Research on Operation Safety Evaluation for Terminal Area Airspace System Based on Set Pair Analysis Method

Qian Wang[1,a], Pingni Liu[2,b], Runze Guo[2,c], Xiangwei Meng[2,d]

[1]Xijing College, Xi'an, Shaanxi, 710123, China

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

[a]gxsh15934896556@qq.com, [b]liupingni0101@126.com, [c]guorenze55@163.com, [d]mengxw11@163.com

Keywords: Terminal Area, Airspace System, Set Pair Analysis, Operation Safety, Contact Degree

Abstract: Concerning the situation that the operation safety evaluation has a lot of uncertainties and dynamics for terminal area airspace system, Set Pair Analysis (SPA) is introduced to use in dynamic evaluation of airspace safety. In the method, firstly, on the basis of system analysis, the operation safety evaluation index system for terminal area airspace system is established from four aspects: human, equipment, environment and management. Then based on this the relationship degree of SPA was adopted to represent the uncertainty knowledge, and the relationship degree value was used to divide the operation safety level of terminal area airspace system. The example shows that, the established model can accurately portray the dynamic change characteristics of operation safety for terminal area airspace system.

1. Terminal area airspace system operation safety evaluation index system

With the rapid development of civil aviation, airspace safety is becoming more and more important.As a necessary part of the controlled airspace, the safety of terminal area airspace is also paid special attention to.Therefore, it is of great theoretical and practical significance to deeply analyze and evaluate the operating safety of the terminal area airspace system.

The terminal control area is mainly used to connect the airport tower control area and the regional control area, and its control interaction. The terminal area generally refers to the space that is within 50~100km from the central airport, or within the control handover point, with the height below 6000m (including) and above the lowest flight level (including), except the control area of the airport tower. The terminal area usually covers one or more busy airports, with large aircraft flow, more airspace restrictions and complex approach control work, resulting in great uncertainty of each subsystem involved in the safe operation of the terminal area airspace system.

To construct an evaluation index system reflecting the actual operation safety of the terminal area airspace system, it is necessary to follow scientific, rational and systematic design principles, master relevant regulations, standards and guidance policies, investigate relevant practice attempts at home and abroad, imitate the latest achievements of accident causation theory, system safety theory and man-machine engineering theory, and understand the operating characteristics of the terminal area airspace system [1]. The terminal area airspace system operation safety evaluation index system is constructed as shown in Fig. 1.

  DOI: 10.25236/isaiee.2020.002

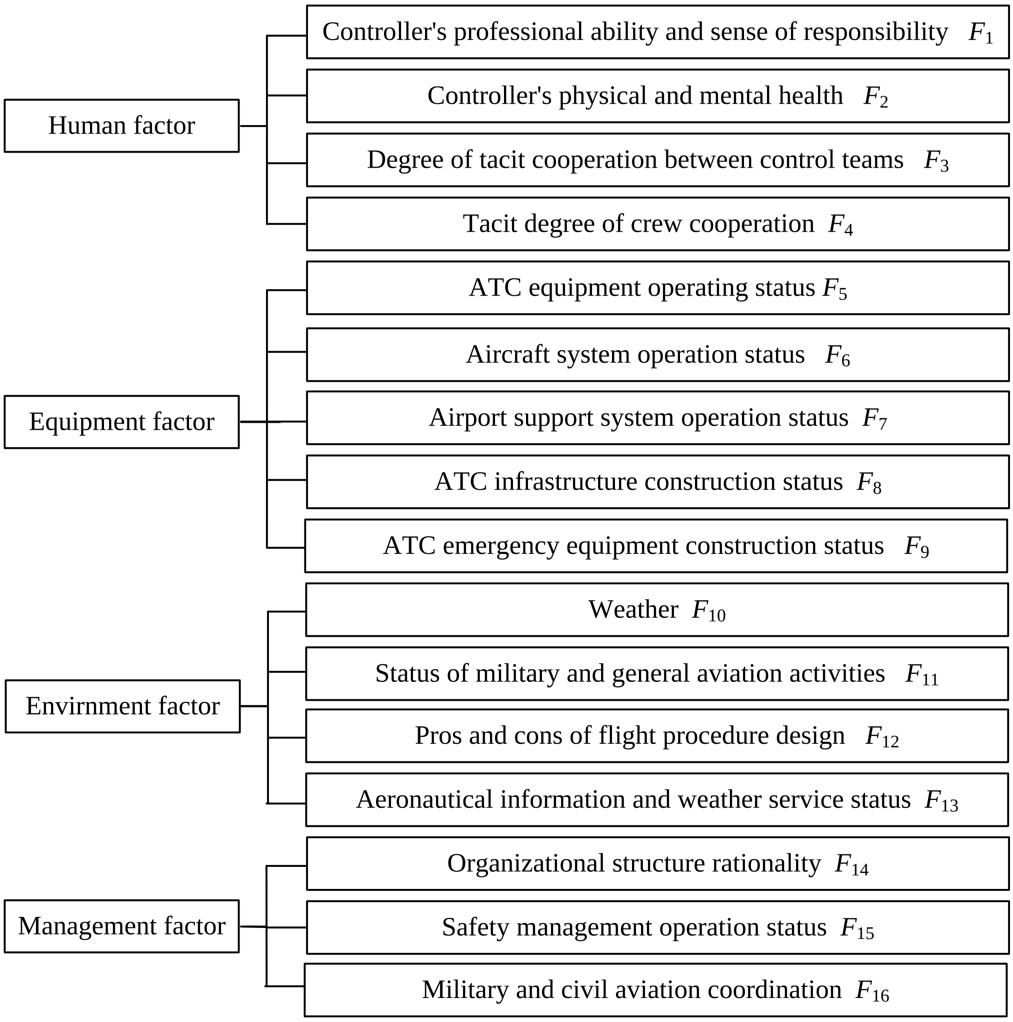

Fig. 1 Terminal area airspace system operation safety evaluation index system

2. Set Pair Analysis Model

Set Pair Analysis (SPA) is a system Analysis method, which can effectively deal with the uncertainty problems caused by ambiguity, gray, randomness and lack of information[2]. Basic idea: Firstly, for the uncertain system, two interrelated sets are formed into set pairs. Then, analyze the identity, difference and opposition of the set pairs. Finally, the same, different and inverse relation degree of set pair is constructed[3][4].

For the unresolved issues, SPA will set and construct a set pair H. $H = (A, B)$. Set pair H has N properties. Among them, S features are shared by set A and B, which is referred to as ‘common‘; P properties are opposite to set A and set B, abbreviated as ‘inverse‘;The $F = N - P - S$ characteristics are neither opposite to set A and set B, nor common, which is referred to as "different". The contact degree μ can be expressed as

$$\mu = a + bi + cj \tag{1}$$

Among them, $a = S / N$ is called the same degree of the set A and B; $b = F / N$ is called the difference degree between set A and set B; $c = P / N$ is called the degree of opposition between set A and B, and $a + b + c = 1$; i represents the difference degree coefficient, which is evaluated in the interval [1, -1]. j is the degree of opposition coefficient, which can be -1.

When SPA is used to evaluate the operation safety of the airspace system in the terminal area, evaluation index system A and safety state level B should be taken as A safety evaluation set pair $H = (A, B)$. Airspace safety state can be divided into three grades: safety (S), basic safety (G) and unsafe

(U). Then, the index weight is introduced to describe the connection degree of the terminal airspace system operation safety evaluation.

From the static perspective, for the evaluation set pair H = (A, B), the connection degree of the terminal area airspace system operation safety evaluation can be described as follows

$$\mu_{A\sim B} = a + bi + cj = \sum_{k=1}^{s} w_k + \sum_{k=s+1}^{s+g} w_k i + \sum_{k=s+g+1}^{s+g+u} w_k j \tag{2}$$

where S represents the number of indexes whose safety level is S, G represents the number of indexes whose safety level is G, and U represents the number of indexes whose safety level is U and $s + g + u = 16$. w_k represents the index weight.

It is found that the operating safety of the terminal area airspace system is not only real-time and dynamic, but also affected by the uncertainty of various evaluation indexes. Therefore, the static evaluation method for the operation safety of the terminal area airspace system does not take into account the influence of time changes and is not scientific and reasonable. Based on the above analysis, if the operational safety of the terminal area airspace system is dynamically evaluated, its contact degree at time t can be correspondingly modified to

$$\mu_{A\sim B}(t) = a(t) + b(t)i + c(t)j = \sum_{k=1}^{S_t} w_k(t) + \sum_{k=s_t+1}^{s_t+g_t} w_k(t)i + \sum_{k=s_t+g_t+1}^{s_t+g_t+u_t} w_k(t)j \tag{3}$$

In the formula, s_t represents the number of indexes whose safety level is S, g_t represents the number of indexes whose safety level is G, u_t represents the number of indexes whose safety level is U, and $s_t + g_t + u_t = 16$. $w_k(t)$ is the corresponding index weight after reordering at time t, so there is

$$\sum_{k=1}^{s_t} w_k(t) + \sum_{k=s_t+1}^{s_t+g_t} w_k(t) + \sum_{k=s_t+g_t+1}^{s_t+g_t+u_t} w_k(t) = 1 \tag{4}$$

According to the principle of "equipartition", the operating safety state of the terminal area airspace system is divided according to the contact degree value $\mu_{A\sim B}(t)$, as shown in Table 1.

Table 1 Airspace safety status division and its relationship degree value

Safety Status	Unsafe (U)	Basic Safety (G)	Safety (S)
$\mu_{A\sim B}(t)$interval	[-1, -0.33]	[-0.33, 0.33]	[0.33, 1]
Acceptance	Unacceptable	Basically Satisfied	Acceptable
Prevention	Must Adopt	Properly Adopt	No Adoption

In order to deeply illustrate the dynamic changes in the operation safety of the terminal area airspace system, the S, G and U information of the safety evaluation index is sorted to represent the dynamic changes in the operation safety of the terminal area airspace system, as shown in Table 2.When S < U, it is called opposite power; When S = U, it is called balance power; When S > U, it is called equal power. According to its dynamic change trend, the air traffic control unit can put forward targeted pre-control countermeasures according to the change trend, in order to effectively reduce and avoid the risk that has an impact on the operating safety of the terminal area airspace system.

3. Example Analysis

Taking Shanghai terminal area airspace system as an example to analyze the object. Shanghai terminal Area is one of the busiest terminal control areas in China. Its surrounding airports have a large number of airports, intensive air traffic activities, frequent changes of aircraft altitude, narrow space for flight maneuver, and complex air route structure, as shown in Fig. 2. These characteristics add a lot of uncertainty to the safe operation of the airspace system, and make it more time-sensitive and dynamic. The example is to establish the safety evaluation model of the airspace based on the constructed safety evaluation index system to evaluate the safety status of the airspace. In combination with the actual situation of airspace security, relevant safety data information of each period from January to June in 2016 is collected in the form of questionnaire survey and interview, as shown in Table 3.

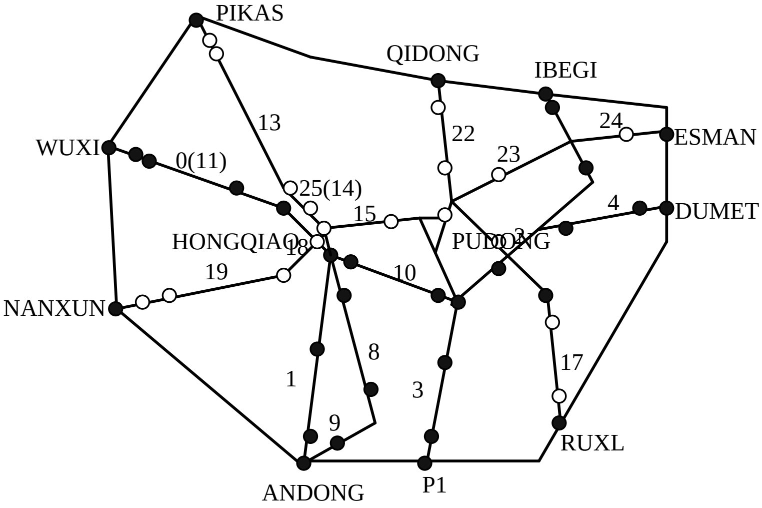

Fig. 2 Air route segment diagram in Shanghai terminal area airspace

Table 3 Evaluation index data of airspace safety

Index Code	Weight w_i	Period					
		1	2	3	4	5	6
F_1	0.175	S	S	U	G	S	G
F_2	0.085	G	S	S	S	U	S
F_3	0.032	S	U	G	S	G	G
F_4	0.029	S	S	S	U	S	U
F_5	0.026	U	G	U	G	U	S
F_6	0.034	G	S	G	S	G	S
F_7	0.024	S	U	S	S	G	G
F_8	0.119	U	G	G	U	S	S
F_9	0.136	G	G	S	G	G	U
F_{10}	0.028	S	S	U	S	S	U
F_{11}	0.123	G	G	U	S	S	U
F_{12}	0.078	U	U	G	U	G	S
F_{13}	0.013	U	S	S	G	U	G
F_{14}	0.024	G	U	U	S	U	S
F_{15}	0.030	S	S	G	S	G	G
F_{16}	0.044	S	U	S	U	S	S

Through processing the index data in Table 3 by Formula (3), the contact degree of the safety assessment of the airspace from January to June can be calculated as follows:

$$\mu_1 = 0.362 + 0.402i + 0.236j$$

$$\mu_2 = 0.394 + 0.404i + 0.202j$$

$$\mu_3 = 0.331 + 0.293i + 0.376j$$

$$\mu_4 = 0.380 + 0.350i + 0.270j$$

$$\mu_5 = 0.518 + 0.334i + 0.148j$$

$$\mu_6 = 0.410 + 0.397i + 0.193j$$

4. Conclusion

The operation safety of terminal area airspace system is a dynamic changing process. Therefore, a combined operation safety evaluation model of terminal area airspace system is proposed based on SPA and Markov chain. In the evaluation, firstly, the system constructs the terminal area airspace system operation safety evaluation index system; Then, the index weight is introduced into SPA and combined with the concept of set pair potential, the security level is divided into the equal power, balance power and opposite power. The analysis of an example shows that the proposed method is simple, easy to operate, and the evaluation results are reliable, which can reflect the actual safety level of the terminal area airspace system.

References

[1] H. F. Jia. Research on factors influencing airspace sector complexity based on DEMATEL method. Aeronautical Computing Technique, 46(4), (2016) 48-51

[2] S. C. Tian, L. Wang, H.X. Li, et al. Application of risk evaluation in coalmine gas hazard based on model of SPA. Journal of Safety and Environment, 6(6), (2006), 103-106.

[3] Y. Gao, X. Z. Wang. Research on assessment and prediction of flight safety situation based on SPA-Markov. Journal of Safety Science and Technology, 12(8), (2016), 87-91

[4] Y. Kang, K. L. Xu, J. X. Liu. SPA-Markov chain model for evaluating and forecasting urban buried gas pipeline risk. China Safety Science Journal, 22(3), (2012), 147-152

Table 2 Dynamic change situation of airspace safety

ID	*S,G,U* relation	Equal,Balance,Opposite Power And Their Reaction	Safety Level
1	$S<U$, $S>G$, $G<U$	Very Strong Opposite Power, Need To Take Safety Measures Urgently	Unsafety
2	$S<U$, $S=G$, $G<U$	Strong Opposite Power, Need To Take Safety Measures Urgently	Unsafety
3	$S<U$, $S<G$, $G<U$	Relatively Weak Opposite Power, Need To Take Safety Measures Urgently	Unsafety
4	$S<U$, $S<G$, $G=U$	Weak Opposite Power, Need To Take Safety Measures Urgently	Unsafety
5	$S<U$, $S<G$, $G>U$	Very Weak Opposite Power, Need To Take Safety Measures Urgently	Unsafety
6	$S=U$, $S>G$, $G<U$	Strong Balance Power, Need To Take Safety Measures	Basic Safety
7	$S=U$, $S=G$, $G=U$	Equal Balance Power, Need To Take Safety Measures	Basic Safety
8	$S=U$, $S<G$, $G>U$	Very Weak Balance Power, Need To Take Safety Measures Urgently	Unsafety
9	$S>U$, $S>G$, $G>U$	Very Strong Equal Power, No Need To Take Safety Measures	Safety
10	$S>U$, $S>G$, $G=U$	Strong Equal Power, No Need To Take Safety Measures	Safety
11	$S>U$, $S>G$, $G<U$	Relatively Strong Equal Power, No Need To Take Safety Measures	Safety
12	$S>U$, $S=G$, $G>U$	Weaken Equal Power, Need To Take Safety Measures	Basic Safety
13	$S>U$, $S<G$, $G>U$	Very Weak Equal Power, Need To Take Safety Measures	Basic Safety