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Automated Early Warning for Atm Safety Risks Based on Fuzzy Reasoning

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Abstract: The establishment of an automated risk early warning mechanism closely linked to the air traffic flow management system and information management system plays a positive role in ATM risk management. In this study, a fuzzy reasoning-based approach was proposed to effectively extract the key ATM risk factors for establishing a rapid early warning mechanism. The fuzzy IF-THEN rules were used to build up a fuzzy rule base on the base of experts' knowledge and then through a multi-input fuzzy logic, the different kinds of the unsafe models were ranked. Finally, an extraction of key attributes for ATM safety risks early warning was realized. The result is that the most important attribute is weather conditions, followed by controller's ability in handling large flows and the influences from military activities rank in the third place. The use of this approach is an exploration in the intelligent warning technology for ATM safety risks.

Key words: Information technology, safety early warning, fuzzy reasoning, ATM, feature extraction

INTRODUCTION

ATM risk factors are the most fundamental elements and units triggering ATM accidents and incidents. A single risk factor usually does not result in system failure but the interaction and mutual enhancement of multiple risk factors may give rise to system malfunction (Luo *et al.*, 2009) and (Yang and Luo, 2012). The risk sources of ATM unsafe events are a dynamic changing process. In order to effectively identify and evaluate ATM risk factors and establish a rapid early warning mechanism, the level of automation and processing capability must be improved to increase the accuracy and timeliness of risk prediction. Therefore, the establishment of an automated and intelligent risk early warning mechanism closely linked to the air traffic flow management system and information management system will play a positive role in ATM risk management.

Scholars in China and abroad have studied assessment of ATM safety risks mainly from the theoretical and methodological perspective (Li, 2011; Du *et al.*, 2010; Yuan *et al.*, 2006; Brooker, 2006). All the above scholars mainly use static analysis methods which are difficult to capture the dynamic changes of risks and do not do a good job in analyzing different consequences of the risks brought about by changes in risk factors along with time.

This study proposes studying assessment of ATM safety risks by fuzzy reasoning. Expert's experiential knowledge will be utilized and fuzzy reasoning theories will be applied to reflect the influences of dynamic risk

factors and the issue of early warning for ATM risks will be investigated from an automated and intelligent perspective to increase the response speed of earning warning for ATM risks and realize dynamic intelligent early warning.

ANALYSIS OF EARLY WARNING INDICATORS FOR ATM SAFETY RISKS

SHELL Model which was first proposed by Elwyn Edwards in 1972, can help describe the mutual relationships between various factors of the aviation system. It consists of liveware, hardware, software and environment. The International Civil Aviation Organization (ICAO) also recommends this method for analysis of ATM safety risks. In terms of establishment of the indicator system, Jia (2008) proceeds from the four aspects of general ATM system which includes such sub-systems as communications, navigation, meteorology, ATC and information. However, his study fails to take the detectability of the early warning for safety risks when selecting the indicators. For example, among the personnel indicators, "lack of emergence response ability of personnel" and "lack of sense of responsibility of personnel" are very difficult to detect. In order to realize automated and intelligent early warning, key indicators should be selected based on Jia, G.J.'s work and a dynamic risk assessment indicator system should be formulated by taking the detectability of indicators into comprehensive consideration.

Table 1: Initially extracted ATM safety risk assessment indicator system

	Level-1	Level-2	No.
ATM safety risk assessment indicator system oriented to real-time monitoring	Personnel	Controller's ability in handling large flows	F1
	Equipment	Rate of malfunction of current equipment	F2
	Environment	Weather conditions during operation	F3
		Influences from military activities	F4
	Management	Information communication between different departments	F5
		Job satisfaction	F6

Table 2: Fuzzy semantic description of ATM safety risk assessment indicators

No.	Risk indicator	Severity	Rate
F1	Controller's poor abilities in handling large flows	Very high	Medium
F2	High malfunction rate of current equipment	Very high	Low
F3	Poor weather conditions during operation	High	High
F4	Great influences from military activities	Medium	Medium
F5	Poor information communication between various departments	High	Medium
F6	Low job satisfaction	High	Low

Finally, the factors for assessing ATM safety risks in China are shown in Table 1.

EXTRACTING STATE FEATURE PARAMETERS THROUGH FUZZY REASONING METHOD

Fuzzy semantic description of risk indicators: The basic steps used in fuzzy reasoning are illustrated in Fig.1. In the figure, the Severity and Rate of risk indicators may be seen as the input variables for the fuzzy control system.

Define the variable of x and $T(x) = \{\text{Severity, Rate}\}$. Language set $T(x)$ is the word set of x and $T(x) = \{\text{very low, low, medium, high, very high}\}$. Then, the fuzzy language of $T(x)$ is used to describe the ATM safety risk assessment indicator variable x .

The above fuzzy language is used to describe the indicators of F1 to F6 to obtain the fuzzy semantic description of the indicators, as shown in Table 2.

Establishing membership function for indicators: Prof. Zadeh (1965) defined fuzzy set as fuzzy sub-set A in domain U and A is a set represented by membership function μ_A . The mapping:

$$\mu_A: U \rightarrow [0, 1]$$

In the domain U , A is a fuzzy sub-set and μ_A is the membership function of fuzzy sub-set A . $\mu_A(x)$ is the grade of membership of x to A and represents the grade of membership of x in domain U to fuzzy sub-set A . $\mu_A(x)$ is a continuous value in the closed interval $[0,1]$. $\mu_A(x) = 1$ means that x totally belongs to A while $\mu_A(x) = 0$ means that x does not belong to A at all. When $0 < \mu_A(x) < 1$, the value of $\mu_A(x)$ represents the degree of the grade of membership of x to A .

The input for the fuzzy rule base established in this study includes the two conditions of risk Severity and

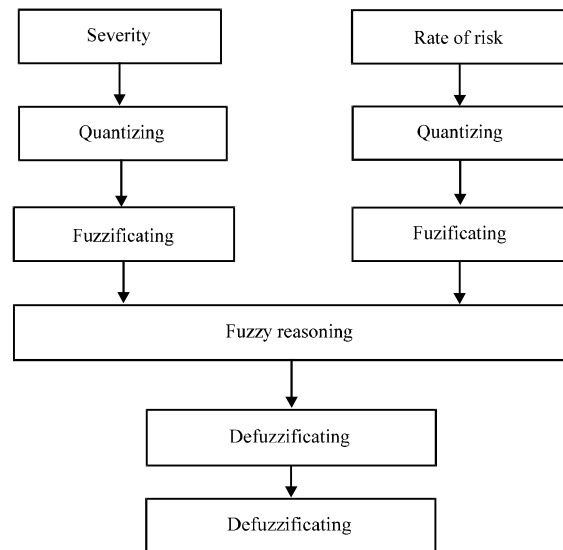


Fig. 1: ATM safety risks fuzzy logic flow

Rate. The output is a semantic variable Risk Assessment, abbreviated as "RA" which is also described as "Very Low (VL), Low (L), Medium (M), High (H) and very high (VH)". Both input variables (Severity and Rate) and output variable (RA) are described by 5 fuzzy words and assume that the domains for Severity, Rate and RA are all $[1, 2, 3, 4, 5]$. Y-axis represents the range of membership grade of fuzzy assessment which is $[0, 1]$. The value "1" means total belonging, the value "0" means not belonging and the value between 0 and 1 means partial belonging. As distribution of the fuzzy probability is relatively uniform, triangular membership grade curve is used and judging from the overall effect between input variables and output variable in Fig. 2, the system surface constructed from the input and output variables is smooth and meet the design requirements.

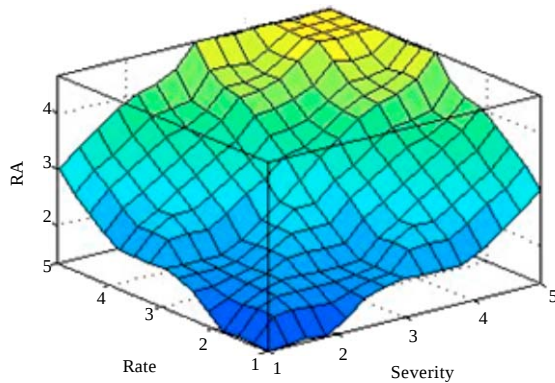


Fig. 2: Overall effect between the input and output variables

Table 3: Risk assessment fuzzy rule base

Rate RA severity	VL	L	M	H	VH
VL	VL	VL	L	L	M
L	VL	L	L	M	H
M	L	L	M	H	VH
H	L	M	H	VH	VH
VH	M	H	VH	VH	VH

Establishing fuzzy rule base: The fuzzy rule base is established by knowledge expression of expert experience and comprehensive analysis and assessment of risk levels produced by different combinations. During the study, order relation analysis method (Guo, 2007) is used to determine the fuzzy rule base. According to this book, the appropriate number of experts is 10 to 30. Therefore, 30 copies of expert questionnaire were sent out and 25 copies were retrieved. Expert feedback suggestions tend to become stable at about 23 people and major fluctuations no longer occur in rule formulation. The complete rule base with 25 results is shown in Table 3.

Fuzzy reasoning and solution and defuzzification:

Assume A is a fuzzy set on X and B is a fuzzy set on Y. The fuzzy relation is “if A, then B”, expressed as $A \rightarrow B$. Multi-input fuzzy reasoning is often applied in the design of multi-input single-output systems.

It is known that the major premise of reasoning is “IF A and B, THEN C”. Assume $A \in F(x)$, $B \in F(y)$, $C \in F(z)$. Then the implicative relation is:

$$R = A \times B \times C = (A \times B) \rightarrow C$$

or:

$$R(x, y, z) = A(x) \wedge B(y) \wedge C(z)$$

When the input minor premise “IF A’ and B” is known, then C’ may be deduced:

$$\begin{aligned} C' &= (A' \cap B') \circ [(A \cap B) \rightarrow C] \\ &= [A' \circ (A \rightarrow C)] \cap [B' \circ (B \rightarrow C)] \end{aligned}$$

In light of multi-input variables, MAX/MIN is used for fuzzy reasoning. Consider the following form of fuzzy reasoning: Rule 1: A_1 and $B_1 \rightarrow C_1$, Rule 2: A_2 and $B_2 \rightarrow C_2, \dots$, Rule n: A_n and $B_n \rightarrow C_n$. Premise: x_0 and y_0 . Conclusion: C' . From the premise “ x_0 and y_0 ” and various fuzzy rules A_i and $B_i \rightarrow C_i$ ($i = 1, \dots, n$), the membership grade of C_i which is the result of reasoning by Rule i, is:

$$\mu_{C_i}(z) = \mu_{A_i}(x_0) \wedge \mu_{B_i}(y_0) \wedge \mu_{C_i}(z) \quad (1)$$

The membership grade of the final result C' is:

$$\mu_{C'}(z) = \mu_{C_1}(z) \vee \mu_{C_2}(z) \vee \dots \vee \mu_{C_n}(z) \quad (2)$$

Defuzzification by center-of-gravity method means conversion of language value of output language variable into a single value, i.e. “center of gravity”. The “center of gravity” of fuzzy set C is calculated by (3):

$$z_0 = \frac{\sum_{i=1}^m \mu_{C'}(z_i) \cdot z_i}{\sum_{i=1}^m \mu_{C'}(z_i)} \quad (3)$$

in which z_i is the maximum value of each language variable and z_0 is the overall output value.

The values for controller’s ability in handling large flows, equipment malfunction rate and frequency of military activities are obtained from civil aviation statistical data. These values are normalized with 5 as the full score to obtain the relative assessment values. The quantitative values for information communication between different departments, job satisfaction and weather conditions during operation are obtained by means of questionnaire survey and weighted average calculation. Then the values are converted into relative assessment values with 5 as the full score. Finally, the Severity and Rate of various risk modes are assessed and valued, as shown in Table 4.

Calculate the value of RA by fuzzy reasoning and defuzzification calculation method of this study. Finally, RA values are ranked in terms of their degree of importance, as shown in Table 5.

As can be clearly seen from the ranking of risks in Table 5, the most important state feature parameter in ATM safety risk assessment is weather conditions during operation, followed by controller’s ability in handling

Table 4: Assignment summary table

No.	Risk	Severity	Rate
F1	Controller's ability in handling large flows	4.8	2.7
F2	Rate of malfunction of current equipment	4.8	1.6
F3	Weather conditions during operation	4.0	3.8
F4	Influences from military activities	3.4	3.4
F5	Information communication between different departments	3.8	2.6
F6	Job satisfaction	3.8	2.4

Table 5: Ranking of ATM safety risks

No.	Risk	Severity	Rate	RA	Rank
F1	Controller's ability in handling large flows	VH	M	4.42	2
F2	Rate of malfunction of current equipment	VH	L	3.33	4
F3	Weather conditions during operation	H	H	4.80	1
F4	Influences from military activities	M	M	3.40	3
F5	Information communication between different departments	H	M	3.33	4
F6	Job satisfaction	H	L	3.17	5

large flows and the influences from military activities rank in the third place. Therefore, in daily operations, efforts should be made to strengthen real-time monitoring of weather conditions and make the necessary preparations for adverse weather. Controllers should improve their control abilities under large flows. The military should advise civil aviation units in advance in case of conflicts between military and civil aviation and civil aviation units should formulate contingency plans beforehand so as to mitigate the influences from military aviation. The other factors should also be given due consideration while focusing on these key indicators.

CONCLUSION

The study summarizes the major risk factors affecting ATM safety and optimizes the ATM safety risk assessment indicator system for the purpose of early warning.

This study carries out comprehensive assessment of ATM operation state by fuzzy reasoning and extracts the state feature parameters for ATM safety risk assessment.

In the future, more investigations will be carried out to determine the warning threshold value and efforts will be made to deepen the analysis of early warning for risks.

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REFERENCES

- Brooker, P., 2006. Air traffic management accident risk. Part 2: Repairing the deficiencies of ESARR4. *Safety Sci.*, 44: 629-655.
- Du, H.B., H. Li, L.P. Yuan and X. Li, 2010. Risk assessment model for air traffic control based on fuzzy-ANP method. *China Safety Sci. J.*, 12: 79-85.
- Guo, Y.J., 2007. *Comprehensive Evaluation Theory, Method and Application*. 1st Edn., Science Press, Beijing, ISBN: 9787030187963.
- Jia, G.J., 2008. Study on the system and comprehensive evaluation of safety risk assessment indexes for the ATM. Master's Thesis, Wuhan University of Technology, Wuhan.
- Li, H.Y., 2011. Evaluation of safety risk in ATM based on the gray relational analysis. *Sci. Technol. Eng.*, 11: 7584-7587.
- Luo, F., G.J. Jia, G.M. Chen and F.H. Zhou, 2009. Design and optimization of index system for the ATC safety risk management. *China Safety Sci. J.*, 8: 115-122.
- Yang, Z. and F. Luo, 2012. Optimization of air traffic safety risk early warning index based on rough sets. *J. Wuhan Univ. Technol. (Inform. Manage. Eng.)*, 34: 776-780.
- Yuan, L., R. Sun and Y. Cheng, 2006. Fuzzy evaluation and unascertained mathematics based safety risk assessment in ATM system. *J. Civil Aviation Univ. China*, 24: 55-57.
- Zadeh, L.A., 1965. Fuzzy sets. *Inform. Control*, 8: 338-353.