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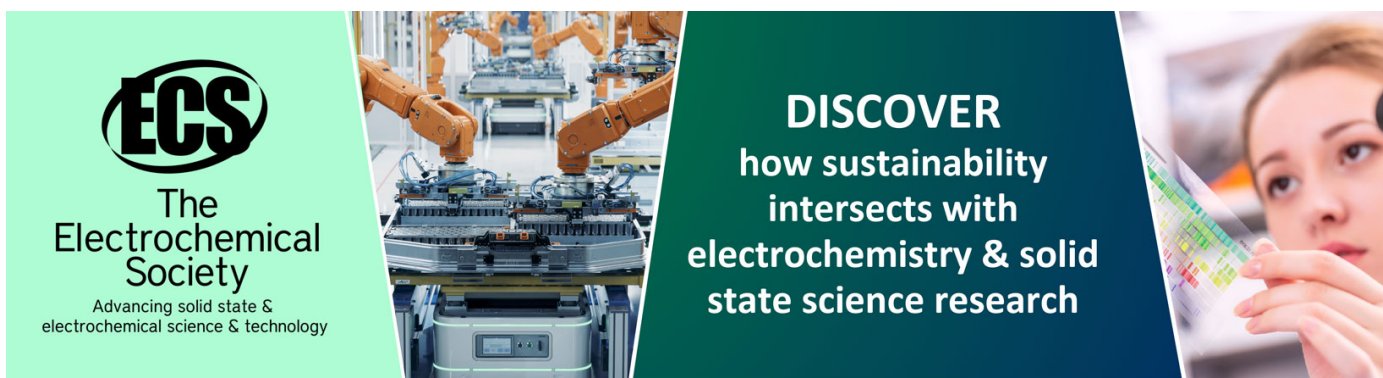
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Research on Test Verification Index system of New Generation Electronic equipment

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Abstract. Aiming at the problem that the existing testability verification test index system does not match the requirement of testability verification of equipment under the system of field replaceable module, a testability verification test index system for the new generation equipment electronic system is put forward. Firstly, aiming at the reform of the two-level maintenance support system caused by the system of field replaceable modules, the requirement of testability verification under the system is analyzed. Then, based on the characteristics of the new generation of equipment testability design and the task goal of the two-level maintenance support system, a testability verification index evaluation system is constructed. Finally, a fuzzy hierarchical evaluation model based on the index system of Topsis optimization is established, and the comprehensive evaluation of testability is realized. The analysis of examples shows that the index system is simple and effective, which provides a way to test the new generation of electronic equipment.

1. Introduction

In the process of equipment design and development, in order to confirm the correctness of testability design and analysis, identify the design defects and check whether the product has completely fulfilled the testability design requirements, we need to carry out testability test [1]. Line Replaceable Module(LRM) developed from the US Army's "gem platform" and "gem pillar" program, it has been widely used in the new generation of combat equipment represented by F-22 and JSF fighters, and triggered the reform of the two-level maintenance and support system of the above-mentioned equipment of the US Army [2-4]. The application of the field replaceable module system and the corresponding two-level maintenance support system improves the reliability of the equipment. The readiness rate and the efficiency of testing and maintenance reduces the cost of life cycle, but the research on testability verification is lagging behind [5, 6].

With the development of the equipment technology of our army, the equipment of LRM system is being put into use step by step. However, the existing testability verification test index system is based on the previous generation of equipment and three-level maintenance support system, and the index selection and sample size do not match with the LRM system, it is necessary to put forward the corresponding test verification test index system. Therefore, considering the structure of LRM system



and the operation characteristics of two-stage maintenance support system, a testability verification test index system for LRM system is put forward in this paper.

2. Research on testability Evaluation Index for LRM system

2.1. Requirement Analysis of testability Verification for LRM system equipment

With the modularization of weapons and equipment, the improvement of information level, the progress of test and maintenance methods, as well as the problems of waste of resources and heavy burden in the original maintenance support system, the US military pioneered the reform of the two-level maintenance support system in the use of the F-22 and JSF fighter planes. The concept of the system is "forward replacement, rear maintenance", making the whole system flat [7].

As can be seen from the diagram, replacement maintenance is adopted at the basic level. When the fault occurs, the fault is diagnosed by the function test in the field, and the fault is isolated to the LRM level [8]. The base level needs to minimize test maintenance time under the condition of ensuring fault detection rate, coverage rate and isolation to LRM, and simplify the test method. The test mainly relies on the in-machine test (Build-in-test, BIT) and portable test diagnostic equipment. At the base level, the fault LRM is tested in the inner field by general / special test equipment, and the fault is isolated to the minimum replaceable unit, and the effective maintenance is realized through the replacement of the components / parts, and the parts are renewed as spare parts.

To sum up, in this maintenance system, the basic level testing requirements are mainly oriented to the field of testing and maintenance work. Testability verification mainly assessed of the BIT and the fault detection ability to match portable detection equipment, coverage degree of failure mode, the ability to accurately isolate the fault to LRM level, false alarm and the speed at which testing, isolation and replacement maintenance can be achieved. In addition, it also needs to face the maintenance ability of troops, check whether the maintenance resources are sufficient, economical and reasonable.

2.2. Index system construction

Based on the analysis of testability requirements under two-level maintenance system, a testability evaluation index system is constructed, which is shown in figure 2, through extensive investigation and iteration.

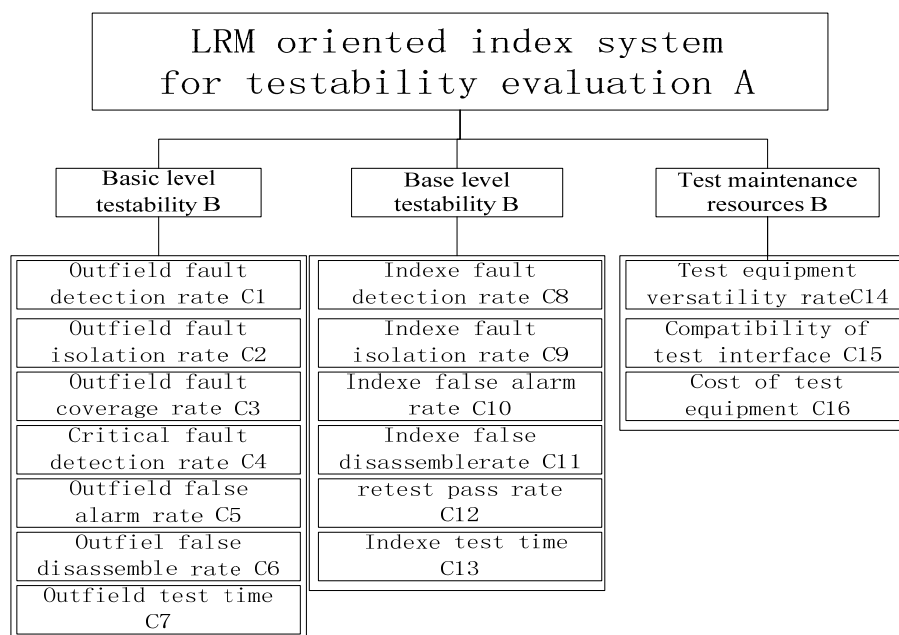


Figure 1. LRM oriented index system for testability evaluation

In figure 1, the index evaluation system includes three secondary indexes which is basic level testing, base level testing and maintenance resources, and 17 more specific third level indexes.

(1) Basic level testability. It includes seven indicators such as the fault detection rate of the field. The outfield fault detection / isolation / coverage rate indicates the fault detection rate, the fault isolation rate and the coverage degree of the fault mode which can be achieved by using the battlefield detection means such as BIT and portable detection equipment. It is important to note that the outfield fault isolation rate is required to be isolated to a single LRM. The critical fault detection rate represents the ability to correctly detect critical faults, in which the critical fault indicates that the system is in a state of endangering task completion, personnel safety or resource use. The false alarm rate / false disassembly rate of the field is used to characterize the false alarm situation when using the detection methods available in the battlefield. Too high false alarm rate and false disassembly in the field will lead to the waste of LRM spare parts. The above indicators can be calculated according to the definition of document [1] [1]. In the field, the time-consuming of the test process is related to the success of the test maintenance work and whether the combat task can be realized. However, in engineering, fault detection time and isolation time are difficult to be accurately measured, especially the starting time of fault isolation is difficult to determine. Therefore, the concept of outfield test time is defined to characterize the time consuming of fault detection and isolation. This index adopts the average field test time measure, that is, using the prescribed method, and correctly realizes the average time required for a fault detection and isolation. The calculation is shown in formula (1).

$$MT_{t,field} = \frac{\sum (t_{Di} + t_{Ii})}{N_I} \quad (1)$$

t_{Di} denotes the time required to detect the i th fault t_{Ii} indicates the time required to isolate the i -th fault. N_I indicates failure number of successful isolation.

(2) Base level testability. It includes 7 indexes, such as fault detection rate of inner field. The field fault detection/isolation rate represents the ability to detect and locate faults when the field test equipment is used, and the faults in the field should be isolated to the smallest possible replaceable unit. The false alarm rate / false disassembly rate / retest pass rate represent the occurrence of false alarm in the inner field. The above indexes can also be calculated as defined in reference [1] [1]. Similarly, the infield test time is defined to represent the time taken to achieve adequate detection and isolation in the infield, which can be measured by reference to (1) the average test time.

(3) Test maintenance resources. The test equipment versatility rate is used to measure the additional pressure on the logistics of the troops to achieve the test work of an equipment. The compatibility of test interface indicates the matching degree of test equipment and equipment, which affects the efficiency of test work. The cost of test equipment is also one of the indicators to characterize the pressure of testing work on logistics procurement, which is not conducive to testability growth.

2.3. Description of indicator assessment modalities

Among the above indexes, such as the fault detection rate / isolation rate of the internal and external fields, can be effectively verified by the testability verification test based on fault injection. Testing time, false alarm rate/false disassembly rate/retest eligibility rate and other quantitative or qualitative indicators often need to be evaluated manually with reference to testability verification tests and feedback from natural data.

In general, testability verification tests assess testability by examining the "three-rate" test. If we need to consider the influencing factors of testability comprehensively, we can establish an evaluation model of multi-attribute decision making on the basis of experiment.

3. Fuzzy hierarchical Evaluation Model for Topsis Optimization

3.1. Basic principle of algorithm

The key techniques of testability comprehensive evaluation include: establishing hierarchy structure of evaluation factors, determining evaluation set, determining index weight, and index evaluation. The most important step is to determine the weight of indicators according to the hierarchical structure of the index system. In this respect, some scholars used AHP to determine the weight of radar equipment and artillery equipment respectively, and determined the index by the method of fuzzy comprehensive evaluation [9, 10]. Analytic Hierarchy Process (AHP) is proposed by Saaty. Based on expert knowledge and subjective experience, the judgment matrix is constructed by comparing the importance of the two indexes, and the weight is determined according to the eigenvector. The method uses mathematical models to eliminate subjective elements of evaluation as much as possible, but does not take into account the ambiguity of human thoughts, and there are still some disputes on consistency [11]. Therefore, some scholars put forward the Fuzzy Analytic Hierarchy Process (FAHP) [11, 12]. The commonly used fuzzy membership function includes triangular fuzzy number, trapezoid fuzzy number and Gao Si fuzzy number. However, Gao Si fuzzy number primitive function does not exist, so it is difficult to realize engineering application. The construction of triangular fuzzy numbers and trapezoidal fuzzy numbers is often artificially selected, and there is still a lot of subjectivity in the construction [13, 14]. Topsis is based on the constructed ideal solution $F(x)^+$ and the negative ideal solution $F(x)^-$. The distance between the target and the ideal solution S^+ and the distance S^- between the target and the negative ideal solution is taken as the criterion of ranking. The formula (2) is calculated.

$$C^* = \frac{S^-}{S^- + S^+} \quad (2)$$

At the same time, the statistical distribution characteristics of C^* can be obtained, which can be used to construct approximate triangular fuzzy numbers. In this way, the subjective problem of fuzzy number construction can be solved.

3.2. Using Topsis and Variance to construct triangular Fuzzy numbers

The expert system is first used to assign the pairwise importance of the indexes. FAHP often takes a 3-scale assignment between 0, 1, 2, let a_{ij} be the index i relative to j , then the assignment rule is shown in Table 1.

Table 1. Fuzzy scaling assignment rules

scale	mean
0	i is not important than j
1	i equal j
2	i is important than j

Assume that there are n experts who scored a_{ij} , and the scoring sequence is $(a_{ij, 1}, a_{ij, 2}, \dots, a_{ij, n})$ according to the Minkowski distance method [15], S^+ and S^- Equations (3) and (4).

$$S^* = \left\{ \sum_k [F(a_{ij, k}) - F(x_M)]^p \right\}^{\frac{1}{p}} \quad (3)$$

$$S^- = \left\{ \sum_k [F(a_{ij,k}) - F(x_0)]^p \right\}^{\frac{1}{p}} \quad (4)$$

Let $C_{ij,k}^*$ be the ideal solution for the a_{ij} scoring of the k expert. C_{ij}^* is the ideal solution for the a_{ij} scoring by all the experts. The m_{ij} is the ideal solution value of C_{ij}^* in this scoring. σ_{ij}^2 is the variance of C_{ij}^* . Then $C_{ij}^* \sim N(m_{ij}, \sigma_{ij}^2)$ is considered. In this way, we get the Gao Si fuzzy number of C_{ij}^* . The isosceles triangular fuzzy number figure shown in formula (5) is established in the right angle coordinate system.

$$\mu_A(x) = \begin{cases} \frac{x-L}{m_{ij}-L}, & L \leq x < m_{ij} \\ \frac{R-x}{R-m_{ij}}, & m_{ij} \leq x < R \\ 0, & x = \text{else} \end{cases} \quad (5)$$

To approximate the area, the size of L and R should satisfy equation (6).

$$\frac{(R-L)}{2} = 2\pi\sigma_{ij}^2 \quad (6)$$

After the establishment of triangular fuzzy numbers, FAHP can be used to determine the weight of indicators at all levels.

3.3. Using Fuzzy Analytic hierarchy process to determine weights

Firstly, a fuzzy judgment matrix is established according to the evaluation of the pairwise importance of the index, as shown in formula (7).

$$D_{ij,m \times n} = \begin{bmatrix} (l_{11}, m_{11}, u_{11}) & \cdots & (l_{1n}, m_{1n}, u_{1n}) \\ \vdots & \ddots & \vdots \\ (l_{n1}, m_{n1}, u_{n1}) & \cdots & (l_{nn}, m_{nn}, u_{nn}) \end{bmatrix} \quad (7)$$

Then, the $D_{ij,n \times n}$ is de-obscured, the steps are as follows:

1) The probability matrix $BB_{n \times n} = \{b_{ij}\}_{n \times n}$ is constructed, where the b_{ij} form is (8).

$$b_{ij} = \frac{l_{ij} + 4m_{ij} + u_{ij}}{6} \quad (8)$$

2) An expert fuzzy evaluation matrix S is constructed, as shown in equation (9).

$$S = \begin{bmatrix} 1 & 1 - \frac{e_{12}}{2(l_{12} + m_{12} + u_{12})} & \dots \\ 1 - \frac{e_{12}}{2(l_{21} + m_{21} + u_{21})} & 1 & \dots \\ \vdots & \vdots & \ddots \\ 1 - \frac{e_{12}}{2(l_{n1} + m_{n1} + u_{n1})} & 1 - \frac{e_{12}}{2(l_{n2} + m_{n2} + u_{n2})} & \dots \\ 1 - \frac{e_{1n}}{2(l_{1n} + m_{1n} + u_{1n})} & & \\ 1 - \frac{e_{12}}{2(l_{2n} + m_{2n} + u_{2n})} & & \\ \vdots & & \\ 1 & & \end{bmatrix} \quad ; \quad e_{ij} = u_{ij} - l_{ij} \quad (9)$$

3) Multiplying the probability matrix B and the corresponding elements of the expert fuzzy evaluation matrix S to obtain the judgment matrix T, that is, the element $t_{ij} = b_{ij} \cdot s_{ij}$. T is adjusted to the fuzzy complementary judgment matrix P according to the equation (10).

$$p_{ij} = \frac{1}{2}(1 + t_{ij} - t_{ji}) \quad (10)$$

4) Check the consistency of P, adjust the test again and again until it meets the requirement of consistency. Be limited to space and refrain from repeating the consistency test.

According to the actual situation, the weight value of each index can be calculated according to formula (11), assuming that the experts in the expert system take equal weight.

$$\omega_i = \frac{1}{n} - \frac{1}{2\alpha} + \frac{1}{n\alpha} \sum_{j=1}^n p_{ij} \quad (11)$$

In the form, $\alpha \geq (n-1)/2$, $i=1,2,\dots,n$.

4. Case Analysis

The missile launch control system under a LRM system is taken as an example. The system realizes the data transfer with the superior computer, the exchange of information between the lower computer and the upper computer to complete the logical relation processing, state control and detection of the whole process of the launch control execution.

First, take three primary indexes as an example to determine the weight of the three indexes to the target layer.

1) Through the expert system, the relative importance of the three indexes is assigned according to Table 1, and the ideal solution and variance are calculated according to the formula (2) (3) (4), as shown in Table 2.

Table 2. Expert system importance assignment results

Index	Expert in order					The ideal solution	The variance
	1	2	3	4	5		
a_{12}	0.5	0.6	0.6	0.4	0.5	0.576	0.043
a_{13}	0.7	0.7	0.7	0.6	0.6	0.730	0.036
a_{23}	0.7	0.6	0.6	0.7	0.6	0.708	0.035

2) The value of $(R-L) / 2$ is determined according to formula (6). As shown in table 3.

Table 3. triangular fuzzy numbers $(R-L) / 2$

Index	a_{12}	a_{13}	a_{23}
$(R-L)/2$	0.273	0.229	0.221

The comparison judgment matrix is obtained as shown in the expression (12).

$$D = \begin{bmatrix} (0.500, 0.500, 0.500) & (0.303, 0.576, 0.849) \\ (0.151, 0.424, 0.697) & (0.500, 0.500, 0.500) \\ (0.041, 0.270, 0.499) & (0.071, 0.292, 0.513) \\ (0.501, 0.730, 0.959) \\ (0.487, 0.708, 0.929) \\ (0.500, 0.500, 0.500) \end{bmatrix} \quad (12)$$

3) The equation (12) is defuzzified according to equations (8), (9), and (10). The weight value is obtained by formula (11), and the weights of three first-order indexes are obtained as shown in Table 4.

Table 4. weights of primary indicators

first-order indexes	B_1	B_2	B_3
weight	0.399	0.346	0.255

Similarly, you can get the weight of all the secondary indicators. Then, according to the test results and the fuzzy comprehensive evaluation data of the field data and expert experience [9], the evaluation values of each secondary index can be obtained. After unifying the dimensionality of the above evaluation values, a comprehensive evaluation can be carried out. Table 5 shows the results of the field testability comprehensive evaluation of the subjects.

Table 5. Integrated scoring results of primary indicator B_1

Secondary index	Dimensional graded	weight
Outfield fault detection rate	0.90	0.192
Outfield fault isolation rate	0.92	0.327
Outfield fault coverage rate	0.92	0.091
Critical fault detection rate	0.95	0.236
Outfield false alarm rate	0.66	0.042
Outfiel false disassemble rate	0.57	0.021
Outfield test time	0.75	0.091
Comprehensive score	0.890	

Finally, the comprehensive evaluation of the other primary indicators and target levels can be deduced from the above process and be limited to space, which will not be restated in this paper.

5. Conclusion

1) According to the characteristics of the equipment under LRM system and the operation characteristics of the corresponding two-level maintenance support system, this paper analyzes the testability verification requirements for the LRM system, and finally puts forward a testability

verification index system suitable for the LRM system based on these requirements.

2) Based on the index system of testability verification, a fuzzy hierarchical evaluation model of Topsis optimization is put forward, and the comprehensive evaluation based on the above index system is realized. The model is simple and accurate.

3) The Topsis is used to determine the maximum possible value of triangular fuzzy number, and the shape of triangular fuzzy number is determined according to the distribution characteristics of the score, which makes the construction of fuzzy number more accurate, and the final comprehensive evaluation result is optimized.

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