Quality-Risk Identification and Screening of Aircraft Major Overhaul Project Based on HHM-RFRM

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Abstract. With the rapid development of aviation science and technology, the structure and performance of aircraft are more and more complex, and the difficulty of maintenance is correspondingly increased. As a result, quality problems are more likely to occur during the maintenance process. In order to improve the quality of aircraft major overhaul, it is necessary to identify and analyse the risks that affect the quality of aircraft major overhaul. This paper comprehensively uses the improved HHM-RFRM method. At first, the risk factors that may exist in the process of aircraft major overhaul are identified by HHM. And then uses the improved FMEA to carry out triple standard filtration. The multiple standard evaluation is used for further filtering. Finally, 10 important factors are obtained. The purpose of this paper is to put forward a general method to identify the quality-risk of aircraft maintenance projects, which has a certain guiding significance for different levels of aircraft maintenance projects.

1. Introduction

Aircraft maintenance refers to the sum of the theories, methods and technical means used to maintain or restore the operational performance of aircraft and improve the safety and reliability of aircraft. In the whole life cycle of an aircraft, aircraft maintenance work is usually one of the longest and most important links, which is an important guarantee for the normal performance of the aircraft. Aircraft major overhaul belongs to the preventive repair of aircraft maintenance, and the principle of quality first should be adhered to. Any error or any potential risk factor will cause certain or even serious impact on other links.

With the rapid development of aviation science and technology level, the performance and the structure of the aircraft is more and more complex, the degree of precision is getting higher and higher, the repair mode diversifies, which make more and more problems appear during the process factories repair aircraft. Besides, aircraft maintenance still basically rely on design maintenance and experience in maintenance[1]. There exist big quality risks, and the study on quality-risk of aircraft maintenance project need to be boost. While the identification of key quality-risk factors is the cornerstone and premise of project quality-risk research.

Risk identification refers to the process of identifying actual and potential risk events or factors by means of perception, judgment or classification[2]. Common ways to identify risks include historical document analysis, Delphi method, brainstorming method, scenario analysis, SWOT analysis, flow chart method and so on. Aircraft maintenance is a complex and systematic project. And the repair quality is affected by many factors. The above methods can’t comprehensively and systematically identify the quality-risk factors, which may lead to omissions.
In order to analysis more systematic and comprehensive, this paper introduces the Hierarchical Holographic Modeling (HHM) and the model of Risk Filtering, Ranking and Management Framework (RFRM). Through the improved of HHM-RFRM method, the quality-risk of the aircraft major overhaul project can be identified from different aspects of the system to the utmost extent, and the key quality-risk factors can be filtered out, which lays a good foundation for the next step of risk management.

2. The method of HHM-RFRM

2.1. The basic method of HHM-RFRM

HHM is a comprehensive and systematic methodology, which is suitable for risk identification of large-scale, complex, multi-attribute and multi-hierarchical projects. It mainly analyses the essential characteristics of a project from different perspectives, levels and dimensions in an all-round and in-depth way. On this basis, a nearly complete quality-risk set of complex system can be obtained through repeated iteration and layer by layer analysis[3]. However, while it ensures the integrity and completeness of risk identification, it may cause the redundancy of risk factors. Even when analysed from different perspectives, there may still be situations where the boundaries cross, meaning that risk factors with similar connotations may emerge.

The basic RFRM method is divided into eight stages: scenario identification, scenario preliminary filtering, double standard filtration, multiple criteria evaluation, quantitative rating, risk management, evaluate the important scenarios that are filtered out, operational feedback. This paper focuses on the first four steps of RFRM.

HHM-RFRM method is a method that combines the theory of hierarchical holographic modeling with the framework of risk filtering, rating and management. Besides, it is a method that combines qualitative and quantitative. In this method, applying HHM method to RFRM’s scene identification, and then through the subsequent filtering and screening of RFRM, can effectively make up for the deficiency of HHM method.

(a) Scenario identification: Build HHM model and describe various risk scenarios from different levels and perspectives of the system.

(b) Scenario preliminary filtering: Risk scenarios are usually optimized according to expert opinions or experience to filter out redundant or unimportant risk scenarios.

(c) Double standard filtering: The core is to further define the scope by qualitative method according to the possibility of risk scenarios and the severity of the consequences, so as to simplify the risk scenarios.

(d) Multiple standard evaluation: The remaining risk scenarios are evaluated according to the 11 indexes corresponding to the three major risk factors, reducibility, redundancy and robustness, that can defeat the system’s defense ability.

| Code | Evaluation Indexes | Concrete Content |
|------|--------------------|-----------------|
| D1   | Imperceptibility   | The risk cannot be detected before the damage occurs |
| D2   | Uncontrollability  | The damage cannot be controlled or prevented by taking measures |
| D3   | Multiple failure modes | There are many or even unknown ways of failure that can cause damage to the system |
| D4   | Irreversibility    | The adverse conditions cannot be restored to their original state |
| D5   | Duration of impact | The adverse effects lasted for a long time |
| D6   | Chain effect       | The adverse effects can spread to other subsystems / systems |
| D7   | Operation environment | Risks arising from external pressures |
2.2. Improvement of HHM-RFRM method

(1) In the first step, scenario identification, the concept of multi-dimensional risk factors is proposed. By constructing M-dimensional risk scenarios, i.e., risk scenarios composed of M risk factors, not only risk factors can be identified, but also interactions of complex risk factors can be analysed, which is more in line with the complex characteristics of aircraft major overhaul projects.

(a) Two-dimensional risk scenarios

(b) Three-dimensional risk scenarios

Figure 1. Construction of M-dimensional Risk Scenarios.

(2) In the third step, standard filtration can be upgraded to triple standard filtration. On the basis of the original risk severity and risk occurrence frequency, detectable degree of risk can be added. In this stage, the improved FMEA method can be used to effectively identify the risk consequences, risk possibilities, risk detectable degree of the system quality-risks in each maintenance process.

In the traditional FMEA method, the three factors of risk, severity(\(S\)), frequency(\(O\)) and detectable degree(\(D\)), are quantified subjectively firstly. Then, the product of the three is directly taken as the Risk Priority Number (RPN) which is used as the ranking standard to indicate the priority of the risk to be dealt with[4]. This method is simple and easy to operate, but it lacks differentiated treatment of expert evaluation results. Excessive subjectivity will affect the evaluation accuracy. To reduce data noise, some studies directly assign different weights to different levels of experts, but this is still too simplistic. In this paper, the weight is further refined. Experts are given different weights in the judgment of different factors according to different fields they are familiar with and different focuses they pay attention to. The specific meaning is as follows.

When \(n\) experts participate in the evaluation, the evaluation weight matrix of experts for the severity, occurrence frequency and detectable degree of risk is set as

\[
W = \begin{bmatrix} W_S & W_O & W_D \end{bmatrix} = \begin{bmatrix} w_{s1} & w_{o1} & w_{d1} \\ w_{s2} & w_{o2} & w_{d2} \\ \vdots & \vdots & \vdots \\ w_{sn} & w_{on} & w_{dn} \end{bmatrix}
\]

(1)

Where \(\sum_{j=1}^{n} w_{sj} = 1, \sum_{j=1}^{n} w_{oj} = 1, \sum_{j=1}^{n} w_{dj} = 1\).

In view of risk \(R_i\), \(N\) experts respectively gave their evaluation scores. The score matrix of risk \(R_i\) is given by

\[
M_i = [A_i \quad B_i \quad C_i] = \begin{bmatrix} a_{i1} & b_{i1} & c_{i1} \\ a_{i2} & b_{i2} & c_{i2} \\ \vdots & \vdots & \vdots \\ a_{in} & b_{in} & c_{in} \end{bmatrix}
\]

(2)
So, for risk $R_i$, there is

$$
\begin{align*}
S_i &= W_S^T \cdot A_i, \\
O_i &= W_O^T \cdot B_i, \\
D_i &= W_D^T \cdot C_i,
\end{align*}
$$

(3)

The Optimized Risk Priority Number (ORPN), which is the product of $S_i \cdot O_i \cdot D_i$, is defined as:

$$
ORPN_i = S_i \cdot O_i \cdot D_i
$$

(4)

After calculating the ORPN value of all remaining risk factors after filtering in the previous step, sorting and filtering can be carried out according to the value of $ORPN_i$.

3. Quality-risk identification of aircraft major overhaul project

3.1. HHM framework for quality-risk factors of aircraft major overhaul project

Based on a large number of literature research and field investigation, this paper constructs the HHM framework for quality-risk identification of aircraft major overhaul projects supported by different dimensions such as aircraft major overhaul process, aircraft system composition, quality-risk sources and repair mode, as shown in figure 2.

![HHM framework for quality-risk identification of aircraft major overhaul projects](image)

Figure 2. HHM frame diagram of the aircraft major overhaul project.

Aircraft major overhaul is a complex system engineering. The overhaul process is more complex and delicate, which has slightly different according to aircraft types. It is generally carried out in accordance with the process of fault detection and reception, aircraft disassembly, structural repair, accessory repair, aircraft assembly, aircraft flight test and aircraft transfer.

The maintenance process involves dozens of professional jobs, such as mechanical, structural, hydraulic, electronic, radio, etc. It corresponds roughly to the system composition of the aircraft, which generally includes the airframe, hydraulic system, avionics system, flight control system, fuel system, etc.

Referred to the requirements of 5M1E and combined with the actual situation of aircraft major overhaul project, six quality-risk sources in the process of aircraft major overhaul are summarized: man factor, machine factor, material factor, method factor, environment factor, organization and management factor.

With the continuous improvement of the requirements for the depth of aircraft repair, coupled with the increasingly high degree of precision, some aircraft components, especially avionics equipment,
cannot be repaired by the repair factory because of the lack of repair capability and qualification. In the case that independent repair cannot meet the demand or resources are limited, it shall be completed by outsourcing repair.

The HHM frame diagram of the aircraft major overhaul project shows the basic situation of the aircraft major overhaul project from different perspectives. In this paper, the quality-risk of aircraft major overhaul project is coupling analysed from two aspects of aircraft major overhaul process and quality-risk sources. The HHM sub-framework of quality-risk identification for aircraft major overhaul project is constructed as the direct framework model of the risk identification, as shown in figure 3. The identification process is mainly carried out from the perspective of quality-risk sources, based on the aircraft major overhaul process.

Figure 3. Quality-risk identification model of aircraft major overhaul project.

Through the above model, risk factors under each quality-risk source are identified one by one in different process stages of aircraft major overhaul. After analysis, synthesis and preliminary filtering, the following 38 major risk factors are identified, as shown in table 2.

Table 2. Main quality-risk factors of aircraft major overhaul projects.

| Analyse perspective | Code name | Quality-risk factors | Concrete content |
|---------------------|-----------|----------------------|------------------|
| Man factor          | F1        | Ability of qualification | Level of skills and experience; The standard degree of repair and maintenance; The diversity of troubleshooting means; The management ability of the manager. |
| & Aircraft major overhaul process | F2        | Quality consciousness | Have good quality awareness. Strictly follow the maintenance procedures, through standard operation methods for maintenance. |
|                     | F3        | The style of work     | Whether the style is loose, whether the lack of responsibility; |
|                     | F4        | Work proficiency      | Whether the repair record is standard and complete; |
|                     | F11       | Human resources       | Maintenance quality is up to standard |
|                     | F12       | State of body         | Whether the senses, thinking and body are normal |
|                     | F17       | State of mind         | Work pressure degree, work enthusiasm |
|                     | F18       | Social relations      | Whether the relationship between family members and other members of society is harmonious or not will affect working state |
|                     | F19       | Design of aircraft    | Whether there are defects in the anti-error design of the aircraft; |
| Machine factor      | F21       | Condition of aircraft | Whether the maintainability design is perfect |
| & Aircraft major overhaul process | F22       | Repair equipment / tools | Aircraft age, whether there is structural corrosion of the body |
|                     | F24       | Repair testing equipment | The quantity and quality of the equipment (such as whether the accuracy is up to the standard); Maintenance and measurement of equipment; Clean state; Maintenance process omission |
|                     | F28       | Safety equipment      | The quantity and quality of the equipment is in place and the quality is reliable |
| Material factor     | F30       | The information system | Whether the information system is complete, robust and normal |
| & Aircraft major overhaul process | F34       | Inventory support capacity | Quantity of aircraft spare parts in reserve |
|                     | F35       | Special material support capability | Some aircraft parts are special, such as imported parts. |
|                     | F37       | Outsourced repair quality | Is it possible to get imported parts or find a suitable replacement. |
|                     | F38       | Quality of purchased materials | Some parts rely on external repair, quality standards. |
|                     |           |                      | Whether the quantity and quality of supply meet the demand. |
3.2. **Triple standard filtration of quality-risk of aircraft major overhaul project based on FMEA**

Joined with FMEA conventions, 10 granularity evaluation language sets were selected to describe the different levels of the three factors S, O and D of aircraft major overhaul project’s quality-risk, which are shown in table 3, 4 and 5.

**Table 3. Descriptions of quality-risk’s severity in aircraft major overhaul project.**

| Degree of potential adverse consequences | The description of severity degree | Score |
|-----------------------------------------|-----------------------------------|-------|
| Ruin                                    | The aircraft was fatally damaged, completely irreparable/fatal injured to the occupants/failed to meet quality targets/seriously behind schedule | 10    |
| Extremely serious                       | The damage to the aircraft is extremely serious, and the repair cost is extremely high/the repair time is extremely long/the damage to the people using the aircraft is extremely serious | 9     |
| Very serious                            | The damage to the aircraft is very serious, the repair cost is very high/the repair time is very long/the damage to the people who use it is very serious | 8     |
The aircraft was severely damaged, which resulted in high repair costs/long repair hours/serious injury to the people using it

The aircraft suffered more serious damage, which resulted in higher repair cost/longer repair time/more serious injury to the users

Moderate damage to the aircraft, acceptable repair costs/repair will take a certain number of man hours

Lighter damage to the aircraft/faster repair/less impact on the repair quality of other links

Slight damage to the aircraft/quick repair/slight impact on the repair quality of other links

Minimal damage to the aircraft/quick repair/minimal impact on other parts of the repair quality

Aircraft overhaul project has no impact

| Probability of risk occurrence | The description of occurrence frequency degree | Score |
|-------------------------------|-----------------------------------------------|-------|
| >=96%                         | It will almost certainly happen                | 10    |
| 86%~95%                      | It happens a lot                               | 9     |
| 76%~85%                      | Frequent occurrence                            | 8     |
| 66%~75%                      | Occurs more frequently                         | 7     |
| 51%~65%                      | Medium frequency of occurrence                | 6     |
| 36%~50%                      | The frequency of occurrence is moderate to lower| 5     |
| 26%~35%                      | Less likely to happen                          | 4     |
| 16%~25%                      | Rare occurrence                                | 3     |
| 6%~15%                       | rare                                           | 2     |
| <=5%                         | Almost never happens                           | 1     |

| Detection rate | The description of detection degree | Score |
|----------------|------------------------------------|-------|
| <=5%           | Rarely detect risk points          | 10    |
| 6%~15%         | Difficult to identify risk points  | 9     |
| 16%~25%        | Little chance of identifying risk points | 8     |
| 26%~35%        | Less chance of identifying risk points | 7     |
| 36%~50%        | Below moderate chance of identifying risk points | 6     |
| 51%~65%        | Moderate chance of identifying risk points | 5     |
| 66%~75%        | High chance of identifying risk points | 4     |
| 76%~85%        | Higher chance of identifying risk points | 3     |
| 86%~95%        | Very high chance of identifying risk points | 2     |
| >=96%          | Can be detected                    | 1     |

Seven experts were invited to score the S, O and D for each of the 38 risk factors. And their weight matrix is

\[
W = \begin{bmatrix}
W_S & W_O & W_D
\end{bmatrix} = \begin{bmatrix}
0.20 & 0.18 & 0.16 & 0.18 & 0.05 & 0.18 & 0.05 \\
0.18 & 0.12 & 0.07 & 0.20 & 0.18 & 0.18 & 0.07 \\
0.18 & 0.10 & 0.07 & 0.18 & 0.09 & 0.20 & 0.18
\end{bmatrix}^T
\]

The score matrix from \(M_1\) to \(M_{38}\) are obtained by experts' scoring.

The optimal risk priority numbers of these 38 risk factors, from \(ORPN_1\) to \(ORPN_{38}\) are obtained by equation (3) and (4). The distribution of ORPNs is shown in table 6 below.
According to the distribution of ORPN value, 20 of the 180 risk factors, with ORPN value between 0 and 200, have relatively low risk compared with others. Therefore, these 20 factors are screened out. And the remaining 18 factors, such as qualification ability, quality awareness, move on to the next stage.

3.3. Multiple standard filtering for quality-risk of aircraft major overhaul project

For each risk scenario, it is not comprehensive to consider only the three influencing factors mentioned above. The reducibility, redundancy and robustness of the system of each scenario should also be considered. Refer to reference [4], this paper selects five risk evaluation criteria D2, D4, D5, D6 and D8, which are the most widely applied among the 11 indexes for defeating the system defense ability. The experts then score each of the 18 risk factors. Through assessing the impact of each risk factor from a wider range of perspectives, filtering is done.

This process was scored by 7 experts respectively and then added directly. The expert scoring results are shown in table 7.

| F1 | F2 | F3 | F4 | F11 | F12 | F17 | F18 | F19 | F21 | F22 | F24 | F28 | F30 | F34 | F35 | F37 | F38 |
|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| D2 | 1  | -3 | -1 | 2   | -1  | 4   | 6   | 5   | 4   | 2   | 6   | -3  | -5  | -3  | 0   | -1  | 0   | -3  |
| D4 | 6  | 4  | 5  | 2   | 0   | 5   | 4   | 4   | -4  | -2  | -3  | -3  | -5  | 1   | -1  | 2   | 4   |
| D5 | 6  | 5  | 6  | -4  | 5   | -5  | 0   | -5  | 3   | 3   | 5   | 3   | 4   | 3   | 5   | 2   | 5   |
| D6 | 2  | 6  | 5  | -1  | 4   | -3  | -6  | -3  | 2   | 1   | 4   | 1   | 1   | 2   | 5   | 5   | 6   |
| D8 | 2  | 2  | -3 | -1  | 1   | 1   | -1  | 0   | 3   | 0   | 2   | -1  | -1  | -1  | -1  | 5   | 6   |
| Σ  | 17 | 14 | 12 | -2  | 11  | -3  | 4   | 1   | 16  | 2   | 15  | -3  | -4  | -4  | 10  | 10  | 19  |

In the comprehensive evaluation, the risk factors with high scores are more likely to occur and should be paid more attention to. It can be seen from table 7 that there are 10 risks with a total score greater than 10. So these 10 risk factors, F1, F2, F3, F11, F19, F22, F34, F35, F37 and F38, are reserved as the objects of subsequent studies.

4. Conclusion

Aircraft major overhaul project is complex project, with large scale, multiple levels, high degree of precision, etc. It is faced with a variety of risks, as well as strong secrecy and great impact. In order to facilitate the subsequent risk management, risk identification and screening must be done first. This paper adopts HHM-RFRM method to study. Firstly, the quality-risk factors of the aircraft major overhaul project were comprehensively identified through the HHM model system, and then 10 main risks were filtered out through the improved FMEA and multiple standard filtration. It provides reference for the quality-risk prevention and control of the aircraft major overhaul project. In addition, this method can be used as a reference for the identification of quality-risk in different stages of aircraft maintenance, and even for other large equipment.

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