Research on Safety Risk Evolution of Military Aviation System Based on ANP-SD

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Abstract. With the development of equipment, the complexity of China's military aviation system continues to increase. The system risk is transformed from the initial independent risk factor to the cross-influence risk factor, which makes the system risk control difficult. In order to maintain the safety level of military aviation system, the factors affecting the safety level of the system are analysed from five aspects: personnel, machine, environment, management and logistics. The analytic hierarchy process (ANP) is used to construct the model of the system risk factors and the system dynamics method is used to establish the risk evolution simulation model, and quantitatively analyse the sensitivity of risk factors to explore the basic rule of risk evolution.

1. Introduction
The update of equipment contributes to the complexity of the military aviation system and brings a series of problems. Simple risk factor analysis has not been suitable for nowadays complex military aviation systems, and the interconnection and impact of risks have gradually become the main factors affecting the overall safety level of the system. Therefore, a method that can be used to analyse the risk evolution for the accidents prevention is put forward, and the general mechanism is obtained through system simulation by processing the existing data.

At present, research objects on risk evolution at home and abroad are mostly concentrating on large and complex systems. Jiang Xin et al. constructed a system dynamics model of risk evolution of cross-operation using system dynamics, and simulated the self-organizing formation path of risk evolution [1]; Chen Shuai conducted system dynamics modeling and simulation of risks in civil aviation maintenance system and the relationship between risk factors is studied [2]; Zhao Yiqing et al. constructed a risk evolution model associated with tailings pond accident hidden danger using system dynamics, and characterize the rule of risk evolution of tailings ponds by combining with the complex network methods [3]; Liu Qing et al. constructed the risk evolution model of navigation of ships in the Three Gorges Dam area with the method of system dynamics, and simulated the risk evolution process of navigation of ships under the influence of various factors with VENSIM software [4].

At present, there are few researches on system risk evolution in the field of military aviation, and no mature mechanism has formed. Considering that the military aviation system is of large-scale and complex with nonlinear and multivariable characteristics, this paper combines the analytic hierarchy process (ANP) and the system dynamics method (SD) to construct the safety risk evolution model based on ANP weight calculation, using the SD simulation software VENSIM to analyse the sensitivity of risk factors. Forming the regulation of the risk evolution, and providing a theoretical basis aim at improving the safety management level of military aviation systems.
2. Construction of safety risk evolution indicator system for military aviation systems

2.1. The establishment of military aviation system safety risk evolution indicator system

Military aviation system is a typical complex man-machine system built with complicated structure and various elements. Referring to the theories and models of safety analysis, such as REASON model, SHEL model and FMECA model, etc. and from the perspective of system safety, the influencing factors mainly contain personnel, equipment, environment, management and logistics support. After repeated discussions with 5 experts in the field of aviation safety and combined with the analysis of existing data, 18 risk factors in 5 risk links was finally determined, as shown in Figure 1.

![Figure 1. Military aviation safety risk evolution indicator system.](image)

2.2. The construction of ANP network structure based on indicator system

The ANP is a decision-making method to adapt to the non-independent hierarchical structure and proposed by Professor T.L.Saaty of the University of Pittsburgh in the 1990s. It is developed and extended on the basis of the analytic hierarchy process (AHP). It shows the relationship between each element of a system by a network-like structure, instead of the simple hierarchical structure of AHP [5].

The typical network structure description of ANP usually consists of two parts. The first part is the control layer, including the problem objectives and decision criteria. The second is the network layer,
which is composed of all the elements of the control layer and the internal is a network structure where elements interact with each other [6].

According to the safety risk evolution system established in Figure 1, the network structure model of ANP as shown in Figure 2 is established, where the first level indicators are $C_i (i = 1, 2, 3, 4, 5)$, the second level indicators are $C_{ij} (i = 1, 2, 3, 4, 5; j = 1, 2, 3, 4, 5)$.

### 3. Construction and analysis of risk evolution model of military aviation system

System Dynamics is a kind of system analysis technique based on the feedback control theory proposed by professor J.W. forrester of Massachusetts institute of technology (MIT) in 1956, which quantitatively studies nonlinear, multiple feedback and complex time-varying systems by means of computer simulation [7].

#### 3.1 Establishment of risk evolution model of military aviation system

According to Figure 1, it can be divided into five subsystems, and the relationship among every factors in the subsystem is presented through the model. As shown in Figure 3, SD flow diagram of the safety risk evolution of the military aviation system is drawn.

![Figure 3. Military aviation system safety risk evolution SD flow diagram.](image)

#### 3.2 Simulation analysis of safety risk evolution of military aviation systems

Based on the results of the expert ratings and the weight values, we present the initial values of the horizontal variables in the model, as well as the SD equations for the main variables. The model
simulation period is 48 weeks and the step size is 1 week. VENSIM software was used for the sensitivity analysis. The results are shown in Figure 4, Figure 5, Figure 6 and Figure 7.

**Figure 4.** Simulation results of various factors affecting personnel safety level

Analysing the simulation result in Figure 4, and the conclusion was drawn as follows.

1) First of all, as can be seen from the four figures, when the safety level of each factor reduced 10%, the safety level of personnel is lower than 70 due to management factors and environmental factors, and their influence is greater than that of equipment and logistics factors.

2) The impact of management and environment factors on personnel safety level were analysed together and it was found that when both of them reduced 10%, the impact of management was appreciable before week 12th, and the safety level of personnel had dropped below 70 at about week 11th. The influence of environment was more noticeable after week 12th, and lasts longer than that of management. From the picture above, combined with equipment and logistics support factors the former influence on personnel safety was less than the latter. Comparing the images of the foregoing with management and environmental factors, it can be drawn that under the 10% rise of four factors, the promotion of equipment and logistics safety level didn’t bring significant rise to the personnel safety level while the management and environment factors are just the opposite which can be inferred that they possess greater influence on safety level.
In Figure 5, it can be seen as listed below.

3) First of all, the environment has a greater impact on management, followed by logistics support and equipment factors. The main reason for that is the significant impact of the working environment on the management safety level. The working environment includes the basic facilities construction of the workplace, interpersonal relationships, and work enthusiasm. It is necessary to consider the improvement of management level from these aspects.

4) The reason that logistics support factors and equipment factors have little effect on the safety level of management may be that equipment is mainly affected by management factors, and its impact on management factors is small. Logistic support factors are independent of management factors and therefore have less impact.
(3) Logistics support impact on equipment

**Figure 6.** Simulation results of various factors affecting equipment safety level

From Figure 6,

1) It can be seen that environmental factors have the greatest impact on equipment safety levels, followed by management factors and logistics support factors. The reason for the greater impact of environmental factors is that the natural environment has a greater impact on the use of equipment.

2) The impact of management and logistics support factors on equipment is slightly different. The impact of management on the safety level of equipment is mainly concentrated around week 8th, and the impact is greater than the logistics support factor. The impact of logistics support factors on equipment safety level is mainly concentrated around week 12th and lasts longer than that of management.

**Figure 7.** Simulation results of environmental factors affecting logistics support safety level

Analysing the simulation result in Figure 7. It can be seen that when the environmental safety level is reduced by 10%, the level of logistical safety is rapidly reduced. However, when the environmental safety level is increased by 10%, the level of logistical safety is growing slowly. The reason may be that natural environment has a great impact on logistical support safety level.

4. Conclusion

Based on the analysis of these key aspects of military aviation system safety risk, the indicator system of it was formed. ANP method was used to construct a military aviation system safety risk evolution ANP structure model, and Super Decision software was used to determine the weight of indicators. The risk evolution model is established by using system dynamics method, and the basic rule of risk evolution is quantitatively analysed. From the results of various factors sensitivity simulations, it can be concluded that:

1) The safety level of personnel in military aviation systems is mainly affected by management and environmental factors. The influence of management factors is relatively large and rapid. The influence of environment factors is slow and continuous. The equipment and logistics support factors...
have little influence on personnel safety level. Improving the safety level of personnel begins with management. Improving the level of management safety can quickly raise personnel safety level, and it is necessary to continuously improve the level of environmental safety.

2) The level of management safety is mainly affected by environmental factors and is less affected by logistics support factors and equipment factors. Promoting the level of management safety is mainly based on improving the safety level of the work environment, such as optimizing infrastructure construction, maintaining the harmony of interpersonal relationships, and inspiring the enthusiasm of personnel.

3) The level of equipment safety is mainly affected by environmental factors, and management and logistics support factors have less impact on it. The natural environment cannot be changed, but the improvement of equipment can be made according to the characteristics of the environment. For example, in coastal with high humidity, equipment can be regularly rust-proofed. At the same time, the impact of management and logistical support factors cannot be ignored.

4) Logistic support factors are mainly affected by environmental factors. Different equipment support plans can be formulated for different weather conditions to ensure that there are emergency plans in case of special circumstances to ensure the safety of logistics support.

These conclusions provide a reference for managers to correctly analyse and reduce the risk of military aviation.

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