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CFIT Risk Assessment Model on Destination Airport Based on Fuzzy Linguistic

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Abstract: CFIT Risk Assessment Model on Destination airport is a risk model based on which can provide an objective and impartial judgment though synthesizing human expertise and various risk factors on destination airport. At the end of this article, we present an example to show the feasibility of this model and list steps of construction of CFIT RAM index system and process of solving the model.

Key words: CFIT, risk assessment, fuzzy linguistic, destination airport, model

INTRODUCTION

CFIT occurs when an airworthy aircraft is flown, under the control of a qualified pilot, into terrain (water or obstacles) with inadequate awareness on the part of the pilot of the impending collision (FAA, 2003). According to FAA information, general aviation CFIT accidents account for 17% of all general aviation fatalities. More than half of these CFIT accidents occurred during IMC (FAA,2003).

At present, there are two main methods on the destination airport CFIT risk assessment. One is to have experts to make assessment based on their knowledge and experience. This method obviously has subjectivity and arbitrariness defects. The other is to use the Flight Safety Foundation CFIT Checklist Section 1 of Part I (destination airport CFIT) to score the indicators to assess the destination airport CFIT risk (Flight Safety Foundation 2003). However, by carefully studying the Flight Safety Foundation CFIT Checklist, we found this method is too simple and some definitions in the checklist are unclear and in most cases it's unable to reflect the actual situation. In practice, this method is difficult to effectively reveal the destination airport CFIT risk.

In fact, the destination airport CFIT risk assessment is a complicated comprehensive evaluation process and its complexity is mainly reflected in: There are many affected factors; The relationship between factors is complex; and many factors are uncertain or difficult to quantify. Considering the complexity in the evaluation process, we propose a new assessment method based on fuzzy linguistic. This method makes full use of assessment information, takes advantage of group decision making and mathematical statistics. It is a combination of qualitative and quantitative method.

INDEX SYSTEM ON THE DESTINATION AIRPORT CFIT RISK ASSESSMENT

By systematically studying the destination airport CFIT risk factors and referring to the Flight Standards Division Advisory Circular (AC-97-FS-2011-01) of the Civil Aviation Administration of China --airport operation minima (CAAC., 2011), FAAAC61-134 the General Aviation Controlled Flight into terrain Awareness and the Flight Safety Foundation CFIT checklist, with the principles of systemic, comprehensive and comparable, we build the CFIT risk evaluation index system as follows:

Instrument approach procedure (A_1): The Instrument Approach Procedure (IAP) provides a safe route (including loss of destination opportunity missed approach route) for an aircraft to safely avoid or flyover obstacles. To meet the requirements of aircraft approaching and destination, generally there will be more than two IAPs designed for the same destination runway. The ease of use on IAPs and program design standard consistency and the coordination of the external environment of airport are the main instrument approach procedure risk assessment characters. In general, the better the assessment characters are, the less the risk is and vice versa.

Availability of Airport airspace (A_2): Airport airspace is the physical environment for aircrafts. In the actual operation, the airport airspace can be impacted by temporary restrictions for certain airspace and many external factors, such as, military activities, strong convective weather, general aviation operations. Thus it brings different levels of risk to the approaching and the destination aircrafts.

Weather conditions (A_3): Weather conditions is outside factor when aircrafts flying in the airport airspace; it is the major reference factor for flight crew to determine the aircraft to continue to approach and destination or execute missed approach and also it directly affects the flight crew to obtain sufficient visual reference of the runway continuously for a safe destination to be made. In general, the better the airport weather conditions is, the better the flight crew can obtain visual reference information, consequently, the less the risk of the approach and the destination aircraft.

Capability of the air traffic management services (A_4): The capability of air traffic management services refers to the use of air traffic management method, the ability to develop the control plan and the controller's capability, etc. The stronger the capability of air traffic management services is , the higher the quality of the air traffic management services for the aircraft is, hence, the better they can ensure the safety of the aircraft approach and destination, thus reduces the risk of aircraft flight approach and the destination.

Airport terrain and obstacle distribution (A_5): When an airport is located in the mountains, or there are obstacles around the airport , especially when obstacles exist in the direction of approach and destination, the flight crew may get extra stress and may affect the normal operation of the flight crew. Hence, the risk of approach and destination safety of an aircraft is increased. Meanwhile, when an aircraft is destination in an airport located in the mountains, it more than often encounters downdraft which will cause the airplane to occur in the different turbulence, affect the stability of the aircraft flight and increase aircraft destination difficulty. Obviously, the more flat the airport terrain is, or the lower the quantity and the less artificial or natural obstacles' height are, the lower the risk in terms of the approach and destination aircraft is.

Navigational aids (NAVAID) performance (A_6): The Airport NAVAID includes radio navigation facilities (such as VOR, DME, ILS, etc.) and visual navigation aids (such as runway markings and approach lighting systems, runway lighting system, etc.,). Generally speaking, the better NAVAID performance is, the higher the precision of the guidance for aircraft is, the smaller range the aircraft deviated from the runway centerline is, the lower the risk of aircraft in approach to destination.

Other interference factors (A_7): Other interference factors mainly refer to the destination airport runway available data, airport electromagnetic environment, lighting interference around the airport, visual landmarks interference, birds and wildlife activities and so on. The above interference factors will increase the risk of aircraft approach and destination in different degrees. Obviously, the less of the above interference factors are, the less the risk faced by the aircraft approach and destination is.

THE METHOD OF RISK ASSESSMENT ON THE DESTINATION AIRPORT CFIT BASED ON FUZZY LINGUISTIC MULTI-ATTRIBUTE GROUP DECISION-MAKING ASSESSMENT

The risk assessment on the destination airport CFIT is reflected in multiple indicators determined by multiple attributes, it is a typical multi-attribute decision making problem (Chen, 2010; Chen, 2012). Considering the weights of evaluation index are every-changing, we adopt the G1 method to determine the weights of index. In addition, in the actual evaluation, the indexes are hard to quantify. So we employ fuzzy linguistic assessment method to obtain the evaluation index.

Multiple attribute group decision making based on the fuzzy linguistic assessment: A Multiple attribute group decision making problem based on the fuzzy linguistic is described as follows:

Let R_i (i = 1, 2,...n)stands for the set of alternatives and A_j (j = 1, 2,...m) be the set of attributes. For the R_i with respect to the attribute A_j (j = 1, 2, ...m), we can obtain the fuzzy linguistic assessments attribute value d_{ij}. Hence, we can get the decision matrix $D = (d_{ij})_{n\times m}$; Let $w = \{w_1, w_2, \dots w_m\}$ be the weight vector of attributes, where, $0 \le w_j \le 1$ and:

$$\sum_{j=1}^{m} w_j = 1$$

Method G1 to determine the weight of the index: Method G1 is proposed by Guo (2007), it is a kind of subjective weighting method. G1 method is simple, intuitive, high-performance operable, isotonic resistant and there is no limit to the number of elements or indicators and no need to construct the process in determining the weight of each index judgment matrix, no need to do consistency. Steps to determine weighting values of assessment using G1 method:

- **Step 1:** Determine the order relationship of the evaluation index
- **Step 2:** Obtain the value of relative importance judgment ratio r_k of x_{k-1} and x_k

Let r_K be the relative importance judgment ratio of x_{k-1} and xk, rk = w_{k-1}/w_k, where k = m, m-1,..., 3, 2 and w_k is the weight of x_k. When the value of r_k is 1.0, or 1.2, or 1.4, or 1.6, or 1.8, we think index x_{k-1} is the same important as x_k, or x_{k-1} is somewhat important than x_k, or x_{k-1} is obviously important than x_k, or x_{k-1} is strong important than x_k, or x_{k-1} is extremely important x_k, respectively.

- **Step 3:** Calculate the weight coefficient w_m:

$$w_m = \left[1 + \sum_{k=2}^{m}\prod_{i=k}^{m} r_i\right]^{-1},\ w_{k-1} = r_k \times w_k\ \ (k = m, m-1, \cdots, 3, 2) \quad (1)$$

Calculate the comprehensive weight λ: By applying Eq. 1, we can get the evaluation index weight matrix Q from L experts. Let set $\omega = (\omega_1, \omega_2, \cdots \omega_l)$ be L expert weights, then the comprehensive weights λ of evaluation indexes are as follows:

$$\lambda = \omega \times Q = (\omega_1, \omega_2, \cdots \omega_l) \times \begin{vmatrix} w_{11} & w_{12} & \cdots & w_{1i} \\ w_{21} & w_{22} & \cdots & w_{2i} \\ \vdots & \vdots & \cdots & \vdots \\ w_{l1} & w_{l2} & \cdots & w_{li} \end{vmatrix} \quad (2)$$

Indicator assessment set and its corresponding interval numbers: For the assessment results of qualitative indicators based on the evaluation of fuzzy linguistic, we can convert the results using interval number expression using Table 1 and 2 (Xu and Da, 2002; Xu, 2003).

It should be noted that, in the 7 evaluation indicators of the destination airport CFIT risk, the Instrument Approach Procedure (IAP), airport airspace available, weather conditions, the capacity of the air traffic management services, navigational aids (NAVAID) performance and other interference factors belong to the effective attribute and airport terrain and obstacle distribution belong to cost attribute.

The comprehensive evaluation value of the destination airport CFIT risk: Firstly, aggregate all the index A_j of the destination airport CFIT risk (R_i) from all experts using the combined weighted set-valued statistics method. Let ψ denote the evaluation scope of index A_j $(A_j \in A(j = 1, 2, \cdots, M))$ of the destination airport CFIT risk (R_i), then the i-th evaluation, the corresponding evaluation scope denoted as ψ. The evaluation interval numbers of the i-th (i = 1, 21, ..., N) decision-maker is denoted as:

$$\left[u_{j1}^{(i)}, u_{j2}^{(i)}\right] \text{ and } \left[u_{j1}^{(i)}, u_{j2}^{(i)}\right] \in \xi$$

Secondly, calculate the comprehensive evaluation value of A_j of the destination airport CFIT risk (R_i) based on gravity decision theory (Wang, 2007):

$$u_j = \frac{1}{2} \times \frac{\sum_{i=1}^{N} w_i \left[\left(u_{j2}^{(i)}\right)^2 - \left(u_{j1}^{(i)}\right)^2\right]}{\sum_{i=1}^{N} w_i \left[u_{j2}^{(i)} - u_{j1}^{(i)}\right]} \quad (3)$$

Thirdly, obtain the comprehensive evaluation value vector of all indicators (attributes) of the destination airport CFIT risk (R_i):

$$U_A = [u_1, u_2, \cdots u_M]^T \quad (4)$$

Fourthly, calculate the comprehensive evaluation value of the destination airport CFIT risk (R_i) using weighted average method.

$$r = \sum_{j=1}^{n} w_j \times U_A \quad (5)$$

From the interval where r is in Table 1, we can get the level about the destination airport CFIT risk (R_i).

ILLUSTRATIVE EXAMPLE

An airport needs to make risk assessment of its ILS precision approach procedure and ILS (Glide Path (GP) inoperative) non-precision approach procedure of runway RWY30. This airport has an expert group which consists of 5 sub-groups: Flight procedures designers, flight crew, air traffic controllers, flight performance

Table 1: The value scale of the destination airport CFIT risk

Scale	Lowest risk (V_1)	Lower risk (V_2)	Moderate risk (V_3)	Higher risk (V_4)	Highest risk (V_5)
value	[0.80,1.0]	[0.60,0. 80)	[0.40,0.60)	[0.20,0.40)	[0,0.20)

Table 2: The fuzzy linguistic assessments and the corresponding interval number

Fuzzy linguistic scale	Cost attribute	Very good	Good	Moderate	Bad	Very bad
	Effective attribute	Very bad	Bad	Moderate	Good	Very good
Interval number expressions	[0,0.2)	[0.2,0.4)	[0.4,0.6)	[0.6,0.8)	[0.8,1.0]	

experts, airport management experts. Each sub-group makes assessment of the weights of indicators and levels of indicators by following the evaluation indicators system mentioned in this paper. Considering the different professional backgrounds of experts and degrees of familiarity with the problems of the experts, we decided the weight of experts is Z = (0.25, 0.20, 0.20, 0.20, 0.15) after discussion.

Calculate the comprehensive weight λ: The calculation steps to determine weights of each indicator are as follows:

The first step is to determine the order relationships between the same levels of each index.

The order relationships between the evaluation indexes are:

- **Expert 1:** $U_1 \succ U_2 \succ U_3 \succ U_4 \succ U_5 \succ U_6 \succ U_7$
- **Expert 2:** $U_1 \succ U_3 \succ U_4 \succ U_2 \succ U_6 \succ U_5 \succ U_7$
- **Expert 3:** $U_3 \succ U_2 \succ U_1 \succ U_4 \succ U_6 \succ U_5 \succ U_7$
- **Expert 4:** $U_2 \succ U_4 \succ U_3 \succ U_1 \succ U_6 \succ U_5 \succ U_7$
- **Expert 5:** $U_4 \succ U_3 \succ U_2 \succ U_1 \succ U_6 \succ U_5 \succ U_7$

The second step is to obtain Value r_k based on the relative importance of between u_{k-1} and u_k.

The values of r_k from experts are as follows according to the order relationships between the evaluation indexes:

- **Expert 1:** r_2 = 1.2, r_3 = 1.4, r_4 = 1.2, r_5 = 1.2, r_6 = 1.2, r_7 = 1.0
- **Expert 2:** r_2 = 1.4, r_4 = 1.4, r_4 = 1.2, r_5 = 1.2, r_6 = 1.0, r_7 = 1.2
- **Expert 3:** r_2 = 1.2, r_3 = 1.0, r_4 = 1.2, r_5 = 1.2, r_6 = 1.0, r_7 = 1.4
- **Expert 4:** r_2 = 1.2, r_3 = 1.2, r_4 = 1.0, r_5 = 1.2, r_6 = 1.0, r_7 = 1.4
- **Expert 5:** r_2 = 1.2, r_3 = 1.2, r_4 = 1.0, r_5 = 1.0, r_6 = 1.2, r_7 = 1.4

Finally, by using the Eq. 1 to calculate the weight coefficient w_m, we obtained evaluation index weight matrix Q given by experts. Combined with expert weight Z = (0.25, 0.20, 0.20, 0.20, 0.15) and Eq. 2, we got the comprehensive evaluation indexes weights.

λ = (0.2008, 0.1718, 0.1710, 0.1522, 0.1139, 0.061, 0.0842)

The comprehensive risk assessment value of destination airport CFIT: Each expert made assessment of ILS precision approach procedure and fuzzy linguistic levels

Table 3: The statistical results about each evaluation index of the destination airport CFIT risk

Index system expert	A_1	A_2	A_3	A_4	A_5	A_6	A_7
1	v_2	v_2	v_4	v_3	v_4	v_4	v_2
2	v_1	v_2	v_3	v_3	v_3	v_5	v_3
3	v_2	v_2	v_4	v_3	v_4	v_4	v_2
4	V_1	v_2	v_3	v_2	v_4	v_3	v_3
5	v_2	v_3	v_3	v_2	v_3	v_4	V_3

of evaluation indicators, as shown in Table 3. And by apply Table 2, the fuzzy linguistic assessment scales are converted to interval numbers. As to the ILS (GP inoperative) non-precision approach procedure, besides the fuzzy linguistic evaluation levels given by the five experts on the evaluation index A_1 are, v_3, v_3, v_3, v_4 and v_4, respectively , the rest of the evaluation indicators are the same as the ILS precision approach procedures.

Using Eq. 3 and 4 to calculate the comprehensive evaluation value of each index, we got the comprehensive evaluation value vector of each index for the destination airport CFIT risk (R_i) from all the decision-makers:

$$\overline{U_A'} = \left[\overline{u_1}, \overline{u_2} \cdots, \overline{u_M}\right]^T = [0.43, 0.67, 0.42, 0.57, 0.38, 0.29, 0.58]^T$$

Using Eq. 5, we obtained the comprehensive evaluation value 0.55 on the destination airport CFIT risk when using ILS precision approach procedure through the combined weighted arithmetic averaging operator calculation.

Using the same method, we got the comprehensive evaluation value 0.47 on the destination airport CFIT risk when using ILS (GP inoperative) non-precision approach procedure.

From Table 1 and the evaluation values, we concluded that the destination airport CFIT risk is moderate when using ILS precision approach procedure or when using ILS (GP inoperative) non-precision approach procedure.

CONCLUSIONS

The study focuses on the status quo of the evaluation on the destination airport CFIT risk, taking into account the actual situation of the complexity and uncertainty of the destination airport CFIT risk, We employed the G1 method to determine the weight of the index and fuzzy linguistic assessment indexes and built a multi-attribute group decision-making evaluation method based on fuzzy linguistic By applying this method to evaluate each index of the destination airport CFIT risk, we can get comprehensive evaluation value of the destination airport CFIT risk. This method takes full advantage of each evaluation index information, so the evaluation result is objective and reliable. This method also can improve decision-making efficiency, reduce the defects of evaluation work and provide a scientific evaluation of the destination airport CFIT risk.

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