3 Expert weight of risk factors

| Ground speed deviation | Ground elevation deviation | Ground vertical acceleration | Ground distance deviation |
|------------------------|--------------------------|----------------------------|--------------------------|
| 3                      | 1.0034,0.091             | 0.17,0.45,0.41             | 0.05,0.5                 |
| 2                      | 0.41,0.16,0.41           | 0.10,0.36,0.44             | 0.05,0.5                 | 0.5,0.5 |
| 1                      | 0.41,0.41,0.16           | 0.5,0.5,0.5                | 0.5,0.5                  | 0.5,0.5 |
| 4                      | 0.40,0.40,0.18           | 0.18,0.41,0.33             | 0.5,0.5                  | 0.39,0.10,0.21 |
| 5                      | 0.5,0.5,0.5              | 0.5,0.5,0.5                | 0.5,0.5                  | 0.5,0.5 |

### Table 4 Comprehensive assessment of risk factors

| Ground speed deviation | Ground elevation deviation | Ground vertical acceleration | Ground distance deviation |
|------------------------|--------------------------|----------------------------|--------------------------|
| 1                      | 1.2142,0.197             | 1.9953,0.280               | 0.5315,0.077             | 0.7685,0.090 |
| 2                      | 8.0,0.0629               | 7.0,0.0837                 | 7.0,0.0267               | 4.0,0.0305 |
| 3                      | 0.9300,0.144             | 1.3721,0.221               | 0.6796,0.080             | 1.0034,0.091 |
| 4                      | 6.0,0.0454               | 7.0,0.0688                 | 1.0,0.0265               | 7.0,0.0291 |

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.

### Table 5 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                                   |
| 2                        | 0.4365            | 0.8859       | 0.9487                                   | 0.8841                 | 0.3002                                   |
| 3                        | 0.8021            | 0.9871       | 0.7631                                   | 0.5037                 | 0.1221                                   |
| 4                        | 0.9238            | 0.9125       | 0.6003                                   | 0.3599                 | 0.0765                                   |
| 5                        | 0.8114            | 0.8848       | 0.5495                                   | 0.2111                 | 0.0975                                   |

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 systemity 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.

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China Foundation item: the assessment results more accurate and reliable. Avoids the defect of the average expert weight and makes the assessment of the risk factors of each failure mode, which is determined. The weights depend on each expert's description weights, and the description weights are more realistic. The BWM model is combined with the cloud model to calculate the relative weights of different risk factors, and determine the five risk classification levels and classification standards to construct Risk classification model. The independence of expert weights is verified, and the weighting normal cloud model is biased in the severity of risk factors, select the ground speed deviation, ground elevation deviation, and acceleration and ground distance deviation as the risk level grades, and are basically consistent with the prediction method in this paper are roughly the same as the actual risk level. Combining examples to illustrate. The main work is as follows:

Aiming at the ambiguity, randomness and uncertainty in heavy landing risk evaluation due to excessive randomness. This verifies that the independence of expert weights is verified. The weighted normal cloud model is biased in the severity of risk factors, select the ground speed deviation, ground elevation deviation, and acceleration and ground distance deviation as the risk level grades, and are basically consistent with the prediction method in this paper are roughly the same as the actual risk level. Combining examples to illustrate. The main work is as follows:

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