International Symposium on Safety Science and Engineering in China, 2012 (ISSSE-2012)

Airport Safety Risk Evaluation Based on Modification of Quantitative Safety Management Model

Lu Xianfeng\textsuperscript{a,b,*}, Huang Shengguo\textsuperscript{a}

\textsuperscript{a}College of Civil Aviation, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China
\textsuperscript{b}China Academy of Civil Aviation Science and Technology, Beijing 100028, China

Abstract

When management factor is used for parallel modeling together with other factors, it is too difficult to assess its overall influence on risk situation exactly because of its diffuse influence. To solve this problem, airport safety risk evaluation based on modification of quantitative safety management model is brought forward. Airport safety risk evaluation indicator system is established in the model, and fuzzy comprehensive evaluation theory is applied in preliminary assessment. Airport safety management elements are isolated, and performance score and maximum effect are applied in modeling and quantifying safety management. Result of the model is used to modify outcome of evaluation model and its application example is given at last. This method utilizes information of evaluation indicators and management elements effectively and appraises airport safety situation reasonably.

Keywords: Safety risk, Safety management, Fuzzy comprehensive evaluation, Performance score, Modification factor

Nomenclature

\begin{itemize}
\item $m$: comment rate
\item $n$: number of evaluation indicators
\item $A$: number of accidents
\item $B$: evaluation results
\item $ME_i$: maximum effect of element $i$
\item $MF$: modification factor
\item $PS$: performance score
\item $R$: membership grade set composed by membership grade of each indicator for each comment
\item $U$: evaluation set of indicator for the evaluation comment sets of object
\item $V$: risk value
\item $V'$: preliminary risk value
\item $W$: weight set composed by each indicator weight
\end{itemize}

* LU Xian-feng. Tel.: 86-10-64473528 ; fax: 86-10-64473589 .
E-mail address: luxf@mail.castc.org.cn

© 2012 Published by Elsevier Ltd. Selection and/or peer-review under responsibility of the Capital University of Economics and Business, China Academy of Safety Science and Technology. Open access under CC BY-NC-ND license.
1. Introduction

Safe operation of an airport is an important part of aviation safety. A lot of research on airport safety assessment had been carried out, such as the third party risk assessment and management of airport [1], risk assessment modeling combined with the fuzzy linguistic scale and failure risk assessment [2], scoring method [3] to score on airport-related indicators, research on safety and disaster early warning management for civil aviation airport [4-5] using system and forewarning theory, airport risk assessment [6-7] by using grey clustering method combined with the analytic hierarchy process, quantitative analysis of runway incursion risk [8] based on human reliability, early warning model [9] of airport safety based on extension theory, etc. After evaluation indicators were extracted by analyzing a number of significant accidents and safety occurrences, comprehensive evaluation method is used to get the risk value in most of these studies. Since influence on risk is indirect and obscure, safety management factors are grouped into safety indicators class directly or classified as indicators of non-management class with accident types caused by these factors. This method is called ‘general airport safety risk assessment’ in this paper. The corresponding model structure of risk evaluation is shown in Figure 1(a). It is difficult to model safety management and apply in quantifying risk assessment. In this case, an airport safety management model is established through the study of modeling methods, and the value of general airport safety risk assessment is modified by the quantitative result of the management model. Correlation between management indicators and other indicators is separated by using improved evaluation model, highlighting influence of various safety management elements on airport overall safety, and information of evaluation indicators and safety management elements is effectively utilized. Model structure of airport safety risk evaluation based on modification of quantitative safety management model is shown in Figure 1(b). Finally, examples illustrate the application of the model.

2. Structure of airport safety risk evaluation model

2.1. Structure of general airport safety risk evaluation model

Structure of general airport safety risk evaluation model is shown in Figure 1(a). In general, after analyzing evaluation object, indicator system is established consisting of human factors, equipment factors, environment factors and management factors, and then various methods are integrated to evaluate object to get evaluation results.

Fig. 1. Illustration of different structures for (a) general risk evaluation model and (b) risk evaluation model based on modification of quantitative safety management model.

2.2. Structure of airport safety risk evaluation model based on modification of quantitative safety management model

Besides direct human or technical errors, safety management factors or their influence are always found in analyzing civil aviation safety occurrences. Finally, reasons that lead to safety occurrences can be attributed to management issues. Management factors are common and deep level causes of various safety occurrences. In this case, safety management
model is established based on a common set of management factors, which improves the general risk evaluation model to systematically describe various aspects of safety management and reflect common reasons of management. The result of general improved risk assessment model is corrected by a modification factor, which is outputted from safety management model and highlights the impact of the safety management on airport risk. Consequently, airport safety risk evaluation model structure based on modification of quantitative safety management model is gotten, shown in Figure 1(b). The modified airport risk $V$ is expressed as:

$$V = V' \times MF$$  \hspace{1cm} (1)

3. Evaluation model of airport safety risk

3.1. Evaluation indicator system

After counting and analyzing safety occurrences in civil airports of China, referring to indicator systems established in other studies, consulting the experts suggestion, and combining with safety audit data from Civil Aviation Administration of China, indicator system is established consisting of three first level indicators, which are human factors, facility and equipment factors and environment factors. Because of the divergence of influence of management factors and the correlation with other indicators, a modification factor outputted from management model represents the role of these factors. Indicator system of civil airport safety risk is shown in Table 1.

<table>
<thead>
<tr>
<th>Indicator set</th>
<th>Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human factors</td>
<td>Ability, Safety conscious, Team work</td>
</tr>
<tr>
<td>Facility and equipment factors</td>
<td>Airfield pavement condition, Soil ground condition of strips, Fencing/patrol road condition, Apron condition, Condition of lights aiding for navigation, Electrical power supply system condition, Oil supply system condition, De-icing system condition</td>
</tr>
<tr>
<td>Environment factors</td>
<td>Flight volume condition, Atmosphere condition, Airport geographic environment condition</td>
</tr>
</tbody>
</table>

3.2. Mathematical model of evaluation

Fuzzy comprehensive evaluation [10] model is taken as the basic method of airport safety assessment:

$U = \{U_1(\text{very poor}), U_2(\text{poor}), U_3(\text{fair}), U_4(\text{good}), U_5(\text{very good})\}$

$R = \{0.0(\text{very poor}), 0.2(\text{poor}), 0.5(\text{fair}), 0.8(\text{good}), 1.0(\text{very good})\}$

$B = (B_1, B_2, B_3, B_4, B_5) = W \cdot R = (w_1, w_2, \ldots, w_n) \cdot \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ \vdots & \vdots & \cdots & \vdots \\ \cdots & \cdots & \cdots & \cdots \\ w_n & \cdots & \cdots & r_{nn} \end{bmatrix}$ \hspace{1cm} (2)

Where:
\( B_i (i=1, 2, \ldots, m) \) represents membership grade of evaluation results for comment \( U_i \)

\[ W = [w_1, w_2, \ldots, w_n] \], \( w_1, w_2, \ldots, w_n \) represent each indicator weight

\( r_{11}^{ij}, r_{12}^{ij}, \ldots, r_{mn}^{ij} \) represent membership grade of each indicator relative to each comment

3.2.1. Determination of evaluation indicator weight set

Expert investigation method and analytic hierarchy process are integrated to determine weight of each evaluation indicator in the model. First, judgment matrix to describe the relative importance between factors is constructed through the pairwise comparison among factors. The rate scale of 1 to 9 is taken to measure difference of relative importance. Judgment matrix is constructed according to relationship between different indicator and different class of indicator in Table 1. Inquiry form is spread to get the value of each element of different layer, then layer sorted by single-criteria and consistency check, and weight set of second layer indicators for airport safety risk evaluation relative to evaluation objective is gotten at last:

\[ W = [0.216, 0.216, 0.216, 0.032, 0.032, 0.032, 0.032, 0.032, 0.032, 0.058, 0.019, 0.019]. \]

3.2.2. Evaluation indicator set of each element

According to conversion criterion of observation value of indicators and evaluation element set established by Delphi method, membership set composed by membership grade of each indicator relative to each comment is gotten.

\[
\bar{R} = \begin{bmatrix}
0.2 & 0.8 & 0 & 0 & 0 \\
0 & 0.4 & 0.6 & 0 & 0 \\
0 & 0.5 & 0.5 & 0 & 0 \\
0 & 0 & 0.137 & 0.863 & 0 \\
0 & 0 & 0 & 0.33 & 0.67 \\
0 & 0 & 0.333 & 0.667 & 0 \\
0 & 0 & 0.99 & 0.01 & 0 \\
0 & 0 & 0 & 0.956 & 0.004 \\
0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0.46 & 0.54 \\
0 & 0 & 0.465 & 0.535 & 0 \\
0 & 0 & 0 & 0.86 & 0.14 \\
0 & 0 & 0.78 & 0.22 & 0 \\
0 & 0 & 0.35 & 0.65 & 0
\end{bmatrix}
\]

Membership \( r_{ij} \) represents comment rate.

3.3. Preliminary result of airport safety risk evaluation

The preliminary result \( B \) of airport safety evaluation is gotten by (2).

\[ B = [0.043, 0.382, 0.31, 0.185, 0.079]. \] Integrated value of preliminary evaluation \( V' \) is 73.675 by parameter characterization method.

3.4. Safety management model

3.4.1. Model structure

Modeling of safety management has been studied [11-12] and most studies are limited to the selection of indicators. Referring to recommendations of safety management system [13] that is promoted globally by International Civil Aviation Organization, safety management is divided into 12 elements (Table 2). They work together to produce the effect of safety management on safety risk.
3.4.2. Quantification of safety management model

3.4.2.1. Performance of each element

One of the elements of performance score used in the study ranges from 0-100, the scale is as follows:
- $PS=0$ represents a hypothetical absence of activity in the area.
- $PS=40$ represents a more realistic minimum safety performance level that complies the requirement of regulation.
- $PS=70$ represents an average performance of civil airport safety management in China in 2011.
- $PS=100$ represents perfect performance by 2011 standards.

Perfect performance means that no further reduction in failure events could be achieved by improvements in performance. Assuming that safety policy and objectives are perfect by present standards, incidents of collision between vehicles and aircrafts would occur in the safety management model described above. It will come true in the future that perfect performance may be above 100 by present standards, due to the enhancement of civil aviation safety management standard. Then, it is expected that the scale would be redefined. The scale is arbitrary, but is based on safety management auditing [14] practice.

3.4.2.2. Maximum effect

The effect of safety management elements is difficult to predict, as there is lack of quantitative data. The effect is mainly based on judgment, whose scope is generally decided by unsafe occurrences and accidents data, and thus the expected maximum effect of any element is identified:

$$ME_i = \frac{1}{A} \sum_{k=1}^{A} PI_{ik}$$  \hspace{1cm} (3)

Where $PI_{ik}$ is probability that element $i$ could have prevented accident $k$. For simplicity, $PI_{ik}$ is taken as 1 where it is judged that the element prevented the accident, or 0 that it did not.

3.4.2.3. Effect

The effect of each influence is defined at two points:
- Average performance, where $PS=70$ and $MF=1$.
- Perfect performance, where $PS=100$, and $MF=1-ME$. This is the maximum modification factor, denoted as $MMF$.

In order to make consistent predictions for intermediate values and for $PS$ less than 70, a log-linear relationship is assumed (Figure 2) as:
This can invert any given modification factor to a performance score:

$$PS_i = 70 + 30 \frac{\log MF_i}{\log(1 - ME_i)}$$  \hspace{1cm} (5)

The value of $ME_i$ is constrained up to 0.95 in order to prevent instability of this function.

### 3.4.2.4. Modification factors of safety management

The maximum effect of each safety management element is obtained from historical data. Performance scores are allocated by the experts. These are then converted to modification factors using the relationship in Figure 2. The modification factors are combined as follows:

$$MF = \prod_{E=1}^{12} MF_E$$  \hspace{1cm} (6)

Where, $MF_E$ represents modification factor for element E.

### 4. Result and analysis

One medium-sized airport in China in 2011 is taken as an example, performance scores and the maximum effect of each element is shown in Table 3.

Modification factor is gotten by (4) and (6), then value of safety risk evaluation is gotten by (1):

$$V = V' \times MF = 73.675 \times 1.092 = 80.4583.$$  

$MF > 1$ represents that there are problems in airport safety management, which increased the risk value of airport, and the overall risk level is high.

### 5. Conclusion

In this paper, a general airport safety management model is established, and a method of model quantification based on performance and maximum effect of safety management elements is studied. Airport safety risk evaluation model based on
modification of quantitative safety management model is established, which value is the preliminary result of risk comprehensive model modified by quantification result of management model. Interdependence of management indicators and other indicators in general evaluation model is separated, which highlights influence of various elements of safety management on airport overall safety and utilizes information of evaluation indicator and safety management effectively. Application of the model helps to accurately comprehend main problems in civil aviation safety management and reasonably evaluate risk source and safety risk level of civil airports.

<table>
<thead>
<tr>
<th>Safety management</th>
<th>Element</th>
<th>Score</th>
<th>Maximum effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety policy</td>
<td>Safety policy</td>
<td>75</td>
<td>60%</td>
</tr>
<tr>
<td></td>
<td>Safety objectives</td>
<td>58</td>
<td>70%</td>
</tr>
<tr>
<td>Safety policy and objectives</td>
<td>Organization and responsibility</td>
<td>71</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>Emergency response</td>
<td>75</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>Documentation management</td>
<td>68</td>
<td>40%</td>
</tr>
<tr>
<td>Risk management</td>
<td>Hazard identification</td>
<td>73</td>
<td>46%</td>
</tr>
<tr>
<td></td>
<td>Safety risk assessment and control</td>
<td>78</td>
<td>76%</td>
</tr>
<tr>
<td>Safety assurance</td>
<td>Safety information management</td>
<td>71</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>Safety occurrence investigation</td>
<td>68</td>
<td>43%</td>
</tr>
<tr>
<td></td>
<td>Safety supervision and audit</td>
<td>75</td>
<td>56%</td>
</tr>
<tr>
<td>Safety promotion</td>
<td>Training and education</td>
<td>75</td>
<td>32%</td>
</tr>
<tr>
<td></td>
<td>Safety communication</td>
<td>65</td>
<td>45%</td>
</tr>
</tbody>
</table>

Acknowledgements

The authors appreciate the help in discussion and the suggestion from co-workers of China Academy of Civil Aviation Science and Technology (CAST). Special thanks go to Sun Hao for expert technical assistance of the modeling effort.

References