Risk Analysis of Runway Incursion Based on Fuzzy Bayesian Network

Ren-tian YUE, Tian-qi JIA* and Yi-fei ZHAO

College of Air Traffic Management, Civil Aviation University of China, Tianjin, China

*Corresponding author

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Abstract. Runway incursion is a kind of unsafe flight incident which can easily lead to catastrophic collision of aircraft. It is of great significance to analyze the risk and improve the safety of air traffic management. Many factors affect the runway incursion unsafe event, and the analysis of influence degree of various factors has certain difficulty, and the Bayesian network is a kind of uncertainty causality model which can deal with uncertain problems and effectively express and merge multi-source information, therefore, this problem is studied by Bayesian network based on the actual operation data of some domestic airports. Bayesian network calculation model of runway incursion was built based on the analysis of factors by SHELLO model, calculated prior probability based on historical data, then the probability of the occurrence of runway incursion affected by factors was obtained by the model, it turns out L-S cause 66% of the runway incursions, the importance degree of factors and measures are sorted in the final.

Introductions

According to the data of statistical analysis report of China civil aviation unsafe events, between 2009 and the first half of 2011, there were 485 accident proneness and 10041 unsafe events in China civil aviation, including 94 cases caused by runway safety problems. Studies have shown that every 20 percent increase in air traffic is likely to increase the risk of runway incursions by 140 percent [1]. Runway incursion will undoubtedly pose a threat to aviation security in the world, along with the increasingly growth of China air traffic volume, in order to avoid and control the occurrence of such unsafe events, it is of great significance to effectively analyze the risk of runway incursion, to increase the prevention of human error, to enhance the safety assurance ability of air traffic management.

At present, the foreign research results show that the faults of pilots, controllers and drivers are the main factors causing runway incursion. Domestic scholars have also explored the problems of runway incursion and the risk assessment and forewarning management of airport traffic safety. Yang Gao [2] used the Bowtie model to analyze the security risk of airport and analyze the organizational factors that influence airport security risk taking the example of runway incursion. Wei-jun Pan [3] put forward improvement classification and identification and prevention method of human factors combined with human factor analysis, classification system and human error analysis. Xiang Hui [4] established indicator system of airport security risk assessment based on SHEL model. Yang Gao [5] established an airport risk assessment model based on Meta-analysis theory. At present, many domestic researches on the problem of the runway incursion learn from foreign research results, lack of research based on the Chinese airport actual operation data, and the conclusions conform to the overseas operation but exists certain differences with domestic actual situation. Therefore, this paper will analyze the security risks of Chinese runway incursion based on the actual operation data of some domestic airports. Because the runway incursion unsafe events affected by many factors, there is a certain difficulty to analyze the influence degree of various factors on the runway incursion events, and the Bayesian network is a kind of uncertainty causality model can be used to deal with uncertainty problem, and can effectively express and merge multi-source information, thus this paper will use the Bayesian network to analyze the security risk of runway incursion.
Construction of Bayesian Network Model

Construction of SHELL Model

Combining SHELL model and the Reason model into SHELL model \(^6\) can analyze the causes of accidents more comprehensively and also has practical significance for accident prevention and control. The SHELL model is shown in figure 1. The main risk factors of the live ware (L) are ability, restriction and rule, such as perception, cognition, information processing, form awareness, judgment and decision, etc. The risk factors between live ware and software (L-S) include inspection list, flight manual, flight procedure, computer program, information procedure, rules and regulations, etc. The risk factors between live ware and hardware (L-H) mainly refer to whether the human-computer interface meets user needs, including display equipment and communication facilities, etc. The risk factors between live ware and environment (L-E) include environmental color, spatial size, noise, temperature, humidity, air pressure and light, etc. The risk factors between live ware and live ware (L-L) are the most complex and most critical, it involves the content such as communication and team cooperation, including the communication between pilots and pilots, pilots and aircrews, pilots and controllers, controllers and controllers and so on. The risk factors between live ware and organization (L-O) include corporate culture, policy, induction training and education, etc.

![Figure 1. SHELL model.](image)

Construction of Bayesian Network

In view of the runway incursion incidents, according to SHELL model, we start from live ware, software, hardware, environment, controllers and organization respectively, and analyze its influencing factors, and establish a Bayesian network model by using GeNIe, the structure as shown in figure 2.

![Figure 2. Bayesian network structure of runway incursion.](image)

Process of Probability Calculation

General process of solving Bayesian network model is firstly select prior probability of the parent node, and then calculate the posterior probability of sub-nodes, we usually adopt objective methods
to select prior probability of factors that supported by actual data, such as L, L-S, L-H, L-L, and use subjective methods to determine the prior probability of a L-E and L-O.

**Objective Prior Probability of Parent Node**

Firstly determine the objective prior probability of parent node like A1, A2. Because runway incursion unsafe events caused by L, L-S, L-H and L-L are supported by historical data, the probability of occurrence and prior probability of these nodes are calculated through data statistics.

**Subjective Prior Probability of the Parent Node**

Because of the available data of L-E, L-O is limited, the strong uncertainty and it is not easy to use numerical representation, it should be represented through semantic variable evaluated by experts [7], and confirm the probability by solving the ambiguity.

Through semantic variable [7], the probability of occurrence of event is divided into: very high (VH), high (H), fewer high (FH), medium (M), fewer low (FL), low (L) and very low (VL), and the form of fuzzy number and λ - cut sets are shown in table 1. Taking into account multiple experts’ judgments of one factor can give a more accurate probability. The probability calculation formula is

\[
P_{Ai} = \frac{\sum_{j=1}^{n} f_{ij}}{n} \quad i = 1,2 \ldots m.
\]

Where \( P_{Ai} \) represents the fuzzy probability of \( Ai \); \( f_{ij} \) represents the fuzzy value given by the expert \( j \) for the thing \( i \); \( n \) means the number of experts; \( m \) is the number of events.

Solving the ambiguity by choosing value which can represent fuzzy set, the feasibility and the degree of difficulty are considered, and the integral method [8] is chosen. Assuming that \( P_{Ai} \) is an L-R fuzzy number, the formula for solving fuzzy values is

\[
I(P_{Ai}) = (1 - \delta) I_R(P_{Ai}) + \delta I_L(P_{Ai}).
\]

\[
I_R(P_{Ai}) = \frac{1}{2} \left[ \sum_{\lambda = 0.1}^{\lambda = 0.9} \lambda R(P_{Ai}) \Delta \lambda + \sum_{\lambda = 0}^{\lambda = 0.9} \lambda R(P_{Ai}) \Delta \lambda \right].
\]

\[
I_L(P_{Ai}) = \frac{1}{2} \left[ \sum_{\lambda = 0.1}^{\lambda = 0.9} \lambda L(P_{Ai}) \Delta \lambda + \sum_{\lambda = 0}^{\lambda = 0.9} \lambda L(P_{Ai}) \Delta \lambda \right].
\]

Where \( I(P_{Ai}) \) represents the ambiguity value of fuzzy number \( P_{Ai} \), \( \delta \in [0, 1] \) represents the optimistic coefficient, which is used to reflect the opinion of the decision-makers, and \( \delta = 0.5 \) in this paper. \( I_R(P_{Ai}) \) represents the integral value of the inverse function of the fuzzy number right membership function; \( I_L(P_{Ai}) \) represents the integral value of the inverse function of the fuzzy number left membership function; \( \lambda R(P_{Ai}) \) represents the upper bound of the fuzzy number; \( \lambda L(P_{Ai}) \) represents the lower bound of fuzzy numbers; \( \lambda = 0, 0.1, 0.2 \ldots 1 \); \( \Delta \lambda = 0.1 \).

<table>
<thead>
<tr>
<th>Fuzzy language</th>
<th>Fuzzy number form</th>
<th>( \lambda )-cut set</th>
</tr>
</thead>
<tbody>
<tr>
<td>VL</td>
<td>( f_{VL} = (0, 0.1, 0.2) )</td>
<td>( f^UL = [0, -0.1\lambda + 0.2] )</td>
</tr>
<tr>
<td>L</td>
<td>( f_L = (0.1, 0.2, 0.3) )</td>
<td>( f^UL = [0.1\lambda + 0.1, -0.1\lambda + 0.3] )</td>
</tr>
<tr>
<td>FL</td>
<td>( f_{FL} = (0.2, 0.3, 0.4, 0.5) )</td>
<td>( f^UL = [0.1\lambda + 0.2, -0.1\lambda + 0.5] )</td>
</tr>
<tr>
<td>M</td>
<td>( f_M = (0.4, 0.5, 0.6) )</td>
<td>( f^UL = [0.1\lambda + 0.4, -0.1\lambda + 0.6] )</td>
</tr>
<tr>
<td>FH</td>
<td>( f_{FH} = (0.5, 0.6, 0.7, 0.8) )</td>
<td>( f^UL = [0.1\lambda + 0.5, -0.1\lambda + 0.8] )</td>
</tr>
<tr>
<td>H</td>
<td>( f_H = (0.7, 0.8, 0.9) )</td>
<td>( f^UL = [0.1\lambda + 0.7, -0.1\lambda + 0.9] )</td>
</tr>
<tr>
<td>VH</td>
<td>( f_{VH} = (0.8, 0.9, 1, 1) )</td>
<td>( f^UL = [0.1\lambda + 0.8, 1] )</td>
</tr>
</tbody>
</table>

**The Prior Probability of Sub-node**

We usually use the expert meeting method [9] to get the prior probability of sub-nodes, namely the prior probability of L, L-S, L-H, L-E, L-L, L-O. Respectively let several related field experts to analyze the factors that affecting sub-nodes as well as the parent nodes, and respectively give the probability affected by nodes and sub-nodes, and finally draw the conclusion of several experts to get the prior probability of sub-nodes.
Data Calculation

Objective Prior Probability of the Factors of Runway Incursion

Data in this paper are from the China civil aviation unsafe events statistical analysis, and the runway incursion data are these civil airport data that occurring two or more runway incursion accidents during 2009 to the first half of 2011, and look up total take-off and landing flights of corresponding years and airports through the national airport production statistics bulletin to calculate the probability of occurrence of L, L-S, L-H, L-L, and the result of nine airports total take-off and landing flights is 3792874. The calculation results of probability occurrence of unsafe accidents are shown in table 2.

Table 2. L, L-S, L-H, L-L probability of occurrence of an unsafe event.

<table>
<thead>
<tr>
<th>Node</th>
<th>Reason analysis</th>
<th>Number</th>
<th>Probability/$10^{-6}$</th>
<th>Prior probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>A1 Plane slowed down from the runway or controller commands the plane to fly again</td>
<td>8</td>
<td>0.211</td>
<td>0.421</td>
</tr>
<tr>
<td></td>
<td>A2 Aircrews’ error</td>
<td>8</td>
<td>0.211</td>
<td>0.421</td>
</tr>
<tr>
<td></td>
<td>A3 Air control</td>
<td>2</td>
<td>0.053</td>
<td>0.105</td>
</tr>
<tr>
<td></td>
<td>A4 Controllers forget flight dynamics</td>
<td>1</td>
<td>0.026</td>
<td>0.053</td>
</tr>
<tr>
<td>L-S</td>
<td>A5 Runway occupied by cars or foreign matter</td>
<td>4</td>
<td>0.105</td>
<td>0.333</td>
</tr>
<tr>
<td></td>
<td>A6 Animals enter the runway</td>
<td>4</td>
<td>0.105</td>
<td>0.333</td>
</tr>
<tr>
<td></td>
<td>A7 Poorly coordination of civil and military airport</td>
<td>2</td>
<td>0.053</td>
<td>0.167</td>
</tr>
<tr>
<td></td>
<td>A8 Runway examination</td>
<td>1</td>
<td>0.026</td>
<td>0.083</td>
</tr>
<tr>
<td></td>
<td>A9 People into runway disorderly</td>
<td>1</td>
<td>0.026</td>
<td>0.083</td>
</tr>
<tr>
<td>L-H</td>
<td>A10 Mechanical breakdown</td>
<td>3</td>
<td>0.079</td>
<td>0.750</td>
</tr>
<tr>
<td></td>
<td>A11 Landing gear failure</td>
<td>1</td>
<td>0.026</td>
<td>0.250</td>
</tr>
<tr>
<td>L-L</td>
<td>A12 Communication barriers</td>
<td>1</td>
<td>0.026</td>
<td>0.500</td>
</tr>
<tr>
<td></td>
<td>A13 Others</td>
<td>1</td>
<td>0.026</td>
<td>0.500</td>
</tr>
</tbody>
</table>

Subjective Prior Probability of the Factors of Runway Incursion

Choosing four experts to assess the factors of nodes L-E and L-O, assuming that the weight of each expert is consistent, the following will take A14: unreasonable composition of airport as an example, using arithmetic method to calculate the probability of occurrence of A14, and calculation of other factors are the same. The judgement of A14 assessed by experts is {L, VL, VL, L}, plug it into the formula, there is $P_{A14} = [0.05\times 0.5 + 0.12 \times 0.25]$, $I(P_{A14}) = 0.1375$, and the prior probability of A14 is 0.1375. Similarly, the judgement of A15: poor weather conditions assessed by experts is {VL, L, L, L}, $I(P_{A15}) = 0.16875$; the evaluation of A16: ground obstruction is {VL, VL, L, VL}, $I(P_{A16}) = 0.1175$; the evaluation of A17: indifference of enterprise safety culture is {L, L, L, L}, $I(P_{A17}) = 0.2$; the evaluation of A18: imperfect education training is {VL, L, VL, L}, $I(P_{A18}) = 0.1375$; the evaluation of A19: poor wage policy is {FL, L, VL, L}, $I(P_{A19}) = 0.20625$.

The Prior Probability of Sub-nodes of Runway Incursion

The prior probability of each parent node is obtained by the above calculation, consulting 8 relevant experts’ advice and considering that the weight of each expert is consistent, the following results are obtained by calculating the average probability given by 8 experts.

1. When A1 or A4 occurs, the probability of occurrence of L is 0.8, when A2 or A3 occurs, the probability of occurrence of L is 0.5;
2. When A5 or A6 occurs, the probability of occurrence of L-S is 0.8, when A7 occurs, the probability of occurrence of L-S is 0.5, when A8 occurs, the probability of occurrence of L-S is 0.6, and when A9 occurs, the probability of occurrence of L-S is 0.7;
3. When A10 or A11 occurs, the probability of occurrence of L-H is 0.6;
4. When A12 occurs, the probability of occurrence of L-L is 0.7, when A13 occurs, the probability of occurrence of L-L is 0.4;
(5) When A14 or A16 occurs, the probability of occurrence of L-E is 0.3, when A15 occurs, the probability of occurrence of L-E is 0.5;
(6) When A17 or A18 occurs, the probability of occurrence of L-O is 0.3, when A19 occurs, the probability of occurrence of L-O is 0.2;
(7) When L-S occurs, the probability of occurrence of runway incursion is 0.9, when L occurs, the probability of occurrence of runway incursion is 0.7, when L-H occurs, the probability of occurrence of runway incursion is 0.6, when L-L occurs, the probability of occurrence of runway incursion is 0.5, when L-E occurs, the probability of occurrence of runway incursion is 0.4, when L-O occurs, the probability of occurrence of runway incursion is 0.3.

Results Analysis
This article uses GeNIe2.0 to calculate the Bayesian network, its visual operation is simple, the interface is friendly, and there is no need to program, and it is easy to use. The detailed operation process is as follows.
Firstly, Bayesian network is constructed, and then the prior probability of each node is input to the software, and after updating the result, the probability of occurrence of runway incursion is 75.9%. On the other hand, when the value of the node of runway incursion is set to "yes", the probability of each node that influence runway incursion can be received through working backward, and the result is shown in figure 3.

![Figure 3. Probability of each node affected occurrence of runway incursion.](image)

According to the calculation results, the main factor influencing runway incursion is L-S and the probability is 66%, and then the L-H with the probability of 58%, and L-L with a probability of 54%. According to the calculation results, the main order of the factors that influencing runway incursion is L - S > L - H > L - L > L - E > L - O, in order to improve unsafe accidents, measurements can be carried out in the order of A5-A6-A7-A8-A9.

Conclusions
In this paper, we obtain the main factor node L-S that influence runway incursion which calculated by using actual operation data of China civil aviation, namely the runway accidentally occupied, animal or people into runway disorderly, and poorly coordination of civil and military airport are the main factors influencing runway incursion, the results accord with the actual operation of China civil aviation. At the same time, the primary and secondary relation of factors of Chinese runway incursion and the order of taking measures are given. In conclusion, there is a difference between the factors influencing runway incursion in China and European civil aviation, there is a practical significance in objectively understanding the Chinese runway incursion.
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References


