Fuzzy Comprehensive Evaluation of Runway Incursion based on Fault Tree Method

Baoshun XIONG[1, 2, a], Haolin CUI[1, 2, b], Yihui LI[1, 2, c]

[1]Air Traffic Control and Navigation College, Air Force Engineering University, Xi'an, Shaanxi, 710051, China

[2] National Key Laboratory of Air Traffic Collision Prevention, Xi'an, Shaanxi, 710051, China

[a]362802182@qq.com, [b]hlcui888@sina.com, [c]617013838@qq.com

Keywords: Runway Incursion; Fault Tree; Fuzzy Comprehensive Evaluation

Abstract. To overcome the traditional fault tree diagnosis techniques are difficult to resolve random uncertainty and complexity ambiguity. We choice the method of combine fuzzy comprehensive evaluation with fault tree analysis. First of all, we construct a runway incursion fault tree, comprehensive identification system risk factors. Then quantified using fuzzy comprehensive evaluation analysis of the military and civilian airport runway incursion problem to find out the most important factor for the prevention of runway incursions occur provide focused direction. Finally, it is concluded that the comprehensive membership of the runway is 0.5159, and the risk is moderate. Illustrate the runway intrusion will seriously affect the aviation transportation safety.

Introduction

At present, the domestic researchers mainly on the factors of qualitative analysis of runway incursions, the reasons of runway incursions are hardly ever analysis by quantitative systematically. There are many methods for quantitative analysis, including regression analysis, variance analysis and principal component analysis. However, these methods require a large amount of data, but usually it is difficult to satisfy in the actual work, which makes it difficult to find out the rules of the system.

Fault tree analysis as a reliability and safety analysis of a technology, with clear thinking and strong logic, can describe the characteristics of the relationship between cause and effect logic which make complex systems fail, also can quantitative analysis on the weak links. Combing with fuzzy comprehensive evaluation method to confirm the evaluation set of runway incursions and the weight of evaluation factor. Then provide a guidance to prevent runway incursions by figure out the most important factor.

The Presentation of Fault Tree Analysis Methods and Quantitative Analysis

Fault tree analysis is proceeding from top to bottom event or from result to reason in the disable causal relationship. A fault tree is a logical diagram, which depicts the sequence of events.

Suppose the probability of occurrence of the top event T is $P(T)$, the occurrence probability of the bottom event X_i is $P(X_i)$, the system fault tree have K minimum cut sets C_i （$1 \le i \le k$）. The fault tree structure function is represented as the minimum cut set and the event.

$$T = C_1 + C_2 + L + C_k \quad (1)$$

The C_i in type (1)is a accumulate affair of the bottom event it contains.

$$C_i = x_1 x_2 \cdots x_n \quad (2)$$

In general, the minimal cut sets intersect with each other, we can see

$$P(T) = P(C_1 + C_2 + \cdots + C_k) =$$

$$\sum_{i=1}^{k} P(C_i) - \sum_{i<j=2}^{k} P(C_i C_j) + \sum_{i<j<l=3}^{k} P(C_i C_j C_l) + \cdots + (-1)^{k-1} PP(C_1 C_2 \cdots C_k) \quad (3)$$

$P(C_i) = \prod_{i=1}^{n} P(x_i)$, n is the C_i contains the number of bottom events, then the minimum cut set of the key importance of the bottom event x_i

$$W_i = \frac{\partial P(T)}{\partial P(x_i)} \quad (4)$$

Critical degree reflects the degree of impact probability minimum cut set for the end of the event x_i occurrence probability of top event *T*.

Establish the Runway Incursion Fault Tree

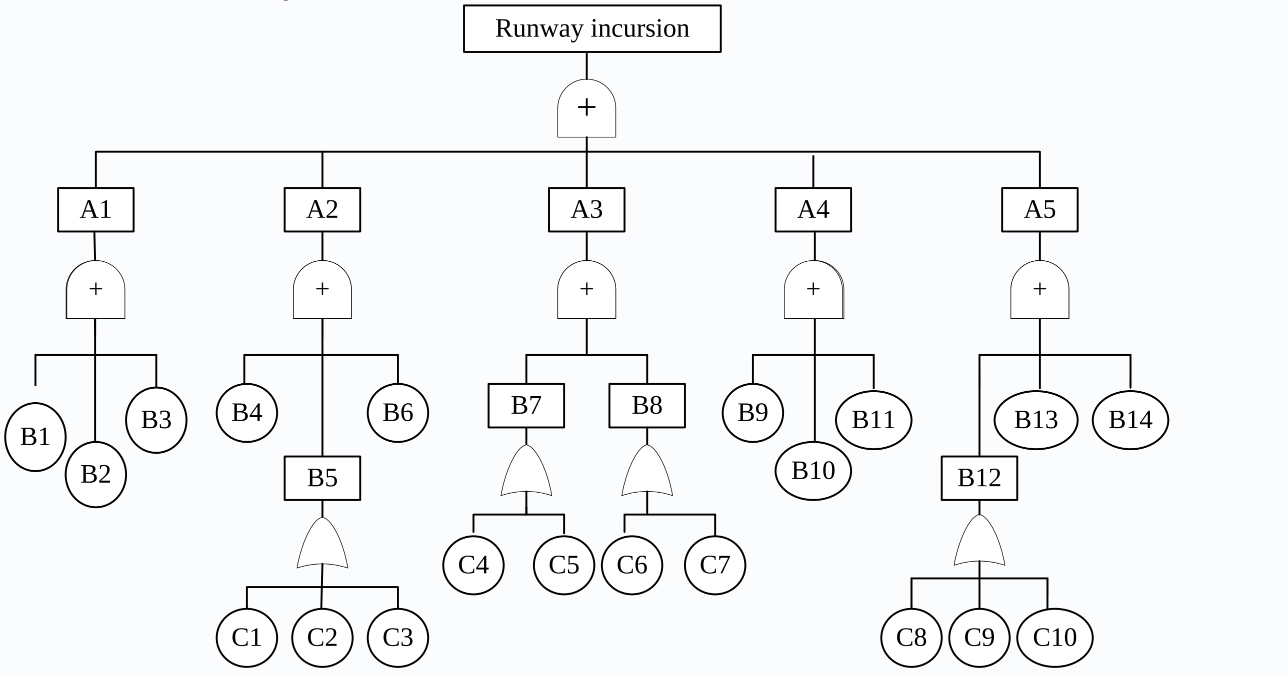

Figure 1 Runway incursion accident tree

Table 1 runway incursion basic event table

Number	Name	Number	Name
A1	Vehicle driver errors	B11	Bad weather conditions, poor visibility
A2	Pilot errors	B12	Obstacles in runway while using
A3	Controller errors	B13	ATC equipment failures
A4	Airport facilities and environmental reasons	B14	Runway operations management issues
A5	Program management reasons	C1	Pilot and controller communicate content is not standard
B1	Driver observe half-heartedness before enter the runway	C2	Between pilot and controller occur obstacles
B2	Implement the controller’s command	C3	Pilot misunderstand the content of phone calls
B3	Vehicle driver isn’t on the prescribed route	C4	Controller sends out too long or instruction
B4	Pilot lost scene consciousness	C5	Controller doesn’t use standard language
B5	Pilot’s and controller’s phraseology issue	C6	Controller lost scene consciousness
B6	Pilot is unready before takeoff	C7	Controller is irresponsibility
B7	The problem of controller’s command	C8	Animals on the runway when using
B8	Controller itself conscious issue	C9	Scattered personnel on the runway when using
B9	Airport layout is complex, the design is unreasonable	C10	Irrelevant vehicle crossing the runway when using.
B10	Airport taxi route, markings and signs are unclear		

Accident Reason Analysis based on Fuzzy Comprehensive Evaluation

The basic steps applying fuzzy theory establish fuzzy comprehensive evaluation mathematical model is:

Step 1: Clear that evaluation model of the target layer is O , the criterion layer of the factor is $U=\{u_1, u_2, \cdots, u_m\}$and the scheme layer of the evaluation is $V=\{v_1, v_2, \cdots, v_m\}$;

Step 2:Set up the weight of the factor set $w=\{w_1, w_2, \cdots, w_i, \cdots, w_m\}$（$w_i$ is the weight coefficient of factor u_i， has $\sum_{i=1}^{m} w_i = 1$）； Construct fuzzy evaluation matrix，a factor of i is set up and the fuzzy evaluation vector of V is $R_i = \{r_{i1}, r_{i2}, \cdots, r_{in}\}$， so fuzzy evaluation matrix is $R = (r_{ij})_{m \times n}$. It represents the corresponding relationship between the U and the evaluation set V;

Step 3 Based on the fuzzy operator $B = w \cdot R$ to analyze and evaluate the evaluation model of the target layer O.

According to established the fault tree above, the factors that cause runway incursions into five categories: the vehicle driver errors, pilot error, the controller errors, the airport facilities for environmental reasons and program management reasons.

In order to achieve the requirements of the accuracy of the assessment, we use e-mail and some other mode questionnaire survey 37 airport controllers in the front line and 10 air traffic control experts to score the five factors of runway incursions and to build fuzzy comprehensive evaluation model, then comprehensive evaluation to identify the larger influence factors.

First of all, based on the risk evaluation index system of runway incursions, we identified five sources of risk. And then, we constructed judgment matrix according to expert evaluation, used the ANC to calculate and plot indicators weights, after that we tested its consistency. Finally, we determined the weight set. The calculation process is omitted.

$$A = (a_1, a_2, a_3, a_4, a_5) = (0.132, 0.291, 0.338, 0.104, 0.135)$$

$$A_1 = (a_{11}, a_{12}, a_{13}) = (0.310, 0.392, 0.298)$$

$$A_2 = (a_{21}, a_{22}, a_{23}, a_{24}, a_{25}) = (0.332, 0.204, 0.103, 0.242, 0.119)$$

$$A_3 = (a_{31}, a_{32}, a_{33}, a_{34}) = (0.280, 0.304, 0.182, 0.234)$$

$$A_4 = (a_{41}, a_{42}, a_{43}) = (0.308, 0.375, 0.317)$$

$$A_5 = (a_{51}, a_{52}, a_{53}, a_{54}, a_{55}) = (0.180, 0.242, 0.180, 0.148, 0.250)$$

We determined evaluation criteria for each runway incursion risk factors, the impact will be divided into five levels, very large (0.9) large (0.7), general (0.5), small (0.3) and very small (0.1). Evaluation sets Standard membership degree is V= (0.9, 0.7, 0.5, 0.3, 0.1)

Employ $M(\cdot, \oplus)$ to operation, use $B_i = A_i \cdot R_i$ five risk factors to evaluation

$$B_i = A_i \cdot R_i = (b_{i1}, b_{i2}, \cdots, b_{im}) (i = 1, 2, \cdots, s)$$

$$B_1 = A_1 \cdot R_1 = (0.310, 0.392, 0.298) \bullet \begin{bmatrix} 0.33 & 0.33 & 0.34 & 0 & 0 \\ 0 & 0.17 & 0.5 & 0.33 & 0 \\ 0 & 0 & 0.5 & 0.5 & 0 \end{bmatrix}$$

$$= (0.1024, 0.1689, 0.4504, 0.2784, 0)$$

Similarly, calculate the B_2， B_3， B_4 and B_5

$$B_2 = A_2 \cdot R_2 = (0.1672, 0.1655, 0.3528, 0.1732, 0.1413)$$

$$B_3 = A_3 \cdot R_3 = (0.0785, 0.2618, 0.3773, 0.1826, 0.0998)$$

$$B_4 = A_4 \cdot R_4 = (0.1570, 0.6237, 0.2193, 0, 0)$$

$$B_5 = A_5 \cdot R_5 = (0.1099, 0.2201, 0.4406, 0.1988, 0.0306)$$

Evaluation matrix $B = A \cdot R$

$$= (0.132, 0.291, 0.338, 0.104, 0.135) \bullet \begin{bmatrix} 0.1024 & 0.1689 & 0.4504 & 0.2784 & 0 \\ 0.1672 & 0.1655 & 0.3528 & 0.1732 & 0.1413 \\ 0.0785 & 0.2618 & 0.3773 & 0.1826 & 0.0998 \\ 0.1570 & 0.6237 & 0.2193 & 0 & 0 \\ 0.1099 & 0.2201 & 0.4406 & 0.1988 & 0.0306 \end{bmatrix}$$

$$= (0.1199, 0.2535, 0.3443, 0.1666, 0.0839)$$

In accordance with the principle of maximum degree of membership, controller error is the biggest influence factor of the runway incursion.

Calculate comprehensive membership degree.

$P = B \bullet V^T$ =0.5159

This data indicate that military and civil aviation airport runway incursion risks medium to large**.**

Conclusions

Through the establishment of a runway incursion fault tree, we can master the rules why runway incursions occurred. At the same time, we can take preventive measures against the minimal cut sets. Meanwhile it is helpful to formulate safety measures program and safety checklist, and to identify risk factors in the system, which this article didn't give out minutely, we will continue to study it.

The causes of runway incursions which the fault tree is given, that are used to establish the secondary models by fuzzy comprehensive evaluation method, then the experts set the weight by score to help us to establish evaluation set and to calculate the various risk factors. Finally we obtain that the biggest impact factor is controller errors, which provide a key direction to prevent runway incursions for the future.

The final calculation comprehensive membership degree is 0.5159, with that we can obtained military and civil airport runway incursion risk is medium to large, which indicate runway incursion will seriously affect the safety of air transport. Evaluation results coincide with reality, which also proved the model is reliable.

Acknowledgement

In this paper, the research was sponsored by the Nature Science Foundation of Shaanxi Province (Project No. 2015JM7364).

References

[1] L. H. Gao, J. J. Tian. Fuzzy comprehensive assessment model of vehicle safety states based on fault tree analysis . Journal of Jilin University, (2011), 95-100.

[2] P. Peter. Fuzzy-model-based Parity Equations for Faults Isolation.Control Engineering Practise,(1999),261-270.

[3] Y. C. Mo, H. W. Liu, X. Z. Yang.Efficient fault tree analysis of complex fault tolerant multiple-phased systems.Tsinghua Science and Technology, (2007), 122-127.

[4] Z. Y. Yang. Fuzzy Comprehensive Evaluation on the Mechanical Behavior of the Central Rock Pillar between Twin Neighborhood Tunnels. Proceedings of 3rd IEEE Internation Conference on Environmental and Compbuter Science, 3, (2010), 413-417.

[5] X. Q. Zhang, W. T. Yang. Reason analysis of runway incursions based on grey theory. Journal of Safety and Environment, 10(5), (2010), 160-162.

[6] J. H. . Analysis and countermeasure of Disadvantageous factors with regard to takeoff line tower control of military-civil aerodrome. Journal of Air Transport Management, (2003), 20-25.