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Fuzzy-ANP based Research on the Risk Assessment of Runway Excursion

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Abstract Runway excurision accident is the fourth largest type of aviation accident. How to implement risk assessment on it is a necessary issue which need to be studied. In the analysis of the principle of triangular fuzzy mathematics and ANP, establish the risk assessment model. Then an application example in an airport is givened. The results showed that the main factors affect the safety of runway excursion are airline operation and management of unreasonable, inadequate crew training and runway management is not sufficient etc. The airport unit should focus on improving these factors. The analysis conclusion indicates that Fuzzy-ANP helps determine the focus of risk assessment.

Keywords Runway Excursion; Triangular Fuzzy Number; ANP; Risk Assessment; SHELL

1 Introduction and risk identified

The global aviation accident data collected by IATA indicates that 591 business aviation aircraft accidents happened during the year 2004 to 2009. And the highest frequency accident type is runway excursion, taking about 27 percentages of all the aircraft accidents. Among the 161 runway excursion accidents, which are the fourth largest global aviation accidents, there are 19 fatal accidents, resulting in 480 people's death. Thus it's necessary to implement risk assessment on runway excursion.

Recently, the common method of risk assessment in the aviation is AHP, which can resolve the complex problems in quantity effectively. However, there are two disadvantages on AHP. Firstly, the method can't exactly reflect the fuzzy and the determination between factors. Secondly, basing on the assume of independence of all the factors in the same hierarchy, it just considers the support and affect to the next hierarchy.

By fully considering the dependence, affection and support of all the factors, Analytic Network Process establishes the net structure to analysis the relationship between factors, effectively resolving the AHP problems. To express the indexes' fuzzy and indetermination, this paper will introduce the triangular fuzzy mathematics to ANP to analysis the risk of runway excursion.

On the basic of SHELL model, the risk of runway excursion can be identified.

The aspects of politics and economy restrict the operation of aviation system, including physics and basic facilities' sufficiency, self-financial condition, the efficiency of management, etc. Most of airlines can control the rough edge of the boundary. According to SHELL model drawing 1, human factor locates at the centre place. We must make the relationship between the centres human and other factors in the model clear to reduce the human pressure. To avoid potential accident, human factor must closely integrate with other parts.The risk factor set of runway excursion is established as table 1.

TABLE 1. The Risk Factor Set of Runway Excursion

factor group	risk factors
L factor(u_1)	poor risk consciousness u_{11}
	poor flight skill of takeoff and descent u_{12}
	decision error of takeoff and descent u_{13}
	disobey SOP's u_{14}
	apperceive error of state and trency u_{15}
L-L factor(u_2)	CRM u_{21}
	dispatcher's calculation error of the loading balance u_{22}
	weather centre doesn't provide information betimes and accurately u_{23}
	airport doesn't provide runway information betimes and accurately u_{24}
	ATC suggestion and statement are not correct or insufficient u_{25}
L-S factor(u_3)	airlines' unreasonable operation management u_{31}
	insufficient airscrew train u_{32}
	unsteady descent discipline u_{33}
	the authority doesn't establish proper runway report standard and system u_{34}
	insufficient runway management u_{35}
L-H factor(u_4)	engineer fault u_{41}
	tyre failureu_{42}
	flap spoiler fault u_{43}
	locking system fault u_{44}

	elevator equipment fault u_{45}
L-E factor(u_5)	badly weather condition u_{51}
	contaminative runway u_{52}
	unreasonable runway design u_{53}
	poor runway visibility u_{54}
	fail to forecast rain and snow u_{55}

2 Runway Excursion Risk Assessment Model Basing on F-ANP

Fuzzy-ANP method is the integration of fuzzy mathematic theory and ANP. The risk assessment steps of Fuzzy-ANP as follows.

1.Establish the risk assessment factors set.

2.Combine the distinguish feather of targeting risk factors, establish ANP framework.

3.Establish the compare matrix and importance matrix of the risk factors group.

4.Establish the compare matrix and importance matrix of the risk factors.

5.ANP super matrix calculation.

6.Sequence the relative importance of risk factors.

According to the existing risk factors set, risk factors group and risk factors are separately taken as control hierarchy and net hierarchy. Considering the relationship of all the risk factors[10-12], the F-ANP framework of runway excursion is established finally. As show in the Figure1 .

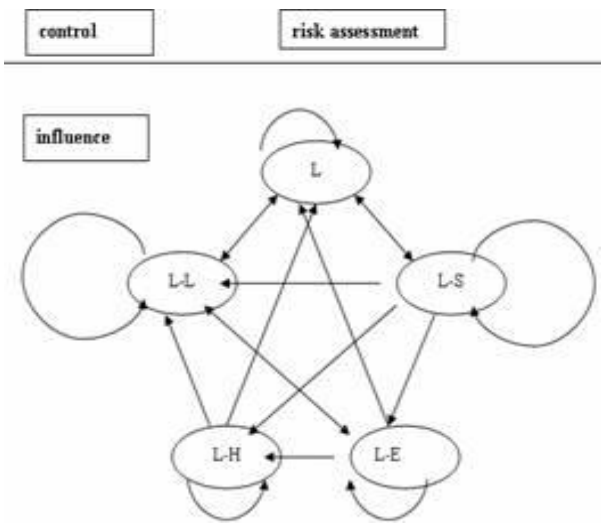

Figure1. ANP framework of runway excursion risk factors

Table 2 shows the influence relationship between risk factors. “1” represents the influence relationship between factor in the line and factor in the row. ”0” represents no influence relationship.

Table 2. the influence relationshipbetween runway excursion risk factors

	u_{11}	u_{12}	u_{13}	u_{14}	u_{15}	u_{21}	u_{22}	u_{23}	u_{24}	u_{25}	u_{31}	u_{32}	u_{33}	u_{34}	u_{35}	u_{41}	u_{42}	u_{43}	u_{44}	u_{45}	u_{51}	u_{52}	u_{53}	u_{54}	u_{55}
u_{11}	1	1	1	1	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
u_{12}	1	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
u_{13}	1	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
u_{14}	1	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
u_{15}	1	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
u_{21}	1	1	1	1		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
u_{22}	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
u_{23}	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1
u_{24}	1	1	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
u_{25}	1	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
u_{31}	1	1	1	1	1	1	1	0	0	0	1	0	1	0	0	1	1	1	1	1	0	0	0	0	0
u_{32}	1	1	1	1	1	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
u_{33}	1	1	1	1	1	1	0	0	0	1	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0
u_{34}	1	1	1	1	1	1	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	1	0	1	0
u_{35}	0	1	1	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	1	1	0	0
u_{41}	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0
u_{42}	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0
u_{43}	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
u_{44}	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
u_{45}	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
u_{51}	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
u_{52}	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1	0	0
u_{53}	1	1	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0

u_{54}	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
u_{55}	1	1	1	1	1	1	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0

3 Example Analysis

According to the ANP framework above, this paper takes an airport for example and applies the method of F-ANP to assess the safety risk of runway excursion.

3.1 Establish the Importance Matrix of Risk Factors Group

Some experts make comparison for the risk factors of runway excursion. Using triangular fuzzy mathematics as decision standard, this paper evaluates from 0.1 to 0.9. By assessing the risk factors, it establishes the comparison matrix.

By assessing risk factor u1(human factor), the comparison matrixes of risk factors group are established as table 3.

Table3. the comparison matrix basing on the level u1

Human factor base level	u_1	u_2	u_3	u_4	u_5
u_1	(0.5 0.5 0.5)	(0.2 0.3 0.4)	(0.1 0.2 0.4)	(0.2 0.3 0.4)	(0.3 0.3 0.4)
u_2	(0.6 0.7 0.8)	(0.5 0.5 0.5)	(0.4 0.5 0.5)	(0.5 0.5 0.6)	(0.5 0.6 0.6)
u_3	(0.6 0.8 0.9)	(0.5 0.5 0.6)	(0.5 0.5 0.5)	(0.5 0.6 0.7)	(0.6 0.7 0.7)
u_4	(0.6 0.7 0.8)	(0.4 0.5 0.5)	(0.3 0.4 0.5)	(0.5 0.5 0.5)	(0.5 0.6 0.7)
u_5	(0.6 0.7 0.7)	(0.4 0.4 0.5)	(0.3 0.3 0.4)	(0.3 0.4 0.5)	(0.5 0.5 0.5)

Applying the formula

$$S_i = \sum_{j=1}^{m} M_{E_i}^{j} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{E_i}^{j}\right]^{-1} \quad (1)$$

can calculate the importance value between the risk factors groups: S_{12}=（0.042,0.063,0.168）.

Similarly, the other four values are as follows.

S_{11}=（0.073,0.166,0.346） ,

S_{13}=(0.215,0.398,0.553),

S_{14}=(0.110,0.242,0.502),

S_{15}=(0.043,0.057,0.185）

According to formula

$$V(M \ge M_1, M_2, M_3, \ldots M_k) = \min_{i=1,2,3,\ldots k} V(M \ge M_i) \quad (2)$$

$$P'(A_i) = \min V(M_i \ge M_k) \quad (3)$$

$$W' = (p'(A_1), p'(A_2), \ldots\ldots, p'(A_n))^T \quad (4)$$

$$W = (p(A_1), p(A_2), \ldots\ldots, p(A_n))^T \quad (5)$$

The importance values between each other factors groups are as follows.

$V(S_{12} \geqq S_{11})=0.271$ $V(S_{12} \geqq S_{13})=0.531$

$V(S_{12} \geqq S_{14})=0.369$ $V(S_{12} \geqq S_{15})=0.467$

$P'(S_{12})=\min V(S_{12} \geqq S_{11}, S_{13}, S_{14}, S_{15})=0.271$

That is:

$A'_M=(0.291,0.271,0.233,0.142, 0.192)$,

After normalization,

$A_1=(0.258,0.240,0.206,0.126,0.170)$

Through caculating the other base assessment level, A_2, A_3, A_4 and A_5 can be obtained. After integrating, the importance matrix is as follows.

$$A=\begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{pmatrix}=\begin{pmatrix} 0.258 & 0.240 & 0.438 & 0.000 & 0.000 \\ 0.240 & 0.162 & 0.000 & 0.000 & 0.333 \\ 0.206 & 0.272 & 0.562 & 0.333 & 0.400 \\ 0.126 & 0.132 & 0.000 & 0.394 & 0.000 \\ 0.170 & 0.194 & 0.000 & 0.273 & 0.266 \end{pmatrix}$$

3.2 Establish the Importance Matrix of Risk Factors

The method of risk factors importance matrix calculation is the same as the above section. For example, by assessing the base level of u_{11}, u_{12}, u_{13}, u_{14} and u_{15}, the importance vectors W_{11}, W_{12}, W_{13}, W_{14} and W_{15} of u_1 can be drawn. Furthermore, the importance matrix of u1 can be integrated as W'_{11}. Similarly, we can obtain the other importance matrixes. Integrating all the importance matrixes of risk factors as follows can obtain a super matrix[13-14].

$$W=\begin{pmatrix} W_{11} & W_{12} & W_{13} & W_{14} & W_{15} \\ W_{21} & W_{22} & W_{23} & W_{24} & W_{25} \\ W_{31} & W_{32} & W_{33} & W_{34} & W_{35} \\ W_{41} & W_{42} & W_{43} & W_{44} & W_{45} \\ W_{51} & W_{52} & W_{53} & W_{54} & W_{55} \end{pmatrix}$$

3.3 Super Matrix Arithmetic

Firstly, multiply the importance matrix and super matrix of risk factors $W_{ij}=A_{ij}W_{ij}$, and calculate the super weighting matrix. The result is

$$\overline{W}=A\cdot W=\begin{pmatrix} a_{11}W_{11} & a_{12}W_{12} & a_{13}W_{13} & a_{14}W_{14} & a_{15}W_{15} \\ a_{21}W_{21} & a_{22}W_{22} & a_{23}W_{23} & a_{24}W_{24} & a_{25}W_{25} \\ a_{31}W_{31} & a_{32}W_{32} & a_{33}W_{33} & a_{34}W_{34} & a_{35}W_{35} \\ a_{41}W_{41} & a_{42}W_{42} & a_{43}W_{43} & a_{44}W_{44} & a_{45}W_{45} \\ a_{51}W_{51} & a_{52}W_{52} & a_{53}W_{53} & a_{54}W_{54} & a_{55}W_{55} \end{pmatrix}$$

Then get n to limit $\overline{W'_{ij}}=\lim_{n\to\infty}(\overline{W_{ij}})$, obtain a steady matrix and a fixed value, that is: $\overline{W}^{\infty}$.$\overline{W}^{\infty}$= (0.0183 0.0222 0.0341 0.0217 0.0159 0.0530 0.0479 0.0703 0.0315 0.0498 0.0918 0.0817 0.0565 0.0601 0.0807 0.0264 0.0167 0.0108 0.0128

0.0182 0.0303 0.0346 0.0231 0.0204 0.0357）^{T}

Then,we can get the importance vector of runway excursion risk factors as before.

3.4 Result Analysis

Through assessing the risk of runway excursion, we can determinate the total importance sequence of risk factors, and find out that runway excursion is greatly influenced by L-S factor and L-L factor. Among L-S factors, insufficient airscrew train and insufficient runway management are especially serious, which are the major factors influence runway excursion. Then it's the inaccurate weather forecast of L-L factors. Contaminative runway and failing to forecast rain and snow of L-E factors are also important.

Single L factor has less influence on runway excursion than other factors. Although human error had been considered the most important factor of aviation safety, organization factors are the real safety cause in the new SMS. In order to deal with safety problems of the aviation, we should set hands to improve the software factor, such as organization factor, regulation system, SOP's, etc. the result of this paper about controlling the key risk factors correspond the modern safety management thought. To reduce the risk of runway excursion and improve the safety level we must start from organization factor, regulation system, SOP's.

4 Conclusion

1）Applying the SHELL model can identify the risk factors of runway excursion and classify the risk of L-L factors, L-S factors, L-H factors and L-E factors. Furthermore, establish the risk factors sets of runway excursion.

2）To improve the accuracy and objectivity, the paper establishes the comparison set by experts' decision data.

3）Basing on the characters of influence relationship, indetermination and fuzzy of risk factors of runway excursion, the paper chooses fuzzy net analysis method to analyze factor importance and to assess the risk of runway excursion.

Finally, gain the important sequence of factors after evaluating each factor's importance. The result shows that the most important influence factor of runway excursion is human-software factor.

Table4. Super Weighting Matrix of Risk Factors

=

0.195	0.192	0.205	0.196	0.197	0.195	0.000	0.000	0.000	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.130	0.156	0.133	0.139	0.128	0.130	0.000	0.000	0.000	0.130	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.371	0.345	0.370	0.378	0.372	0.371	0.000	0.000	0.000	0.369	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.130	0.127	0.124	0.115	0.130	0.130	0.000	0.000	0.000	0.129	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.173	0.181	0.169	0.171	0.172	0.173	0.000	0.000	0.000	0.172	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.195	0.195	0.197	0.197	0.194	0.200	0.240	0.268	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.438	0.000	0.000	0.000	0.438
0.144	0.164	0.163	0.162	0.162	0.175	0.162	0.129	0.150	0.333	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.361	0.330	0.328	0.329	0.331	0.323	0.272	0.499	0.363	0.400	0.400	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.562	0.333	0.000	0.000	0.562
0.130	0.129	0.129	0.130	0.130	0.123	0.132	0.000	0.217	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.394	0.000	0.000	0.000
0.169	0.183	0.182	0.182	0.183	0.180	0.194	0.103	0.270	0.266	0.266	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.273	0.000	0.000	0.000
0.232	0.181	0.207	0.202	0.208	0.242	0.258	0.000	0.000	0.317	0.258	0.317	0.357	0.000	0.000	0.258	0.258	0.258	0.258	0.258	0.285	0.000	0.000	0.000	0.000
0.116	0.163	0.140	0.147	0.136	0.125	0.240	0.000	0.150	0.099	0.240	0.099	0.108	0.000	0.183	0.240	0.240	0.240	0.240	0.240	0.117	0.150	0.333	0.000	0.000
0.325	0.330	0.344	0.345	0.359	0.319	0.206	0.000	0.363	0.385	0.206	0.385	0.402	0.333	0.370	0.206	0.206	0.206	0.206	0.206	0.505	0.363	0.400	0.000	0.000
0.162	0.135	0.134	0.131	0.127	0.149	0.126	0.000	0.217	0.081	0.126	0.081	0.057	0.394	0.177	0.126	0.126	0.126	0.126	0.126	0.000	0.217	0.000	0.000	0.000
0.165	0.190	0.174	0.175	0.170	0.165	0.170	0.000	0.270	0.119	0.170	0.119	0.077	0.273	0.269	0.170	0.170	0.170	0.170	0.170	0.093	0.270	0.266	0.000	0.000
0.000	0.175	0.182	0.181	0.182	0.182	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.258	0.247	0.438	0.146	0.096	0.000	0.000	0.000	0.000	0.000
0.000	0.155	0.151	0.151	0.153	0.153	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.240	0.193	0.000	0.121	0.265	0.000	0.000	0.000	0.000	0.000
0.000	0.343	0.347	0.346	0.340	0.340	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.206	0.246	0.562	0.275	0.349	0.000	0.000	0.000	0.000	0.000
0.000	0.138	0.136	0.137	0.139	0.139	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.126	0.130	0.000	0.240	0.053	0.000	0.000	0.000	0.000	0.000
0.000	0.189	0.184	0.185	0.186	0.186	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.170	0.184	0.000	0.219	0.237	0.000	0.000	0.000	0.000	0.000
0.204	0.193	0.178	0.175	0.177	0.186	0.000	0.092	0.141	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.240	0.000	0.132	0.000	0.258	0.187	0.341	0.000	0.000
0.156	0.165	0.161	0.160	0.159	0.152	0.000	0.219	0.232	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.162	0.000	0.239	0.000	0.240	0.041	0.079	0.200	0.000
0.360	0.347	0.345	0.346	0.344	0.353	0.000	0.315	0.325	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.272	0.000	0.330	0.000	0.206	0.383	0.420	0.373	0.000
0.108	0.114	0.128	0.130	0.131	0.127	0.000	0.141	0.078	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.132	0.000	0.073	0.000	0.126	0.214	0.064	0.158	0.000
0.172	0.181	0.189	0.190	0.189	0.182	0.000	0.234	0.224	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.194	0.000	0.226	0.000	0.170	0.174	0.095	0.269	0.000

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