Operational Safety Risk Assessment of Civil Aviation based on Grey Clustering

To cite this article: Wan Jian et al 2019 J. Phys.: Conf. Ser. 1168 032109

View the article online for updates and enhancements.
Operational Safety Risk Assessment of Civil Aviation based on Grey Clustering

Wan Jian1, Xia Zhenghong2, Zhu Xinping2

1 China Academy of Civil Aviation Science and Technology, Beijing 100028, P. R. China,
2 School of Air Traffic Control, Civil Aviation Flight University of China, Guanghan Sichuan 618307, P.R. China

Abstract. To enhance the operational safety of civil aviation, based on the data of civil aviation unsafe incidents on 2006-2015, the assessment index was constructed with typical accident and incident events, and the operational safety risk assessment model based on grey whitening clustering was proposed in this paper. Then the weight of each index is determined by the principle of maximizing deviation. Finally, the safety risk in these 10 years was evaluated by actual operation data. According to the result, it was consistent with the actual operation of civil aviation, which verified the rationality of the safety risk assessment indexes taking into account of the typical accidents and incidents. It had changed the traditional safety assessment index and methods of civil aviation based on people, machines, environment and administration, which had positive significance to improve the safety production capacity of civil aviation.

1. Introduction
Recently, the contradiction between rapid growth of flight demand and the relatively weak security infrastructure has become increasingly prominent, while the number of civil aviation accidents and incidents grows rapidly. According to the theory of accident iceberg and Hayne’s law, before every one serious accident, there must be 29 minor accidents and 300 attempted threatened and 1000 accidents potential. How to discover and avoid the hidden danger of the accident potential in time was the key to improve the safety operation of civil aviation. Therefore, operational safety risk assessment was needed urgently to carry out, and find the relevant risks that will endanger the operational safety, reveal the occurrence and causes of the accidents and incidents in order to enhance the safety production capacity of civil aviation.

At present, assessment methods of aviation safety are mostly based on the SHEL model and RESON model. Wang yanyang established one risk assessment methods based on the frequency and its consequences of accidents, incidents and unsafe events[1]. Wen jun evaluated the airline system risk based on the fuzzy comprehensive evaluation method[2]. Ou tao analyzed the operating factors affected the safety of civil aviation and evaluated the civil security situation based on the neural network[3]. Galileo Tamasi studied the risk and risk evaluation process and proposed a qualitative and quantitative method for security risk assessment[4]. Wang lei proposed a quantitative evaluation model of hard landing risk based on the principle of QAR data[5]. Chen kejia established airline safety evaluation index system from the aspects of human, machine, environment and management[6]. Sun ruishan constructed a flight safety evaluation model based on QAR transfinite event[7]. Tang weizhen constructed a multilevel matter-element model for airline safety risk assessment based on risk element
extension\cite{8}. Obviously, most of the research achievements in the field of civil aviation security were focused on the operation safety of airlines. Based on the human, machine, environment and management, the assessment index system is established. The AHP and fuzzy mathematics are used to evaluate the system. However, the assessment result wasn’t objective because of the experts’ artificial factor in weight determination, it was easy to ignore the characteristics of individual evaluation objects.

Therefore, based on the ten years of civil aviation accidents and incidents from 2006 to 2015, the factors affecting the operation safety and its annual variation were analyzed thoroughly, and the typical accidents and incidents were selected to establish evaluation index system, the operational risk assessment model was constructed based on the grey clustering. Then the maximum deviation principle was used to obtain the weight coefficient of the indexes. Finally, the rationality of the grey clustering method applied to the safety risk assessment was proved by an example.

2. Operational safety risk assessment model based on grey clustering

Common security risk assessment methods are divided into qualitative, quantitative and comprehensive evaluation methods. Qualitative evaluation method calculates the risk value based on the possibility and severity consequence of the risk occurrence, and obtains the risk evaluation result of acceptability, expectation or unacceptable. The quantitative methods includes the grey system method and neural network method, the prediction accuracy of the monotonic variation of historical data is higher, and the latter method can find the relation between input and output independently by training and learning, which has higher prediction accuracy. The comprehensive analysis method is a combination of qualitative and quantitative analysis, including the fuzzy mathematics theory, rough set theory and analytic hierarchy process. According to the characteristics of civil aviation safety accident and incident data of small sample and poor information, the grey whitening weight clustering method in grey system theory is used to evaluate its operational safety risk, and its process is as follows.

![Diagram: Operational safety risk assessment model based on grey clustering](image)

The risk assessment model based on grey clustering will select clustering objects, clustering indexes and define grey categories firstly. Based on the actual flight accidents and incident data, whiten weight function was constructed, and the whitening weight function values of each index in each gray level are determined, then the whitening weight function value matrix was obtained. In order to highlight the differences in the evaluation process of each index, the maximum deviation principle is used to determine the weights of the indexes in each grey category, and then the weight coefficient matrix is obtained. These two matrices are multiplied to get the coefficient matrix of grey clustering. Then, the maximum value of each line in the clustering coefficient was found out to
determine the grey category of the object. Finally, the operational safety risk of civil aviation assessment result will be obtained based on the proposed model and approaches.

2.1 Construct whitening weight function

Assuming n as the clustering object, namely the sampling times of civil aviation accidents and incidents. And assume m as the clustering index, namely the kinds of civil aviation accidents and incidents; assume s as grey kinds, namely the assessment results.

( 1,2,..., ; 1,2,..., )

\[ x_{in}^{jm} = \text{represents the observation value of the clustering object number } i \text{ for clustering index } j, \text{ namely the number of incident or accident } j \text{ occurred in the period time of } i. \]

Then n objects for the value of index j were divided into s grey classes, which were called the subclasses of the index j. So the subclass of whitening weight function number k of the index j is denoted as \( (\text{ })( 1,2,..., , 1,2,..., ) \).

And the whitening weight function can describe an evaluation object belonging to a grey class, including four kinds of expression as follows: (1) standard whitening weight function \( f^{k}(x_{i}^{(1)}, x_{j}^{(2)}, x_{j}^{(3)}, x_{j}^{(4)}) \); (2) lower bound measure whitening weight function \( f^{k}[-,-, x_{j}^{(3)}, x_{j}^{(4)}] \); (3) moderate measure whitening weight function \( f^{k}[x_{j}^{(1)}, x_{j}^{(2)}, -,-] \); (4) upper bound measure whitening weight function \( f^{k}[x_{j}^{(1)}, -,-, x_{j}^{(4)}] \).

Where, the value of \( (1), (2), (3), (4) \) are generally assigned in conjunction with actual operational data, then the function value is determined by the index value is in the range of the corresponding of whitening weight function \( f^{k} \).

Finally, the whitening weight function value matrix of grey clustering k was obtained as \( F_{i}^{j} = (f_{ij}^{k})_{nm} \).

2.2 Whitening weight coefficient matrix based on maximum deviation principle

Determining the whitening weight of index is the key importance of grey whitening clustering, assuming \( p_{j} \) is the whitening weight of index j, then if \( P_{j} \) can make the object i generating relatively greater large whitening weight function value under the condition of each grey class, then it shows that the index j plays an important role in comparing each clustering coefficients, which must be given greater weight coefficients. Then we define \( W_{i} = (w_{ij}, w_{j2},..., w_{j,m}) \) as the weight vector of object i, and \( V_{j}(W_{i}) \) stands for the weighted total deviation of the value of the whitening weight function of object i and index j in the all grey classes.

\[
V_{j}(W_{i}) = \sum_{k \neq j} V_{j}^{k}(W_{i}) = \sum_{k \neq j} \sum_{i \neq j} \sum_{i \neq j} |f_{ij}^{k}w_{ij} - f_{ij}^{k}w_{ij}| = \sum_{k \neq j} \sum_{i \neq j} |f_{ij}^{k} - f_{ij}^{k}|w_{ij}
\]

(1)

In order to maximize the differences among all the indicators, maximum deviation principle was used to ensure the total weighted deviations of all the indexes \( V_{j} \) to be maximum value.

\[
V_{j} = \sum_{j \neq i} V_{j}(W_{i}) = \sum_{j \neq i} \sum_{j \neq i} \sum_{j \neq i} |f_{ij}^{k} - f_{ij}^{k}|w_{ij}
\]

(2)

According to optimization theory, Lagrange function was constructed to get the normalization result \( \eta_{i} \) of grey clustering weight vector of object i based on maximum deviation.

\[
\eta_{i} = (\eta_{i1}, \eta_{i2}, \eta_{i3}, ..., \eta_{in}) = \frac{\sum_{j \neq i} \sum_{j \neq i} |f_{ij}^{k} - f_{ij}^{k}|}{\sum_{j \neq i} \sum_{j \neq i} \sum_{j \neq i} |f_{ij}^{k} - f_{ij}^{k}|} \]

(3)

2.3 Grey Classification based on grey clustering coefficient
According to the whitening weight function matrix $F_k$ and the weight coefficient matrix $\eta_i$, its multiplication can obtain the clustering coefficients $\sigma_i$ of each object.

$$\sigma_i = [\sigma_i^1, \sigma_i^2, ..., \sigma_i^n] = [\sum_{j=1}^{n} f_j(x_i) \eta_1^i, \sum_{j=1}^{n} f_j^2(x_i) \eta_2^i, ..., \sum_{j=1}^{n} f_j^n(x_i) \eta_n^i]$$

Finally, the grey coefficients matrix $[\sigma_i^j]$ can be obtained. Then the grey clustering coefficient maximum column of object $i$ can be found to determine which grey class the object belongs to.

3. Example analyses

According to the annual safety report from 2006 to 2015, the number of civil aviation accidents and incidents was 48 and 2198. The proportion of general aviation accidents is as high as 95.5%, the main types of accidents are controlled flight into terrain and aircraft out of control, and its proportion is 42.5% and 17% respectively. Flight crew account for the cause of the accident up to 64.6%, and the unsafe incidents occur in July frequently. The kind of incidents are bird strike, engine failure, lightning strike, rush out of runway and collision with obstacles, accounted for 53.7%, 8.4%, 7.3%, 2.3% and 1.5% respectively. These two kinds of incidents mainly occurred in April and October because of adverse weather, whose proportion is up to 67.2%. Obviously, the accidents probability is relatively lower than that of incidents, and the number of sample is small. Therefore, accident can be regarded as a single index instead of further segmentation in grey clustering analysis. Meanwhile, the frequent occurred incidents such as bird strike, lightning, engine failure, rush out of runway and collision with obstacles were selected as grey clustering index, namely $m=6$. And the specific sample data is shown in Table 1. Ten years from 2006 to 2015 are selected as the assessment objects, namely $n=10$. And the operational safety risk level of civil aviation can be classified into three grey kinds as “high, moderate and low”, namely $s=3$. The grey “high” stands for the smaller the number of accidents and incidents are, the better the security level is. So lower bound measure whitening weight function is adopted in this situation, and moderate measure whitening weight function should adopted for the grey “moderate”, upper bound measure whitening weight function should adopted for grey “low” because the number of accidents and incidents is larger if the safety level is worse.

| Years | Accidents | Typical incidents |
|-------|-----------|-------------------|
|       |           | Bird strike | Engine failure | Lightning | Rush out of runway | Collide with obstacles |
| 2006  | 3         | 51         | 28             | 5         | 3                   | 2                   |
| 2007  | 1         | 52         | 18             | 6         | 4                   | 1                   |
| 2008  | 6         | 47         | 23             | 11        | 4                   | 2                   |
| 2009  | 2         | 72         | 25             | 17        | 8                   | 3                   |
| 2010  | 3         | 110        | 18             | 25        | 8                   | 3                   |
| 2011  | 5         | 134        | 11             | 13        | 3                   | 5                   |
| 2012  | 1         | 148        | 22             | 19        | 4                   | 1                   |
| 2013  | 13        | 161        | 12             | 17        | 5                   | 2                   |
| 2014  | 5         | 192        | 13             | 19        | 4                   | 5                   |
| 2015  | 9         | 191        | 15             | 28        | 6                   | 8                   |
Because there is no fixed patterns and methods to assign the value of whitening weight function, so the actual operation data of the civil aviation in table 1 was used to define the whitening function $f_j^i(*) (j=1,2,3,4,5,6; k=1,2,3)$ which was shown in table 2.

Table 2. Whitening function

| $i=1$ | $i=2$ | $i=3$ | $i=4$ | $i=5$ | $i=6$ |
|-------|-------|-------|-------|-------|-------|
| $k=1$ | $f_j^1[0.5,-0.8,1]$, $f_j^1[0.8,0.1,1]$, $f_j^1[0.1,0.5,1]$ | $f_j^2[0.75,0.25,0.6667]$ | $f_j^3[0.0,0.3333,0.25]$ | $f_j^4[0.0,0.1667,0.5]$ | $f_j^5[0.1,0.5,0.8333]$ | $f_j^6[0.0,0.3333,0.5]$ |
| $k=2$ | $f_j^1[0.5,0.75,0.25]$ | $f_j^2[0.75,0.25,0.6667]$ | $f_j^3[0.0,0.3333,0.25]$ | $f_j^4[0.0,0.1667,0.5]$ | $f_j^5[0.1,0.5,0.8333]$ | $f_j^6[0.0,0.3333,0.5]$ |
| $k=3$ | $f_j^1[0.5,0.75,0.25]$ | $f_j^2[0.75,0.25,0.6667]$ | $f_j^3[0.0,0.3333,0.25]$ | $f_j^4[0.0,0.1667,0.5]$ | $f_j^5[0.1,0.5,0.8333]$ | $f_j^6[0.0,0.3333,0.5]$ |

According to the whitening weight function of each index and actual sample data, the value of the whitening weight function was obtained, then the value matrix of whitening weight function under different grey categories as $F_1$, $F_2$, $F_3$ were obtained. And the grey clustering weight vector of maximum deviation was obtained as $\eta_j$ by formula (3).

Then the grey clustering coefficient matrix can be calculated by formula (4) as $[\sigma_j^i]$ where $\sigma_j^i = \sum_{j=1}^{n} f_j^i(x_j) \times \eta_j = 0.5*0.1010 + 0.78*0.1577 + 0.2022 + 1.0*0.2022 + 1.0*0.2022 + 0.6667*0.1348 = 0.6678$ and then other value can be obtained in the same way. So the matrix $[\sigma_j^i]$ can be got as follows.

Finally, finding out the column where the coefficient reach maximum of each line, then the object belongs to the grey category. Therefore, the operational safety risk assessment results of civil aviation from 2006 to 2015 can be presented in table 3.

Table 3. Operational safety risk assessment results of civil aviation for 2006-2015

| Years | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|-------|------|------|------|------|------|------|------|------|------|------|
| Max   | $\sigma^1$ | $\sigma^1$ | $\sigma^1$ | $\sigma^2$ | $\sigma^2$ | $\sigma^1$ | $\sigma^1$ | $\sigma^2$ | $\sigma^2$ | $\sigma^3$ |
| Results | high | high | high | moderate | high | low | moderate | moderate | moderate | low |

Obviously, half of the ten years’ civil aviation operation safety is in the state of “high” security level, 40% years is in the state of “middle” security level, and 10% years in the state of “low” security.
level. Moreover, the number of incidents continues to rise day by day. Specifically, the number of rush out of runway and off runway incidents reach maximum in 2009 and 2010, and the lightning strikes and engine failure unsafe event are relatively high, so the operational safety level in these two years is middle. In 2013, the number of general aviation accidents reaches its peak of ten years, and the number of birds strike, rush off runway incidents is relatively large, so the safety level is also middle. The number of bird strikes reached its peak, lightening strike and collided with obstacles ranking first, so the operational safety risk level is middle in 2014. Finally, both of the lightning strike and obstacle collision incidents events reach peak value of ten years. Moreover, the number of civil aviation accidents, bird strike and runway deviation unsafe events rank second in the ten years. Therefore, the operational safety level in these two years is very low.

The operational safety risk assessment results based on the grey clustering method are basically consistent with the actual operation, which verified the rationality of the index system considering typical accidents and incidents for civil aviation operation risk assessment. Through the risk assessment, the impact of index for the operation can be recalled, and then measures can be taken to reduce and prevent the occurrence of these accidents or incidents. For example, it is necessary to prevent the lightning events during the summer thunderstorm season, and prevent the deviation from runway because of the low visibility weather in winter, so as to ensure the security capability will adapt the growth of traffic flow.

4. Conclusions
(1) The risk assessment model of civil aviation based on grey whitening clustering was constructed in this paper, typical accidents and incidents were selected as assessment indexes, which changed traditional flight safety evaluated index system and methods based on human, machine, environment and management.

(2) Based on ten years’ unsafe events data of actual operation of civil aviation, which testified the validity and rationality of civil aviation safety risk assessment based on grey clustering method, and the assessment result are basically consistent with the actual operation of civil aviation.

(3) Only the number of incidents occurrence was selected as index, and the annual variation pattern of each index was considered. Therefore, the monthly variation pattern can be further analyzed in the future research.

Acknowledgments
This work was granted by Joint Funds of the National Science Foundation of China and the Civil Aviation Administration (Grant No. U1733105), Science and technology major project of China Civil Aviation (Grant No. MHRD20150102).

References
[1] WANG Y Y, LI M, CAO Y H. Study on safety assessment of China civil aviation industry [J]. Journal of Safety Science and Technology, 2008, 4(5):111-113.
[2] WEN J. Fuzzy comprehensive evaluation of risk in airline safety system [J]. Journal of Safety Science and Technology, 2010, 6(1):44-48.
[3] OU T, ZHOU C C. Simulation assessment model of civil aviation safety based on neural network and its simulation [J]. Journal of Safety Science and Technology, 2011, 7(2):34-41.
[4] Galileo Tamasi, Micaela Demichel. Risk Assessment Techniques for Civil Aviation Security [J]. Reliability Engineering and System Safety, 2011, Vol. 96, PP. 593-599.
[5] WANG L, SUN R S, WU C X, et al. A flight QAR data based model for hard landing risk quantitative evaluation [J]. China Safety Science Journal, 2014, 24(2):88-92.
[6] CHEN K J, JIN L. Grey interval hierarchy evaluation of airline flight safety performance [J]. China Safety Science Journal, 2015, 25(8):146-150.
[7] SUN R S, YANG Y X, WANG L. Study on Flight Safety Evaluation based on QAR Data [J]. China Safety Science Journal, 2015, 25(7):87-92.
[8] TANG W Z. Comprehensive evaluation for the airline flight safety risk based on the matter-elements model [J]. Journal of Safety and Environment, 2015, 15(2):25-29.