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Research on Zonal Inspection Intervals of Civil Aircraft Based on Improved FAHP

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Abstract

One of the most important things in formulating aircraft maintenance program is to determine the zonal inspection intervals. In accordance with the current situation that there has no perfect rating systems of zonal inspection under MSG-3 (Maintenance Steering Group-3) analysis system, a method to calculate the integrate level of zonal rating is to analyze the impact of aircraft zonal rating factors, establish a hierarchical index evaluation system and then utilize the improved fuzzy analytic hierarchy process (FAHP) to determine the indexes' weight. Moreover, the zonal inspection intervals can be established according to the correspondence between rates and intervals. Finally, take a typical zone of an aircraft as an example to verify the method.

***Keywords**: maintenance program, zonal inspection, rating, intervals, FAHP*

1. Introduction

The thinking of modern aviation maintenance has gradually shaped after 1960s. Its major representatives are the Maintenance Steering Group (MSG) repair thoughts and the thinking of Reliability Centered Maintenance (RCM) as well as the whole system and life-cycle maintenance thoughts. The maintenance program formulated according to the latest revision of MSG-3 principle consists of four main parts; namely, systems and power plant analysis(including components, accessories and auxiliary power units), structures analysis, zonal inspection and lightning/HIRF protection system analysis [1, 2]. Correspondingly, MSG-3 analysis method is also divided into four parts. The zonal inspection procedures can be formulated along with the zonal analysis program, which require each part of aircraft zones being evaluated comprehensively after the logical analysis of structures, systems and power plant. These inspection requirements are to be incorporated into the subsequent zonal inspection programs. The maintenance program stipulates specified maintenance types and intervals. Due to the relatively fixed maintenance type of each system, it's crucial to establish maintenance intervals in order to develop the maintenance program [3]. In accordance with the problem that the rating system of zonal inspection under MSG-3 analysis system has no apparent standards, this article attempts to propose a method to determine zonal inspection intervals.

2. The Establishment of Zonal Rating Index System

2.1. The Analysis of Zonal Rating Factors

Zonal analysis procedures include standard zonal analysis and enhanced zonal analysis, which have different considerations. The purpose of standard zonal analysis is to examine the situation and security of accessories installed in certain aircraft zones. There are three indicators needed to be taken into consideration during standard zonal analysis procedures: importance level, density grade and exposure level (including environmental damage level and accidental damage level). The importance level is the measurement of the impact that all kinds of accessories have on aircraft operational security and economical efficiency. The density grade is related to the number of accessories and the degree of difficulty of inspection. The environmental damage level is related to temperature, vibration and liquids (including kitchen liquid, toilet fluids, hydraulic oil, anti / de-icing liquid, chemical liquid, fuel and

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moisture). The accidental damage level is related to factors such as ground support equipments, external object damage, weather, repair frequency, liquid spills, passenger activities, etc. Then, according to the property relations between each indicator, establish the multi-level hierarchical structure of zonal rating factors, which constitutes the zonal rating index system. (See Figure 1).

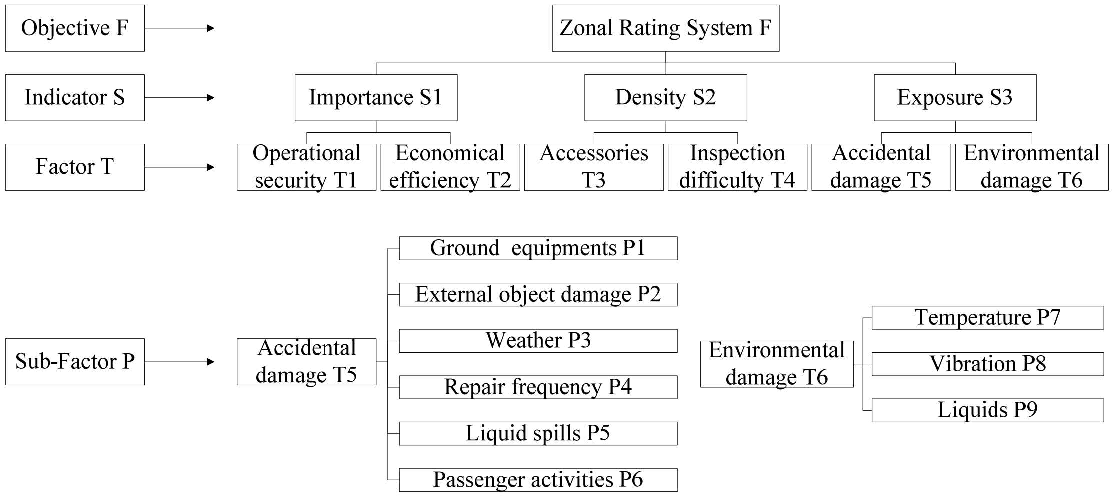

Figure 1. The Hierarchical Structure of Zonal Rating Index System

2.2. Application of Improved Fuzzy Analytic Hierarchy Process (FAHP) to Determine the Index Weight

Fuzzy Analytic Hierarchy Process (FAHP) [4-6] based on traditional analytic hierarchy process takes into account people's judgment fuzziness when evaluating complex matters. It's a decision making approach which brings in fuzzy consistent matrix. This method not only addresses the problem that conventional comprehensive index calculation methods have not considered the integrated impact of each factor [7, 8], but also resolves the defect that Analytic Hierarchy Process (AHP) is largely subject to personal judgments. This article utilizes the improved FAHP method to determine the respective index weights. By refining the hierarchical index system and changing the algorithm formula commonly used in the calculation of factor weights, it will improve the resolution of zonal rating index weights, and augment the credibility of zonal rating index system.

2.2.1. Fuzzy Consistent Matrix

Definition Ⅰ Let the matrix $R=(r_{ij})_{n\times n}$, if it satisfies: $0\le r_{ij}\le 1,\ (i=1,\ 2,\cdots,n;\ j=1,\ 2,\cdots,n)$, then R is called a fuzzy matrix.

Definition Ⅱ If the fuzzy matrix $R=(r_{ij})_{n\times n}$, meets: $r_{ij}+r_{ji}=1,\ (i=1,\ 2,\cdots,n;\ j=1,\ 2,\cdots,n)$, then fuzzy matrix R is called a fuzzy complementary matrix.

Definition Ⅲ If the fuzzy matrix $R=(r_{ij})_{n\times n}$, meets: $\forall i,j,k$, $r_{ij}=r_{ik}-r_{jk}+0.5$, then fuzzy matrix R is called a fuzzy consistent matrix.

Theorem Ⅰ Convert fuzzy complementary matrix R into a fuzzy consistent matrix: Let the fuzzy complementary matrix $R=(r_{ij})_{n\times n}$, sum it up by row and denote as $r_i=\sum_{k=1}^{n} r_{ik}, i=1,2,\cdots,n$, perform the following mathematical transformation $r_{ij}=(r_i-r_j)/2n+0.5$, then the transformed new matrix is a fuzzy consistent matrix.

2.2.2. Algorithm Analysis

The fuzzy consistent matrix is in accordance with the thinking of human strategic decision. Therefore, the FAHP method based on fuzzy consistent matrix has been used a lot in plan optimization when there are many indicators or the evaluation has great ambiguity[9,10]. The general algorithmic steps of FAHP are as follows:

(1) Establish the priority relationship matrix. Create matrices according to the relative importance of each layer factors corresponding to its upper layer. This matrix is a fuzzy complementary matrix. The values in the matrix are scaled from 0.1 to 0.9. When establishing a priority relationship matrix, the value of each element can also be determined as 0, 0.5, and 1. Even though the calculation of this scaling method is relatively simple, the importance level of the two elements compared to each other is ambiguous. In order to accurately describe the relative importance level of any two factors regarding a certain principle, the quantitative scale 0.1□ 0.9 is going to be used in this approach (See Table 1.).

Table 1. 0.1-0.9 quantitative scale

Scale	Definition	Explanation
0.5	Equally important	Two elements are equally important compared with each other
0.6	Somewhat important	One element is somewhat important than the other
0.7	Obviously important	One element is obviously important than the other
0.8	Much important	One element is much important than the other
0.9	Extremely important	One element is extremely important than the other
0.1,0.2,0.3,0.4	Anti-comparison	Compare the element a_i with the element a_j, and obtain judgment matrix r_{ij}; then compare the element a_j with the element a_i, and the judgment matrix is $r_{ji}=1-r_{ij}$

(2) Convert the priority relationship matrix into fuzzy consistent matrix. According to Theorem Ⅰ, the priority relationship matrix is able to be transformed into a fuzzy consistent matrix.

(3) Level of a single layer. Calculate the sequence of importance of each factor in lower layer relative to the upper objective layer based on fuzzy consistent matrix. The sequence method derived from the relationship between elements of fuzzy consistent matrix and weights has a higher resolution, which is able to render decision-making more scientifically. Thus, this method is to be utilized to calculate the weight of each factor. The weight s_i^k of factor A_i relative to the target O_k is:

$$s_i^k = \frac{1}{n} - \frac{1}{2\alpha} + \frac{\sum_{j=1}^{n} r_{ij}}{n\alpha}, i = 1, 2, \cdots, n \quad (1)$$

Parameter α meets $\alpha \geq (n-1)/2$. Array $s_i^k (i = 1, 2, \cdots, n)$ in the downward order, and it will demonstrate the importance level of each factor A_i relative to the target O_k.

(4) Level synthesis. If the intermediate layer is a criterion layer or a sub-criterion layer, it is necessary to integrate each layer and transform the partial weight of importance into the comprehensive weight with respect to the overall objective.

(5) Level of the overall ranking. Based on the ranking of a single layer and the level synthesis, it is available to work out the overall weight ω_i of each factor relative to the whole objective.

$$\omega_i = \sum_{k=1}^{n} \omega_k s_i^k (i = 1, 2, \cdots, n) \quad (2)$$

2.3. The Overall Rating and the Determination of Inspection Intervals

After working out the overall weight of each factor in zonal rating, the integrated rating of aircraft zones is able to be determined and its mathematical formula is as follows: $R = R_n \cdot \omega_n$, where R_n is the score of each index in the factor layer, and ω_n is the overall weights of the factor layer relative to the objective. R_n is the score matrix of every factors decided by a group of experts according to the criteria of index level. Each factor has four levels (High: 1, Intermediate: 2, Low: 3, N/A: 4). The algorithmic expression of R_n is: $R_n = (R_{T1}\ \ R_{T2}\ \ R_{T3}\ \ R_{T4}\ \ R_{T5}\ \ R_{T6})$. The level of accidental damage and environmental damage is the minimum value of the factors rating; namely, $R_{T5} = \min(R_{P1}\ \ R_{P2}\ \ R_{P3}\ \ R_{P4}\ \ R_{P5}\ \ R_{P6})$, $R_{T6} = \min(R_{P7}\ \ R_{P8}\ \ R_{P9})$.

Currently, it is common to utilize the overall rating and inspection intervals conversion table to determine the maintenance intervals. However, this method does not take into consideration the respective weight of each factor to the overall rating. By considering the relationship between overall ratings and inspection intervals, a fitted regression equation is to be established. According to the statistical data of engineering practice and the direction of the development of determining repair intervals in maintenance program, continuous numerical inspection intervals are given in Figure 2. Finally, by incorporating related data from companies like BOEING and AIRBUS, a fitted regression equation has been established to help determine the zonal inspection intervals of certain aircrafts.

$$T = \begin{cases} \text{Re}\,design & R < 1 \\ 21.1R - 19.7 & 1 \le R < 2 \\ 22.5R - 22.5 & 2 \le R < 3 \\ 75R - 180 & 3 \le R \le 4 \\ 120\ or\ more & R > 4 \end{cases} \quad (3)$$

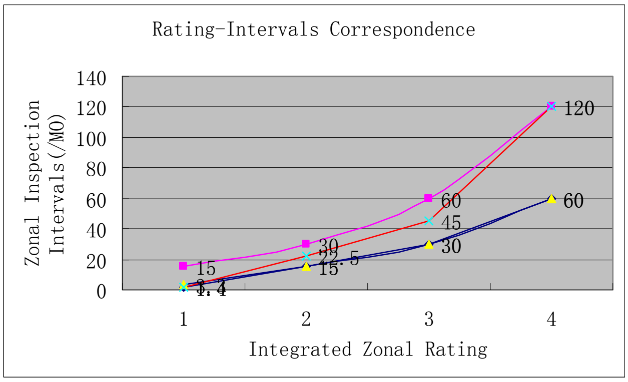

Figure 2. Rating-Intervals Corresponding Relationship

3. Verification

Radome is one of the most important targets of zonal inspection tasks. Radome with eligible strength and stiffness is able to ensure aircraft aerodynamic structural integrity, and effectively guarantee the radar system to work properly. In order to verify the above method, take the radome (ZONE 111) of certain aircrafts as an example for validation.

In accordance with the algorithm step 1, based on the hierarchical structure of zonal rating index system, establish the priority relationship matrix according to the experts' data. The matrix for the layers of objective and indicators is F-S; the matrices for the layers of indicators and factors are S1-T, S2-T and S3-T. These matrices can be obtained by the relative importance of evaluation factors.

Table 2. F-S priority relationship matrix

F	S1	S2	S3
S1	0.500	0.900	0.700
S2	0.100	0.500	0.300
S3	0.300	0.700	0.500

Table 3. S1-T p-r matrix

S1	T1	T2
T1	0.500	0.600
T2	0.400	0.500

Table 4. S2-T p-r matrix

S2	T3	T4
T3	0.500	0.400
T4	0.600	0.500

Table 5. S3-T p-r matrix

S3	T5	T6
T5	0.500	0.700
T6	0.300	0.500

Following step 2, convert the above priority relationship matrices into fuzzy consistent matrices.

Table 6. F-S fuzzy consistent matrix

F	S1	S2	S3
S1	0.500	0.700	0.600
S2	0.300	0.500	0.400
S3	0.400	0.600	0.500

Table 7. S1-T f-c matrix

S1	T1	T2
T1	0.500	0.550
T2	0.450	0.500

Table 8. S2-T f-c matrix

S2	T3	T4
T3	0.500	0.450
T4	0.550	0.500

Table 9. S3-T f-c matrix

S3	T5	T6
T5	0.500	0.600
T6	0.400	0.500

Following step 3, calculate the weight of each factor in the fuzzy consistent matrices. In order to improve the resolution of the ranking results, render $\alpha = (n-1)/2$ in the following calculations.

The weight of each factor in layer S relative to layer F is:

$$\omega_1 = (s_1^1 \ \ s_2^1 \ \ s_3^1)^T = (0.4333 \ \ 0.2333 \ \ 0.3333)^T$$

The corresponding weight of each factor in layer T relative to layer S is:

$$\omega_{21} = (s_{11}^2 \ \ s_{12}^2)^T = (0.5500 \ \ 0.4500)^T$$

$$\omega_{22} = (s_{21}^2 \ \ s_{22}^2)^T = (0.4500 \ \ 0.5500)^T$$

$$\omega_{23} = (s_{31}^2 \ \ s_{32}^2)^T = (0.6000 \ \ 0.4000)^T$$

Following step 5, calculate the overall weight of each factor relative to the whole objective; namely, the respective weight of operational security, economical efficiency, accessories, inspection difficulty, accidental damage and environmental damage in zonal rating.

$$\omega_n = (s_1^1 \cdot s_{11}^2 \ \ s_1^1 \cdot s_{12}^2 \ \ s_2^1 \cdot s_{21}^2 \ \ s_2^1 \cdot s_{22}^2 \ \ s_3^1 \cdot s_{31}^2 \ \ s_3^1 \cdot s_{32}^2)^T$$

$$= (0.2383 \ \ 0.1950 \ \ 0.1050 \ \ 0.1283 \ \ 0.2000 \ \ 0.1333)^T$$

According to the indication from the group of experts, the index score of each factor is:

$$R_n = (R_{T1} \ \ R_{T2} \ \ R_{T3} \ \ R_{T4} \ \ R_{T5} \ \ R_{T6}) = (1.70 \ \ 1.85 \ \ 3.05 \ \ 2.80 \ \ 1.90 \ \ 2.10)$$

Zonal overall rating is:

$$R = R_n \cdot \omega_n = 2.1053$$

Finally, in accordance with the rating-intervals regression equation, the corresponding inspection interval of the radome is: T=24.87 MO.

4. Analyses of the Results

In order to verify the accuracy and precision of this method, it is necessary to compare the above result with the data of mainstream aircrafts regarding certain zonal inspection interval: the data in MRBR (Maintenance Review Board Report) is 24 MO, 5500FC; the data in MPD (Maintenance Planning Document) is 2C. It can be analyzed from the result that the error of zonal inspection interval based on improved FAHP is 3.6% compared with the actual inspection interval, which is eligible.

5. Conclusions

From what has been discussed and analyzed above, here comes the conclusion that:

It's reasonable and effective to utilize the improved FAHP method to determine the weight of each factor. By refining the hierarchical index system and changing the algorithm formula commonly used in the calculation of factor weights, it will improve the resolution of zonal rating index weights, and augment the credibility of zonal rating index system.

The specific inspection interval values can be determined in accordance with the rating-intervals regression equation. According to the statistical data of engineering practice and the direction of the development of determining repair intervals in maintenance program, continuous numerical inspection intervals are rendered, which can facilitate airlines to make reasonable arrangements for inspections according to the real situation, improve maintenance efficiency and reduce costs.

Acknowledgments

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