Chapter 120
Fuzzy Comprehensive Evaluation Model for Flight Safety Evaluation Research Based on an Empowerment Combination

Fumin Deng, Chunqing Wang and Xuedong Liang

Abstract There are many factors on different levels which affect aircraft flight safety evaluations as there are many uncertainties and significant mutual interference between the level's, so it is difficult to attain accurate measurements. In consideration of these flight safety complexities, in this paper, a fishbone diagram is first used to analyze four main factors; the pilots, the aircraft, the environment and the management. We then introduce an innovative method called the 'Multi-factor Comprehensive Safety Risk Evaluation' which allows for the introduction of a more reasonable entropy weight by combining objective data and subjective expert preferences to decide the weight coefficients. These results are then combined with safety system engineering to develop a reasonable but fuzzy flight safety evaluation index by building a "combination empowerment—fuzzy comprehensive evaluation model". From the view of the "human-machine-environment-management systems theory", it is then possible to evaluate accident probabilities to ensure flight safety classification grading control. Finally, combined with the safety evaluation information and suggestions from airline personnel, the above model and method are verified.

Keywords Flight safety · Safety evaluation · Fishbone diagram · Combination empowerment-fuzzy comprehensive evaluation model · Human-machine-environment-management systems theory

120.1 Foreword

The purpose of a flight safety evaluation is to determine all the unsafe factors in the flight system and to identify the main or potential dangers to reduce the flight accident occurrence rate and to effectively improve flight safety. However, the flight safety system is a dynamic, multi variable and complex giant system, with the internal factors and risks often part of the state and some factors being difficult to

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quantify. Therefore, it is very difficult to use traditional evaluation methods to conduct objective and systematic flight system evaluations.

As guaranteeing flight safety is important for the sustainable development of a national civil aviation industry, flight safety risk research has been paid significant attention. Janic [3] used a causality and probability evaluation to evaluate the safety of a civil aviation system, and established a linear mapping relationship between accident factors and the consequences. Shi [6] used a fuzzy evaluation method to calculate the risk probability and severity of the safety risk assessment matrix, and used this to determine the flight safety risk assessment value. Gan [2] proposed a flight safety Relevance Vector Machine (RVM) evaluation method, which made use of the RVM model "black box" to create a simpler and more accurate flight safety evaluation. Wen [4] proposed an evaluation index system for aviation safety risk using an Analytic Hierarchy Process (AHP) to determine the evaluation index weights, to establish a flight safety risk assessment model based on a grey multi-level, and to evaluate the safety status of an airline company in China. Although there has been significant research which has examined flight safety problems and made important contributions to the flight safety risk level evaluations leading to improvements in passenger satisfaction, operational efficiency and innovation, However, in most cases, the weight of each factor was determined in advance or was very subjective, and the actual system needs to be viewed as a dynamic development process. Therefore, it is very difficult to achieve an objective and systematic evaluation using traditional evaluation methods. In addition, while research on safety evaluations is relatively mature, there has been significantly less research on flight safety risk assessment, which needs to consider the problems of multiple indices, ambiguity, and the mutual influences between each index. In view of this, this paper proposes an innovative expert subjective and objective weighting using a validity coefficient combined with a more reasonable weighting method to construct a "combination empowerment—fuzzy comprehensive evaluation model" for flight safety assessment, which not only avoids the problems mentioned above, but also considers the relative importance of the two different weights.

120.2 Establishment of Flight Safety Evaluation Index System

Based on airline safety operation management and implementation combined with the civil aviation companys safety assessment index system [8] and the security audit system index system used by the civil aviation administration in China, a method which combines fuzzy statistics from relevant expert opinions (government safety management personnel 1, pilots working in senior 1 safety management and security researchers 1) is developed, which identifies and eliminates the weaker correlations in the airline security risk assessment evaluation index, reviews the correlation between the evaluation index elements and allows for the construction of a fishbone analysis

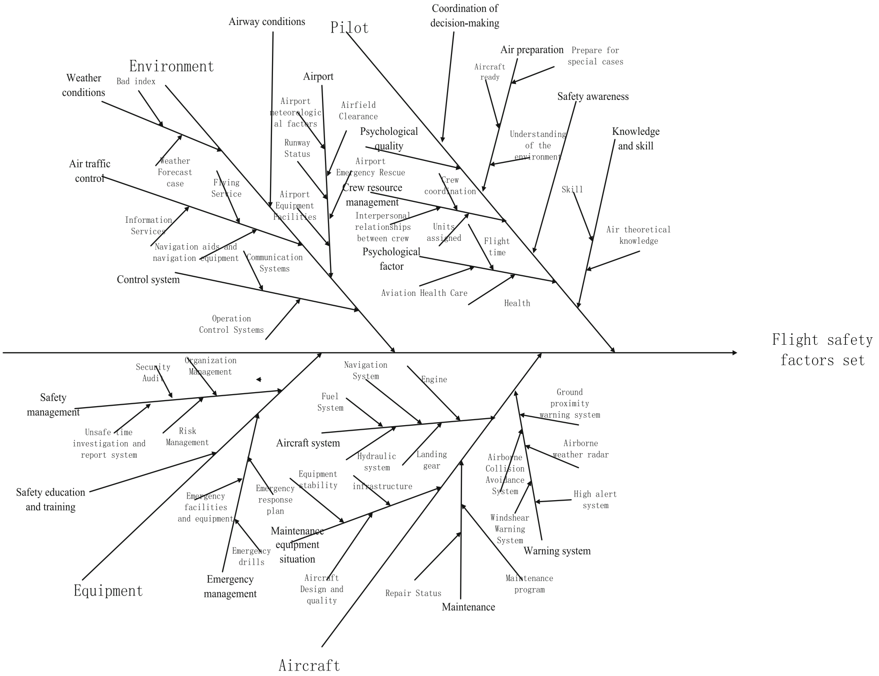

Fig. 120.1 Group conflict coordination framework for emergency decision

that focuses on the factors affecting flight safety, as shown in Fig. 120.1: As shown in Fig. 120.2, a comprehensive picture of the security risk situation at the airline company can be determined by an examination of the four main factors and the security within each factor layer. A comprehensive evaluation can be realized through the use of a fuzzy comprehensive evaluation method. The safety risk assessment of each factor is quantified using the safety assessment index system and relevant expert experience.

120.3 Entropy Weight Fuzzy Comprehensive Evaluation Model

120.3.1 Entropy Weight and Fuzzy Comprehensive Evaluation Model

In this paper, we use a multi-level fuzzy comprehensive evaluation to evaluate the lower levels firstly, and then to evaluate the higher level, finally we get the quantitative evaluation results by the weighted average formula [7]. With this weights combina-

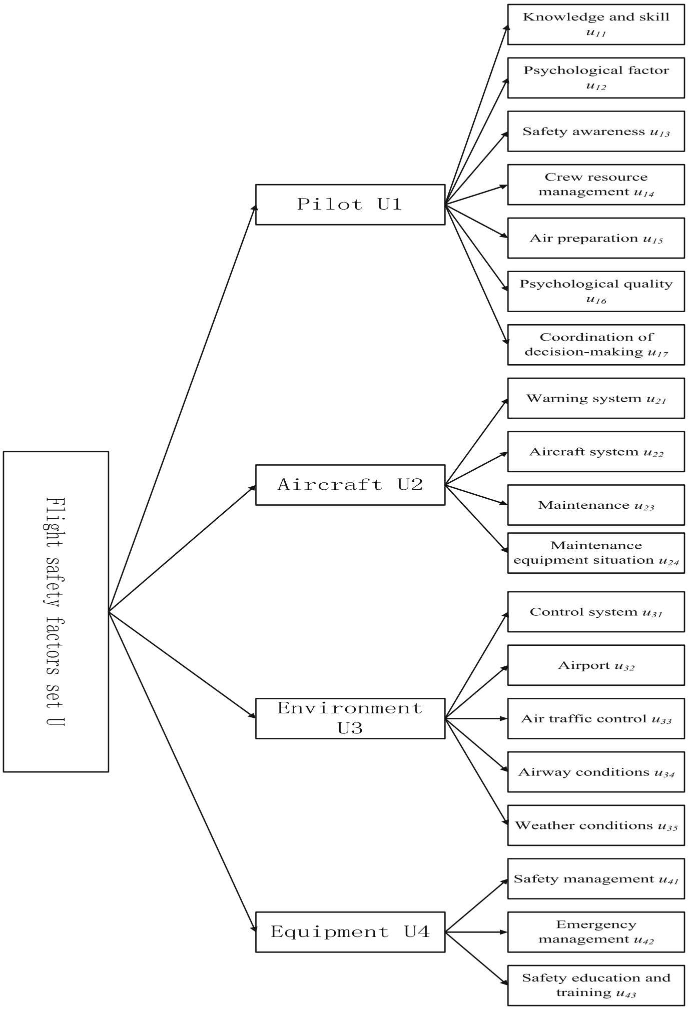

Fig. 120.2 Flight safety factor structural diagram

tion and the fuzzy comprehensive evaluation method, combined with safety system engineering considerations, we can evaluate the accident possibility from the perspective of the "human—machine—environment—management systems theory" to achieve a flight safety classification management and control instrument, the specific process for which is shown in Fig. 120.3.

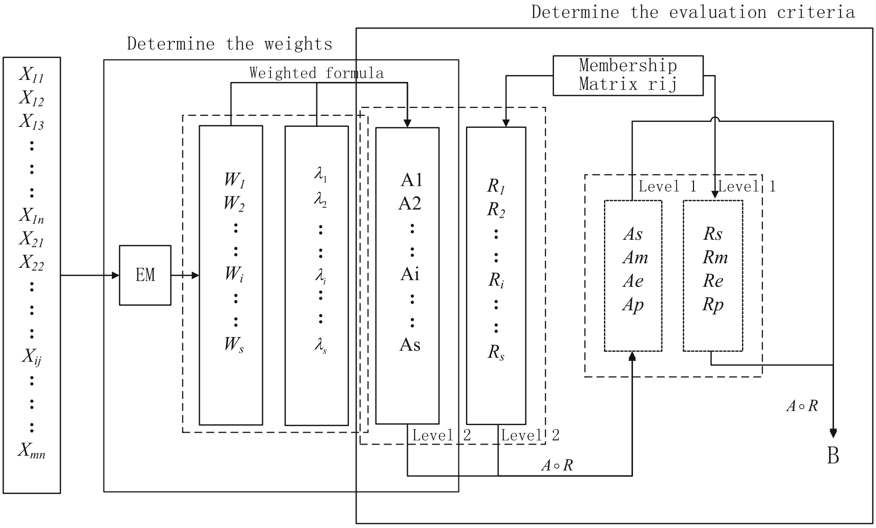

Fig. 120.3 Combination empowerment—fuzzy comprehensive evaluation model

120.3.2 Entropy Weight—Fuzzy Comprehensive Evaluation Model

Step 1. Establish flight safety evaluation factor set. U marked as: $U = \{u_1, u_2, \cdots, u_n\}$ is defined as the factors set that composes safety factors whose number is n. Through field research to collect relevant information on the master data to classify, organize and summarize, combined with expert interviews, collated sets of factors:

$$U = (U_1, U_2, U_3, U_4), U_1 = (u_{11}, u_{12}, u_{13}, u_{14}, u_{15}, u_{16}, u_{17}),$$
$$U_2 = (u_{21}, u_{22}, u_{23}, u_{24}), U_3 = (u_{31}, u_{32}, u_{33}, u_{34}, u_{35}), U_4 = (u_{41}, u_{42}, u_{43}).$$

Step 2. Choose an evaluation set. Set evaluation set V to have m comments. $V = \{v_1, v_2, \cdots, v_n\}$, and v_j $(j = 1, 2, \cdots, m)$ refers to the flight safety evaluation of the jth level. Here, we select the evaluation sets $V = (v_1, v_2, v_3, v_4, v_5)$, from v_1 to v_5 as respectively referring to; outstanding, good, medium, low and poor.

Step 3. Build the comprehensive evaluation characteristic matrix. Assume that the candidate system for $Q = (q_1, q_2, \cdots, q_m)$, the comprehensive evaluation index system for $U = (u_1, u_2, \cdots, u_n)$, and the indicator for the candidate evaluation index with a characteristic matrix $X = (x_{ij})_{m \times n}$ refers to the following [1]:

$$X = \begin{pmatrix} x_{11} & x_{12} & x_{13} & \cdots & x_{1n} \\ x_{21} & x_{22} & x_{23} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & x_{m3} & \cdots & x_{mn} \end{pmatrix}.$$

Of these, x_{ij} refers to evaluation scheme i for the evaluation of scale $j(i = 1, 2, \cdots, m;\ j = 1, 2, \cdots, n)$.

Step 4. Characteristic matrix standardization. Here, we use a range transformation, which affects index standardization, as follows:

$$b_{ij} = \frac{x_{ij} - \min\limits_{1 \le i \le m} x_{ij}}{\max\limits_{1 \le i \le m} x_{ij} - \min\limits_{1 \le i \le m} x_{ij}}, \tag{120.1}$$

where $\max_{1 \le i \le m} x_{ij}$ and $\min_{1 \le i \le m} x_{ij}$ indicate the maximum and minimum value of the different objects in the same index standardization.

Step 5. From the entropy definition, determine the entropy value for the evaluation indices.

$$H_i = -\frac{\sum_{j=1}^{n} f_{ij} \ln f_{ij}}{\ln n}, \tag{120.2}$$

$$f_{ij} = \frac{b_{ij}}{\sum_{i=1}^{m} b_{ij}}. \tag{120.3}$$

Of these, $0 \le H_i \le 1$, $i = 1, 2, \cdots, m$; $j = 1, 2, \cdots, n$, when $f_{ij} = 0$, $f_{ij} \ln f_{ij} = 0$.

Step 6. Calculate the entropy weight of the first j entropy weight in the evaluation index which is defined as:

$$w_i = \frac{1 - H_i}{m - \sum_{i=1}^{m} H_i} \tag{120.4}$$

Of these, $w_i \in [0, 1]$ and $\sum_{i=1}^{m} w_i = 1$.

Step 7. Determine the comprehensive weighted index. Assume the m experts subjective weight vector to be the evaluation index, then combine this with the entropy weight to determine the comprehensive weight for:

$$a_i = (w_i + \mu\lambda_i) \Big/ \sum_{i=1}^{m} (w_i + \mu\lambda_i), \tag{120.5}$$

where a_i is the ith comprehensive weight in the evaluation indices, u is the subjective weight for the relative effectiveness of the objective weight coefficient, in which u sets the scope as $0.3 < \mu < 3$. If $u = 1$, and the subjective weight and objective weight are the same in the weights synthesis [5].

Step 8. Establish membership matrixes. Here, we combine the characteristics of the airline and comprehensive expert interview method after determining the average method to find the score for each index.

Excellent

$$ux = \begin{cases} 0, & 0 \le x < 80, \\ (x - 80)/10, & 80 \le x < 90, \\ 1, & 90 \le x \le 100. \end{cases} \tag{120.6}$$

Good

$$u(x) = \begin{cases} 0, & 0 \le x < 70, \\ (x - 70)/10, & 70 \le x < 80, \\ 1, & x = 80, \\ (90 - x)/10, & 80 < x \le 90, \\ 0, & 90 < x \le 100. \end{cases} \tag{120.7}$$

Fair

$$u(x) = \begin{cases} 0, & 0 \le x < 60, \\ (x - 60)/10, & 60 \le x < 70, \\ 1, & x = 70, \\ (80 - x)/10, & 70 \le x < 80, \\ 0, & 80 \le x \le 100. \end{cases} \tag{120.8}$$

Low

$$u(x) = \begin{cases} 0, & 0 \le x < 50, \\ (x - 50)/10, & 50 \le x < 60, \\ 1, & x = 60, \\ (70 - x)/10, & 60 < x \le 70, \\ 0, & 70 < x \le 100. \end{cases} \tag{120.9}$$

Poor

$$u(x) = \begin{cases} 1, & 0 \le x < 50, \\ (60 - x)/10, & 50 \le x < 60, \\ 0, & 60 \le x \le 100. \end{cases} \tag{120.10}$$

Through the membership function affecting the flight safety factors, set U one by one in the u_i and determine the R_i membership matrix for the various factor sets U.

Table 120.1 The fuzzy evaluation set

Evaluation set V	Excellent (first-level)	Good (second-level)	Fair (third-level)	low (fourth-level)	Poor (fifth-level)
Scores	90	80	70	60	50

$$R = \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{pmatrix}.$$

Note: r_{ij} refers to the evaluation objects from the factors in the u_i to rank the membership degree of the fuzzy subset v_j, $(i = 1, 2, \cdots, n)$.

Step 9. Fuzzy comprehensive evaluation. Use the weighted average of the fuzzy operator "o" whose calculation steps are same with the multiplication of double matrixes to calculate the results between the membership matrix R and the weight matrix W, and it's detailed steps are as follows, fuzzy comprehensive evaluation results are obtained:

$$B = A \circ R = (b_1 b_2 \cdots b_m)\,, \tag{120.11}$$

in which B is a fuzzy subset of V on the evaluation set, and "o" indicates the fuzzy matrix synthesis calculations. According to the weighted average principle and the rank score, the B component processing and the quantitative guideline values, the final evaluation results can be seen to belong to a safe level (Table 120.1).

120.4 The Combination of Empowerment—Flight Safety Fuzzy Comprehensive Evaluation Model

120.4.1 Establishment of the Characteristics Matrix

Based on the flight safety evaluation factor set, the specific data indicators are gathered by the expert interview method and the standard data method, which determines the index weight. Using Eq. (120.1), each index was subject to standardization processing, as shown in Table 120.2: Using Eqs. (120.2) and (120.3), an evaluation of each index's entropy was conducted, as shown in Table 120.3: Using Eq. (120.4), the E1-7 weight vector was determined:

$W_1 = (0.2277, 0.1886, 0.0712, 0.2277, 0.1886, 0.3281, 0.1033)$.

Table 120.2 b_{ij}

i	1	2	3
Translation	mRNA[a]	22 (19–25)	Translation repression, mRNA cleavage
Translation	mRNA cleavage	21	mRNA cleavage
Translation	mRNA	21–22	mRNA cleavage
Translation	mRNA	24–26	Histone and DNA Modification

Table 120.3 H_i

Serial number	Index content	Entropy H_i
u_{11}	Knowledge and skill	0.3168
u_{12}	Physiological	0.4342
u_{13}	Safety awareness	0.7865
u_{14}	Crew resource management	0.7892
u_{15}	Air preparation	0.9676
u_{16}	Psychological factors	0.0155
u_{17}	Coordination of decision-making	0.69

Then, a table showing the various weight factors was derived, as in Table 120.5. The index weight vectors given by the experts were as follows:

$$\lambda_U = [0.4461, 0.2900, 0.0929, 0.1710] .$$

Each secondary index weight vector:

$$\begin{aligned}
\lambda_{U_1} &= [0.2872, 0.0805, 0.1131, 0.2064, 0.0982, 0.1027, 0.1119] ,\\
\lambda_{U_2} &= [0.2876, 0.3179, 0.2876, 0.1069] ,\\
\lambda_{U_3} &= [0.2120, 0.1087, 0.2120, 0.3587, 0.1086] ,\\
\lambda_{U_4} &= [0.4231, 0.3124, 0.2645] .
\end{aligned}$$

According to type (120.3), take $u = 1$ as the available comprehensive weighting vector:

120.4.2 Establish Membership Function

Select the relevant experts to carry out the survey units. Organize expert evaluation results, after the normalization we can get the specific data according to the membership function such as Table 120.4:

Table 120.4 Membership Matrix

Serial number	Scores	The subordinate degree r_{ij}				
		Excellent	Good	Fair	Low	Poor
Knowledge and skill u_{11}	80	0	1	0	0	0
Psychological factor u_{12}	65	0	0	0.5	0.5	0
Safety awareness u_{13}	70	0	0	1	0	0
Crew resource management u_{14}	85	0.5	0.5	0	0	0
Air preparation u_{15}	70	0	0	1	0	0
Psychological quality u_{16}	85	0.5	0.5	0	0	0
Coordination of decision-making u_{17}	80	0	1	0	0	0
Warning system u_{21}	80	0	1	0	0	0
Aircraft system u_{22}	70	0	0	1	0	0
Maintenance u_{23}	55	0	0	0	0.5	0.5
Maintenance equipment situation u_{24}	60	0	0	0	1	0
Control system u_{31}	60	0	0	0	1	0
Airport u_{32}	70	0	0	1	0	0
Air traffic control u_{33}	80	0	1	0	0	0
Airway conditions u_{34}	60	0	0	0	1	0
Weather conditions u_{35}	70	0	0	1	0	0
Safety management u_{41}	85	0.5	0.5	0	0	0
Emergency management u_{42}	80	0	1	0	0	0
Safety education and training u_{43}	75	0	0.5	0.5	0	0

Table 120.5 Comprehensive entropy value method for the door crane weight value calculation in the evaluation indices at all levels of w

Environmental factor U_3	0.1138	Control system u_{31}	0.2035
Managerial factors U_4	0.2959	Airport u_{32}	0.0468
		Air traffic control u_{33}	0.1886
		Airway conditions u_{34}	0.2459
		Weather conditions u_{35}	0.3152
		Safety management u_{41}	0.3572
		Emergency management u_{42}	0.3371
		Safety education and training u_{43}	0.3057

120.4.3 Fuzzy Comprehensive Evaluation

The secondary factors were identified as; $u_{11} \sim u_{17}$ and $u_{21} \sim u_{24}$ and $u_{31} \sim u_{35}$, $u_{41} \sim u_{43}$ for the four primary factor weights U_1, U_2, U_3, U_4, as shown in Table 120.5.

Table 120.6 Entropy value method synthesis and the flight safety calculation process for all levels of the weight value A comprehensive evaluation index

Serial number	Weight A	Serial number	Weight A
Pilot U_1	0.4746	Knowledge and skill u_{11}	0.2575
		Psychological factor u_{12}	0.1346
		Safety awareness u_{13}	0.0921
		Crew resource management u_{14}	0.1383
		Air preparation u_{15}	0.0545
		Psychological quality u_{16}	0.2154
		Decision-making coordination u_{17}	0.1076
Aircraft U_2	0.1886	Warning system u_{21}	0.2704
		Aircraft system u_{22}	0.3531
		Maintenance u_{23}	0.2704
		Maintenance equipment situation u_{24}	0.1061
Environmental factor U_3	0.1033	Control system u_{31}	0.2078
		Airport u_{32}	0.0777
		Air traffic control u_{33}	0.2003
		Airway conditions u_{34}	0.3023
		Weather conditions u_{35}	0.2119
Managerial factors U_4	0.2335	Safety management u_{41}	0.3902
		Emergency management u_{42}	0.3247
		Safety education and training u_{43}	0.2851

From Table 120.6, the single factor membership degree was obtained. Then, from (10) the fuzzy judgment analysis set formulas were derived:

$U_1 = (0.1769, 0.4344, 0.2139, 0.0673, 0)$, $U_2 = (0, 0.2704, 0.3531, 0.2413$, $0.1352), U_3 = (0, 0.0777, 0.3800, 0.5101, 0), U_4 = (0.1951, 0.6624, 0.1426, 0, 0)$.

So, then, the primary factors for membership matrix U were determined:

$$R = \begin{pmatrix} 0.1769 & 0.4344 & 0.2139 & 0.0673 & 0 \\ 0 & 0.2704 & 0.3531 & 0.2413 & 0.1352 \\ 0 & 0.0777 & 0.3800 & 0.5101 & 0 \\ 0.1951 & 0.6624 & 0.1426 & 0 & 0 \end{pmatrix}.$$

From Table 120.5, the primary factor weights were U_1, U_2, U_3, U_4, and by applying Eq. (120.10) the final airline flight safety assessment security results were determined.

$$B = (04746, 0.1886, 0.1033, 0.2335) = (0.1295, 0.4199, 0.1295, 0.4199, 0.0255)\,.$$

By combining evaluation set $V = \{\text{excellent, good, fair, poor}\}$, and based on the maximum membership degree principles, it was concluded that the flight safety level was “fair”.

For every factor, the expert scoring of the membership function allowed for the calculation of the final flight safety factor results: the physiological score was 65 indicating a “fair” state, the engineering equipment, control system and route condition scores were all 60 indicating a “poor” state, the track maintenance score was 55, also indicating a “poor” state. Safety accidents caused by these factors need to be paid attention to by the airport unit, which should develop specific measures to improve the company’s safety management capability and the level of the safety in the flight systems to ensure the overall safety of the airline.

120.5 Conclusions

In this paper we introduced a new, more detailed flight safety evaluation system. The main features of the “combination empowerment—fuzzy comprehensive evaluation model” in this paper are:

(1) The use of a fishbone diagram, which included consideration of the pilot, plane, management and environment, for an initial inductive analysis can not only reflect the comprehensive integrity of a factor set in the flight safety evaluation system, but can also reflect the complete safety assessment process for the correlation between the various factors.

(2) Combining the differences in the objective weights and the arbitrariness in the subjective weights results in a more reasonable weighting which considers the relative importance of the two different weights, thereby avoiding the traditional use of expert experience and historical data weight assignment insufficiency and the use of an entropy weight method which does not reflect the importance of the indicators to the actual problem.

(3) From a systems engineering perspective, we used a “multiple risk factor comprehensive evaluation method” to build the combination empowerment—fuzzy comprehensive evaluation model ”. Accident probability was evaluated using the “human—machine—environment—management systems theory” view, and, by combining information from the subjective and objective evaluations, the subjectivity of traditional flight problem evaluation was reduced, ensuring a more accurate flight safety analysis.

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