Dynamic Assessment of Airline Safety Risk Based on System Dynamics

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Abstract

Air transportation plays an important role in the transportation system, and it is of great significance to ensure the safety of airlines. Based on the operational status of airlines, the airline's safety risk indicator system is obtained through a systematic analytic hierarchy process. The Analytic Hierarchy Process is used to obtain the risk factor weights at each level. According to the complex feedback relationship of each subsystem in the airline safety risk assessment system, the System Dynamics used to construct the dynamic risk assessment model of airline safety risk. Taking Xinjiang Urumqi Airlines as an example, combined with objective data and expert experience to quantify risk factors, through simulation calculation, Urumqi Airlines' 2018 safety risk is dynamically evaluated. The results show that the model can objectively reflect the dynamic changes of airline safety risks. This study can provide decision-making reference for relevant aviation management departments.

Keywords

AHP, SD, Airline, Dynamic risk, Assessment.

1. Introduction

Air transportation has the characteristics of convenience and efficiency. As people's demand for air transportation continues to increase, airlines have rapidly increased in size and number. Comprehensive safety risk assessment of airlines is the key to ensuring the safety of air transportation. Airlines are affected by many factors such as personnel, equipment, environment, and management in operation. The status of each factor changes dynamically with time, and there are complex interactions between them, which is a typical complex system [1]. By sorting out the risk factors that affect airline safety, looking for the causal mechanism of airline risk events, and conducting a risk assessment of airline safety, it can effectively prevent the occurrence of airline risk events.

Aiming at the main influencing factors leading to the occurrence of airline risk events, Ji et al. [2] combined with the "human-machine-environment-management" theory to establish an airline safety evaluation index system. Zhao et al. [3] established a comprehensive risk assessment index system based on the relevant information of the airline safety evaluation system released by the Civil Aviation Administration of China, taking into account the four factors of "man-machine-environment-management". A systematic analysis method can effectively avoid omissions in the identification of risk factors, and is an effective method to construct a risk factor indicator system.

In the airline risk assessment, Yue et al. [4] conducted a qualitative analysis of the airline's safety management model. Gu et al. [5] pointed out that the factors that affect airline safety are often a combination of qualitative and quantitative, and the use of comprehensive integration empowerment method can achieve the unity of subjective and objective empowerment. Other scholars have used Bayes [2], set pair analysis [3], evidence theory [6] and other methods to evaluate airline safety risks. At present, the risk assessment of airlines is mostly quantitative analysis, and various methods are used to solve the uncertainty analysis in the assessment. However, the operation of airlines is a complex system, and there are complex interactions between the factors that affect their safety risks. System Dynamics (SD) can realize the quantitative analysis of the positive and negative feedback mechanism between the various factors of the system and the dynamic change of the system with time, and has been applied in the risk assessment of the aviation field [7,8].

Based on the above analysis, this article will construct airline safety risk indicator system through systematic analysis method based on the actual situation of airline operation, and use AHP method to determine the weight of risk factor indicators at all levels. On this basis, the interaction mechanism between airline operating subsystems is analyzed, a dynamic SD assessment model of airline safety risks is constructed, and the dynamic changes of airline safety risks under time series are studied.

2. Establishment of indicator system

The safety status of airlines is affected in many ways. A reasonable establishment of a safety risk assessment index system is an important prerequisite for airline safety risk assessment. A systematic analysis method can effectively avoid forgetting situations in the process of identifying risk factors. Therefore, based on the relevant aviation regulations issued by the Civil Aviation Administration of China, the operating rules formulated by airline companies, and inquiries from many experts in the field of civil aviation, based on this, a systematic analysis of the main factors affecting airline safety will affect The factors of airline safety are divided into four major subsystems: "personnel factor", "aircraft condition", "navigation environment" and "safety management". For each subsystem, there are multiple sub-risk factors below it, as shown in Figure 1.

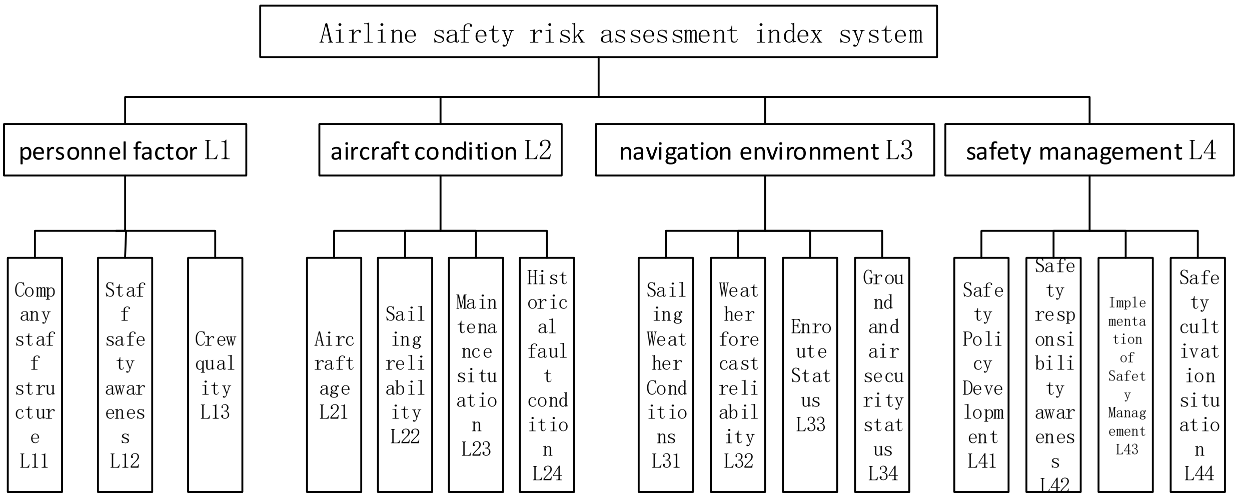

Fig 1 Airline safety risk indicator system

3. SD-based airline safety risk assessment model

3.1 Determine system boundaries

By determining the system boundary, all elements in the system can be included, and at the same time, the system can be ensured to be complete. Therefore, the system boundary of this model is composed of "personal factors", "aircraft conditions", "navigation environment" and "safety management" that cause airline unsafe events, without considering the impact of other factors on airline safety.

3.2 Establishment of dynamic risk assessment model

Airline safety risks are caused by the interaction of many factors. There are complex positive and negative feedback relationships among the four sub-systems of "people factors", "aircraft conditions", "navigation environment" and "safety management", which collectively affect airline safety. People are the most important part of airline safety, and they are the direct cause of unsafe incidents. In the operation of airlines, the professional quality, physical skills, and physiological status of personnel are all different. Aircraft condition is the most critical factor affecting airline safety. The navigation environment subsystem includes the natural environment and the navigation support environment.

Changes in the environment will cause dynamic changes in airline safety risks. The safety management subsystem includes various safety management systems formulated to reduce airline safety risks. In addition, the four subsystems will also interact with each other (such as the navigation environment will affect the condition of the aircraft and then affect the airline safety), and together form the SD model of airline safety risk, as shown in Figure 2.

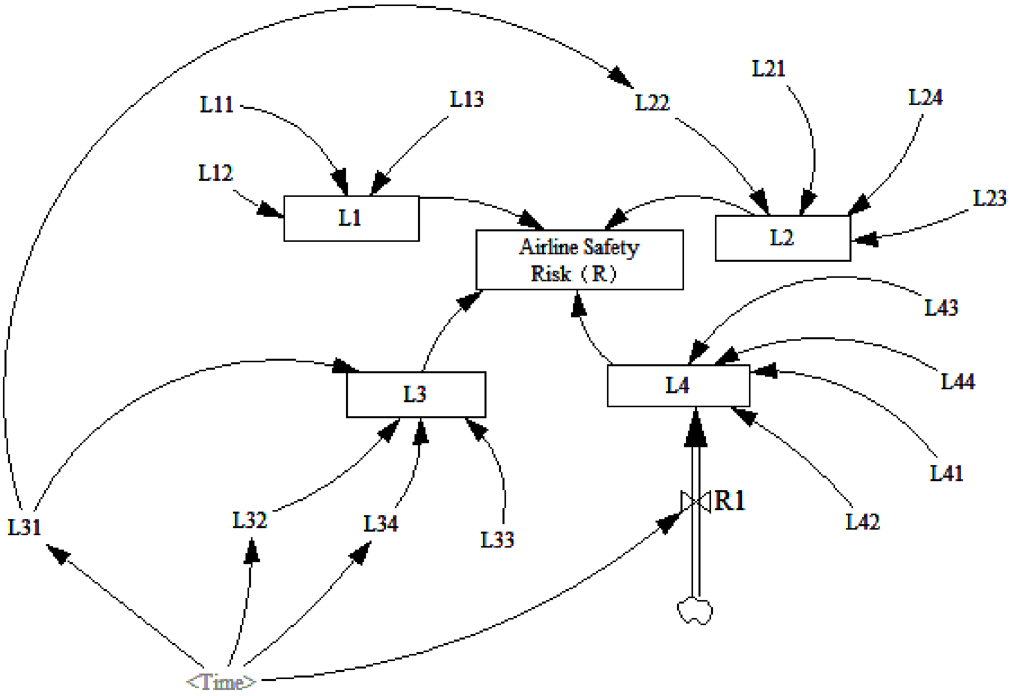

Figure 2 Airline Safety Risk SD Model

3.3 Dynamic equations between factors

In the SD model of airline safety risk, in order to realize the quantitative analysis of risk, it is necessary to determine the system dynamic equations between different factors according to the correlation between the risk factors. Only by entering the corresponding kinetic equations into the SD model can the next quantitative evaluation be performed. The dynamic equation of each factor in the SD model of airline safety risk is shown in Table 1, where λ represents the relationship coefficient between the two factors, C represents a constant, and $\lambda_1+\lambda_2+\lambda_3+\lambda_4=1$.

Table 1 Dynamics equations for airline safety risk factors

$R = \lambda_1 L1 + \lambda_2 L2 + \lambda_3 L3 + \lambda_4 L4$
$L1 = \lambda_{L1L11} L11 + \lambda_{L1L12} L12 + \lambda_{L1L13} L13$
$L2 = \lambda_{L2L21} L21 + \lambda_{L2L22} L22 + \lambda_{L2L23} L23 + \lambda_{L2L24} L24$
$L3 = \lambda_{L3L31} L31 + \lambda_{L3L32} L32 + \lambda_{L3L33} L33 + \lambda_{L3L34} L34$
$L4 = \lambda_{L4L41} L41 + \lambda_{L4L42} L42 + \lambda_{L4L43} L43 + \lambda_{L4L44} L44 + R1$
$L22 = \lambda_{L22L31} L31 + C22$
$L31 = WITH\ \ LOOKUP\left(Time, \left[\left(1, a1\right) - \left(n, a_n\right)\right], \left(1, a_1\right)\left(2, a_2\right)\left(3, a_3\right)\ldots\left(n, a_n\right)\right)$
$L32 = WITH\ \ LOOKUP\left(Time, \left[\left(1, a1\right) - \left(n, a_n\right)\right], \left(1, a_1\right)\left(2, a_2\right)\left(3, a_3\right)\ldots\left(n, a_n\right)\right)$
$L33 = WITH\ \ LOOKUP\left(Time, \left[\left(1, a1\right) - \left(n, a_n\right)\right], \left(1, a_1\right)\left(2, a_2\right)\left(3, a_3\right)\ldots\left(n, a_n\right)\right)$

L11、L12、L13、L21、L23、L24、L34、L41、L42、L43、L44、R1为常量Ci

3.4 The weight of each factor in the system is established

The airline's safety risk index system obtained through systematic analysis shows multi-level and multi-attribute characteristics. When determining the weights of indicators, the weights of indicators determined by subjective judgments often lack science. Analytic Hierarchy Process (AHP) is a systematic analysis method combining qualitative and quantitative analysis, which is applicable to the quantitative analysis of airline safety risk index system. When using the analytic hierarchy process to determine the weights of various indicators in the airline's safety risk assessment model, the analytic hierarchy structure is needed first. In this study, the hierarchical system shown in Figure 1 is used. On this basis, the elements are compared pairwise for each level, and the positive and negative matrix A is constructed using the 1-9 scale method:

$$A=\left(A_{ij}\right)_{n\times n}, \text{ among them, } A_{ij}>0, A_{ij}=\frac{1}{A_{ij}}(i\neq j), A_{ii}=1. \quad (1)$$

For matrix A, obtain the maximum eigenvalue λ_{max} of A by formula 2. Use the sum method to calculate the eigenvector $V=(V_1,V_2,\dots,V_n)^T$ of matrix A and normalize the vector V according to formula 3. Processing, where a_i represents the normalized V_i value.

$$AX=\lambda X \quad (2)$$

$$a_i=\frac{V_i}{\sum_{i=1}^{n} V_i}\ (i=1,2,...,n) \quad (3)$$

In order to test whether the established positive and negative matrices have consistency, a consistency test is used to detect whether the matrices are consistent with logic, as shown in Equations 4 and 5. In the formula, CI is used to judge the consistency degree of the matrix. The smaller the value is, the higher the consistency of the matrix is. The CR indicates the deviation degree between the CI and the average consistency index.

$$CI=\frac{\lambda_{max}-n}{n-1} \quad (4)$$

$$CR=\frac{CI}{RI}<0.1 \quad (5)$$

According to Equation 1-5, the weight of each factor in the model is obtained, as shown in Table 2.

Table 2 Distribution of risk factors in the system

risk factors	Weights	risk factors	weights
L1	0.51	L11	0.05
		L12	0.08
		L13	0.07
L2	0.23	L21	0.06
		L22	0.1
		L23	0.07
		L24	0.07
L3	0.19	L31	0.08
		L32	0.06
		L33	0.07
		L34	0.09

L4	0.07	L41	0.05
		L42	0.04
		L43	0.07
		L44	0.04

4. Case study

Xinjiang has abundant material and tourism resources. With the continuous development of Xinjiang's economic level, the demand for air transportation in the region has continued to rise. The security risks of Urumqi Airlines from January to December 2018 were evaluated. According to the company's management-related data records and other public channels to obtain data in that year, and combined with the industry experts' opinions of the air transport company, each risk factor in the evaluation system model was quantitatively input.

4.1 Quantification of model input parameters

Quantitative processing of risk factors is the prerequisite for risk assessment. In the airline's safety risk assessment index system, factors such as "aircraft age" and "weather conditions" can be obtained through historical data records. For "safety awareness", "safety" Management implementation "and other factors were quantified through expert system scoring and evaluation. The unit of each quantified risk factor is still inconsistent, and the normalization of each factor is performed by using the normalization method of the maximum value, see Equation 6.

$$X_{Ni} = \frac{X_i - X\min}{X\max - X\min} \tag{6}$$

Among them, X_{Ni} represents the i-th factor risk value after normalization processing, Xi represents the original value of the i-th factor data, and X_{max} and X_{min} represent the maximum and minimum values of the i-th factor, respectively. Taking "aircraft age" as an example, the average age of the airline in 2018 is 17.9 years, and the general service life of civil aviation aircraft is 0-30 years. According to formula 3, the initial risk level input of "aircraft age" is 0.59. For factors L31, L32 and L33, the input is a table function, which can be obtained after processing based on meteorological data records.

4.2 Model simulation

The evaluation was conducted for Urumqi Airlines from January to December 2018. When the simulation was performed, the time unit was set to day, the simulation time was 365 days, and the step size was 1 day. The quantified value of the airline's security risk level is between 0-1. A larger value indicates a higher risk. The system risk level is the highest when it is close to 1, and a smaller value indicates a safer system.

According to the quantified initial value of each risk factor and the weight of each factor, it is substituted into the dynamic equation, and then input into the SD risk model of the airline, and the model is simulated to obtain the 2018 risk level of each subsystem that affects the safety risk level of the airline. Dynamic change trend, as shown in Figure 7. Relying on the change of the risk level of the subsystem, we can further obtain the dynamic change of the security risk of the airline in 2018, as shown in Figure 3. It can be seen that the annual risk value of the airline has remained at about 0.04, which is generally at a relatively high level of safety, but the risk level has fluctuated within a year. The risk levels in the first and second half of the year increased first and then decreased.

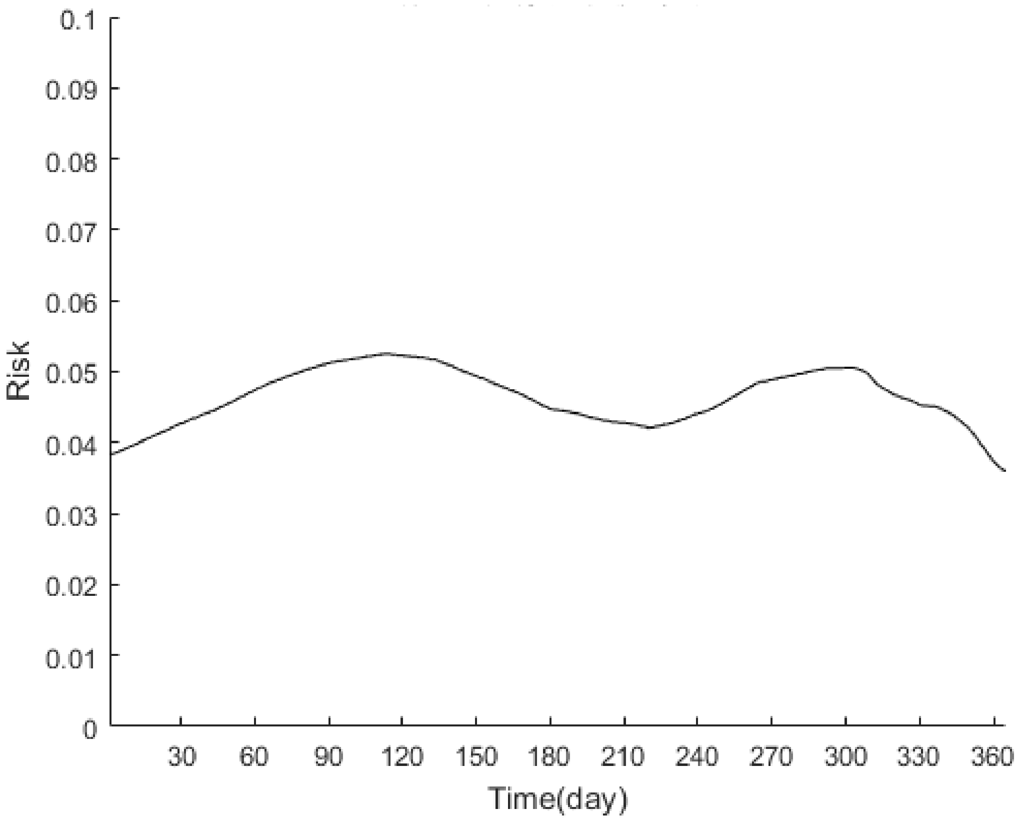

Fig3 Dynamic changes in airline safety risk levels

5. Conclusion

Based on a systematic analysis, this paper constructs a hierarchical airline safety risk index system from the four aspects of "people-aircraft-environment-management", and uses the analytic hierarchy process to determine the weight of each factor. Due to the complex feedback relationship between several subsystems that affect airline safety, a dynamic model of airline safety risk assessment is established using system dynamics, which can reflect the risk changes of complex feedback systems under time series. Through the case study of Urumqi Airlines, it is found that the overall safety level of the airline is relatively high, and the annual risk level fluctuates in an "M" shape. In the next research, we can analyze the change law of airline safety risk level, predict the future risk change trend, and provide scientific support for related departments to conduct risk pre-control.

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