Integrated two distribution types of equipment testability verification test evaluation scheme

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Abstract

Targeting at qualitative and quantitative requirements for indicators in equipment testability verification & test evaluation, a scheme integrating two distribution modes is proposed for equipment testability verification & test evaluation. First, the existing testability verification evaluation schemes are combed and analyzed, evaluation scheme integrating two distribution modes is proposed for equipment testability indicators. Then, mathematical theoretical deduction on the approximation of binomial distribution and normal distribution is conducted. Finally, testability verification test on the developing equipment subsystem is carried out. The results show that the scheme can achieve optimization of sample size while obtaining both qualitative and quantitative indicators, and has strong engineering practice value..

Keywords

Testability verification test, evaluation scheme.

1. Introduction

Testability is an important design feature of products, which is an important support to improve the level of equipment fault detection and isolation and enhance the comprehensive assurance capability. Testability verification is an important way to measure equipment testability design and improve the overall efficiency of equipment. Equipment testability verification is divided into qualitative and quantitative requirements. Quantitative assessment is to verify important technical indicators such as fault detection rate, fault isolation rate, false alarm rate mainly with means of fault injection, real equipment test. Qualitative assessment includes all contents not quantified in testability requirements specified in the technical contract standard.

At present, based on the relevant technical standards(Zhong Tian,2006),the verification evaluation methods of testability indicators are mainly divided into two categories: one is a more accurate method based on binomial distribution, which can only make qualitative evaluation, but not quantitative evaluation of technical indicators such as equipment fault detection rate, isolation rate. The other is approximate method based on normal distribution, which supports quantitative evaluation of testability indicators, but accuracy is not high(Yong Zhang , Jing Qiu, Guanjun Liu, et al.2011). Literature describes in detail current testability evaluation scheme and usage in Chinese army, but engineering practice waits to be further improved. Literatureexpounds and compares testability verification methods in military standards both at home and abroad. It points out that the existing relevant standard methods are not uniform and the contents are not complete, thus failing to meet the requirements of testability evaluation in engineering. Suggestions for change are then put forward. Targeting at the problem of small sample size and bad application effect of traditional evaluation method in testability test, literature(Yin Xiang, Feng Jiang, 2016)proposes small sample testability evaluation method for complex electronic equipment, thus solving the problem of equipment testability evaluation in small sample condition.

Therefore, based on the analysis of the existing methods, this paper uses binomial distribution principle to establish a binomial distribution-based comprehensive evaluation method for equipment testability indicator, solve the problem of simultaneous qualitative evaluation and quantitative evaluation in the testability evaluation, and applies it to testability verification test of a certain type of equipment.

2. Analysis of Existing Testability Verification Methods

In the newly revised GJB-2547A, four testability verification schemes are given for different conditions. Two of these schemes directly judge rejection or receipt based on the test data. Two of the schemes provide magnitude estimation of fault detection rate and fault isolation rate(Xishan Zhang,2015).

2.1 Binomial distribution-based evaluation method

2.1.1 Verification scheme to estimate parameter magnitude

1) Determine the sample size: a determine sample size n1 based on adequacy of the sample used in the test; b consider the statistical evaluation requirements of indicators to determine n_2; c verify used sample size n , take the bigger of n_1,n_2 as used sample size for the test.

2) Parameter estimation

a Unilateral lower confidence limit estimate

When the detection (or isolation) failure frequency F≥0, the unilateral lower confidence limit RL of testability parameter is calculated according to formula (1):

$$\sum_{i=0}^{F}\binom{n}{i}R_L^{n-i}\left(1-R_L\right)^i=1-C \tag{1}$$

Where: R_L - unilateral lower confidence limit;

C- Confidence efficient of unilateral lower confidence limit;

n- Sample size

F- Failure times.

b interval estimation

The confidence intervals (R_L, R_U) of the testability parameters can be calculated using the following formula (2) (3):

$$\sum_{i=0}^{F}\binom{n}{i}R_L^{n-i}(1-R_L)^i=\frac{1}{2}(1-C) \tag{2}$$

$$\sum_{i=F}^{n}\binom{n}{i}R_U^{n-i}(1-R_U)^i=\frac{1}{2}(1-C) \tag{3}$$

Where: R_L - unilateral lower confidence limit;

R_U - Unilateral upper confidence limit.

3) Qualification criterion

a If, under the stipulated confidence coefficient, the estimated lower limit is greater than or equal to the minimum acceptable value, then, it is judged as qualified; otherwise, it is unqualified.

b If the proposed FDR and FIR indicators are not indicated as minimum acceptable value, interval estimation can be made and the indicators in the confidence intervals are qualified.

2.1.2 Verification scheme for minimum acceptable value

Determine the sample size: with minimum acceptable value and confidence coefficient C of the relevant parameters (unilateral lower confidence limitR_L) given, a set of fixed number experimental schemes (n, c) can be obtained by solving the equation (4).

$$\sum_{i=0}^{c}\binom{n}{i}(1-R_L)^i R_L^{n-i} \le (1-C) \tag{4}$$

Where: RL - unilateral lower confidence limit;

C-Confidence efficient of unilateral lower confidence limit;

n- Sample size

c – Acceptance number.

Directly solving equations is troublesome, you can check the relevant data table to find a set (n, c).

2) Acceptance judgment: number of detection (isolation) failuresF<C, then it is judged as qualified; otherwise, it is unqualified.

2.1.3 Verification scheme that considers the risk of both sides

Determine the sample size: GB-5080.5 "Verification test scheme for success rate in equipment reliability test", a fixed number test scheme is given for success rate, which can be used in the verification test scheme of fault detection rate and isolation rate (Ran Chen,2016). This verification scheme is based on the following formula. Directly solving n and c values by the formula is complicated, you can check the data table given by the standard.:

$$\begin{cases} 1-\sum_{i=0}^{c}\binom{n}{i}(1-R_0)^i R_0^{n-i} \le \alpha \\ \sum_{i=0}^{c}\binom{n}{i}(1-R_1)^i R_1^{n-i} \le \beta \end{cases} \tag{5}$$

Where: R_0- Acceptable success rate;

R_1- Unacceptable success rate;

α-Risk of the manufacturer;

β- Risk of the ordering party.

2) Qualification criteria: if detection (or isolation) failure frequencyF<C, then it is accepted.

2.2 Normal distribution-based evaluation method

The normal distribution-based testability verification test is usually carried out based on verification scheme in GJB-2072 "Maintainability Test and Evaluation", specifically as follows:

1) Determine the sample size: The experimental sample size n in the testability verification scheme given by GJB-2072 is no less than 30 fault sample sizes by referring to maintainability verification test.

a When 0.1 <P <0.9, calculate the detection rate under the specified confidence level and the isolation rate lower confidence limit R_L using a formula based on normal distribution:

$$R_L = P + Z_\alpha \sqrt{\frac{P(1-P)}{n}} \tag{6}$$

Where: R_L -unilateral lower confidence limit;

P-Point estimate of fault detection rate or isolation rate;

n -test sample size

Zα- confidence level correlation coefficient.

b When P≤0.1 or P≥0.9 , calculate the detection rate under the specified confidence level and the isolation rate lower confidence limit R_L using formula (7) based on $\chi 2$ distribution:

$$R_L = \begin{cases} \dfrac{2\lambda}{2n-k+1+\lambda} & (P \le 0.1) \\ \dfrac{n+k-\lambda^{'}}{n+k+\lambda^{'}} & (P \ge 0.9) \end{cases} \tag{7}$$

Where:

$\lambda = \frac{1}{2}\chi_{\alpha}{}^{2}(2k)$;

$\lambda^{'} = \frac{1}{2}\chi_{1-\alpha}^{2}[2(n-k)+2]$

2) Qualification criterion: If $P_L \ge P_S$ (lowest acceptable value), then it is accepted; otherwise rejected. Comparison of the above four schemes is shown in Table 1.

Table 1 Comparison of existing testability verification test schemes.

Test scheme		Advantages	Disadvantages	Application condition
Based on binomial distribution	verification scheme that considers the risk of both sides	(1) qualification criterion is reasonable and accurate (2) n and c are explicitly stipulated	(1) parameter estimates are not given (2) The composition characteristics of equipment are not considered.	It is applicable to fault injection test of infield, verification of test parameter values with risk requirements for both parties, and is not suitable for situations where confidence coefficient is required
	Minimum acceptable value	(1) qualification criterion is reasonable and accurate (2) Composition characteristics of equipment are considered	(1) The risk of both parties is not taken into consideration	It is applicable to fault injection test of infield, verification of lowest acceptable values of testability parameters that have confidence coefficient requirement, not applicable to situations where α and β are required
	Test scheme to estimate the parameter magnitude	(1) qualification criterion is reasonable and accurate (2) Composition characteristics of equipment are considered (3) parameter estimates are given	(1) Two much analyses (2) The risk of both parties is not taken into consideration	It is applicable to situations where confidence coefficient is required, not applicable to situations where α and β are required
Based on normal distribution	GJB-2072-94	(1) Simple and easy (2) Lower limit, the approximate value can be obtained	(1) assessment accuracy is insufficient (2) Product characteristics are not considered	It is applicable to situations where confidence coefficient is required, not applicable to situations where α and β are required

3. Biomial Distribution-Based Testability Comprehensive Verification Method

3.1 Comprehensive verification scheme framework

Of the above four schemes, only the verification scheme of GJB-2072 and that of estimated parameter values provide method to estimate magnitude of fault detection rate and fault isolation rate. For testability evaluation, quantitative detection rate, isolation rate indicators are more intuitive and more persuasive, more practical, which are indicator forms more concerned by the manufacturer and ordering party(Tianmei.Li,2010). In the GJB-2072 verification scheme, method of determining the sample size of testability verification test is not given explicitly. It is too complicated to determine the sample size with reference to maintainability. In addition, applicability of the test sample size determined under the maintainability requirement to testability test waits to be verified. However, verification scheme considering risks of both sides has more reasonable and accurate qualification criterion, and the sample size can be easily obtained by table search (Yong Zhang , Jing Qiu, Guanjun Liu, et al.2011). This paper presents a new comprehensive verification scheme for evaluation. First, verification scheme considering the risk of both parties is adopted for judgment of acceptance or rejection. Then, magnitude of detection rate and isolation rate are evaluated by using the verification scheme GJB-2072.

Establishment of this method must be proved by approximation relation between binomial distribution and normal distribution.

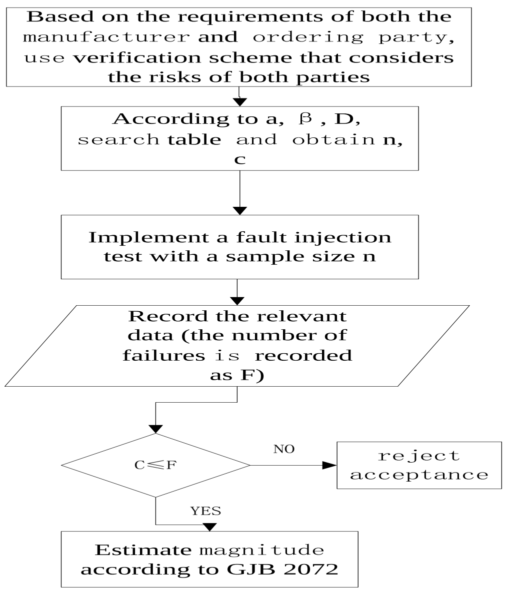

Figure 1 block diagram of binomial distribution based.

3.2 Demonstration of approximation relation between binomial distribution and normal distribution

Repeatedly carry out n independent tests under the same conditions, and there may be only one of two opposite results A and Ā. Assume that probability of A occurring in the same test is: 0 <p <1, then the total number of times k that A appears in n independent tests is a random variable, and the following is always met:

$$P\{X=k\}=C_n^k p^k q^{n-k}, \quad (k=0,1,2\ldots n) \tag{8}$$

The above distribution is called binomial distribution, X follows binomial distribution with parameters n, p, which can be denoted as $X \sim b(n,p)$.

Suppose the probability density of continuous random variable X is:

$$f(\mathrm{x})=\frac{1}{\sqrt{2\pi}\sigma}e^{\frac{-(x-\mu)^2}{2\sigma^2}},-\infty<x\le\infty \tag{9}$$

Where σ, μ are constants, σ> 0, then X follows the normal distribution with parameters σ, μ, which can be denoted as $X\sim N(\mu,\sigma^2)$.

Normal distribution is one of the most common distributions in nature and engineering. A large number of random phenomena follow or approximately follow normal distribution. Literature (Yang Yu,2008) points out that if a random indicator is influenced by many minor independent random factors, and none of them is decisive, then the random indicator can be regarded as following or approximately following normal distribution.

Theorem: Suppose random variable $X_n\sim b(n,p)(0<p<1,n=1,2\ldots)$, then for any x, there is:

$$\lim_{n\to\infty}\left\{\frac{X_n-np}{\sqrt{np(1-p)}}\le x\right\}=\int_{-\infty}^{x}\frac{1}{\sqrt{2\pi}}e^{\frac{-t^2}{2}}dt=\Phi(\mathrm{x}) \tag{10}$$

This theorem is the famous De Moivre-Laplace central limit theorem in probability theory, which is a special case of Levy-Lindbergh's theorem. The theorem shows that when n is sufficiently large, binomial distribution can be approximated to the special case of Burger theorem by a normal distribution. Also, the theorem shows that when n is sufficiently large, binomial distribution can be approximated by a normal distribution, that is, normal approximation of binomial distribution (Gairong Zhou,2004). According to the above theorem, $\frac{X_n-np}{\sqrt{np(1-p)}}$ approximately follows N (0,1) or equivalently, Xn approximately follows N(np,np(1-p)). Then, the above probability can be approximately calculated by normal distribution, that is:

$$\begin{aligned}&P\{X=k\}=C_n^k p^k q^{n-k}\\&\approx\frac{1}{\sqrt{2\pi npq}}e^{-\frac{(k-np)^2}{2npq}}=\frac{1}{\sqrt{npq}}\varphi(\frac{k-np}{\sqrt{npq}})\end{aligned} \tag{11}$$

$$\begin{aligned}&P\{a\le X_n\le b\}\\&=P\left\{\frac{a-np}{\sqrt{np(1-p)}}\le\frac{X_n-np}{\sqrt{np(1-p)}}\le\frac{b-np}{\sqrt{np(1-p)}}\right\}\\&\approx\Phi\left(\frac{b-np}{\sqrt{np(1-p)}}\right)-\Phi\left(\frac{a-np}{\sqrt{np(1-p)}}\right)\end{aligned} \tag{12}$$

Value equivalently accurate to $P\{\mathrm{a}\le X_n\le \mathrm{b}\}$, can be easily obtained by searching the standard normal distribution function table. In principle, formulas (l1) and (12) apply to any given P and a sufficiently large n. However, when P is larger or smaller, the approximate effect is poorer. For the requirements of n and p, empirical criteria has that $npq\ge 9$ must be satisfied, and it is best to satisfy $0.1\le P\le 0.9$ in application. The above demonstration process provides a theoretical basis for binomial distribution-based comprehensive equipment testability verification scheme proposed in this paper.

3.3 Indicator evaluation & calculation method

In the first step, determine the sample size; GB-5080.5 "verification test scheme for success rate in equipment reliability test" provides fixed number test scheme for success rate, which can be used as verification test scheme for fault detection rate and isolation rate. The verification scheme is based on formula (13), and directly solving n and c by the formula is complicated. Instead, data table given by the standard can be searched.

$$\begin{cases} 1-\sum_{i=0}^{c}\binom{n}{i}(1-R_0)^i R_0^{n-i} \le \alpha \\ \sum_{i=0}^{c}\binom{n}{i}(1-R_1)^i R_1^{n-i} \le \beta \end{cases} \tag{13}$$

Where: R_0 - Acceptable success rate;

R_1 - Unacceptable success rate;

α - Manufacturer's risk

β - Ordering party's risk.

In the second step: parameter estimation

$$\lim_{n\to\infty}\left\{\frac{X_n-np}{\sqrt{np(1-p)}}\le x\right\}=\int_{-\infty}^{x}\frac{1}{\sqrt{2\pi}}e^{\frac{-t^2}{2}}dt=\Phi(x) \tag{14}$$

(1410)

Where: RL -unilateral lower confidence limit;

P -Point estimate of failure detection rate or isolation rate;

n-Test sample size

Z_α Correlation Coefficient with Confidence Level.

In the third step: qualification criterion;

If $R_L \ge R_S$ (lowest acceptable value), then it is accepted; otherwise rejected.

4. Test Verification

A subsystem functional block diagram of typical equipment is known that there are 47 fault modes in the system. The fault samples are distributed according to the method in GJB-2072-94. Under this system, with detection rate indicator as an example, GJB-2072 verification scheme and binominal distribution-based comprehensive testability verification scheme are respectively used for experiments.

4.1 GJB 2072 verification scheme

GJB-2072-94 does not provide the specific formula of sample size value. Combining methods of GJB1135.3-91, GJB1770.3-93, sample size is selected according to formula (15) (Junyou Shi,2011)

$$n=\frac{\left(Z_{1-\frac{\partial}{2}}\right)^2 P_s(1-P_s)}{\delta^2} \tag{15}$$

Where, $1-\frac{\partial}{2}$ is 100($1-\frac{\partial}{2}$)percentile of standard normal distribution, which is 1.64 by searching the table. The detection rate required value is 80%, δ is the maximum deviation. GJB1135.3-91 specifies that its value range is 0.01～ 0.05. The relationship between sample size n and the maximum deviation δ is shown in Figure 2:

As can be seen from the curve, the value of δ has a great influence on sample size, up to 4303 and down to 171. In order to facilitate the real equipment test, δ = 0.05 is taken in the test. The calculated sample size is about 172.1 and 172 samples are taken for fault injection test. Unilateral lower limit is calculated according to formula (6), the test results are shown in Table 2.

Table 2 GJB 2072 verification scheme test results.

sample size	number of successful samples	point estimate	unilateral lower confidence limit
172	138	80.23%	80.27%

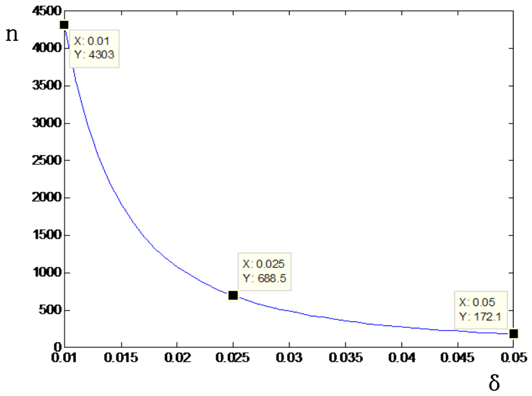

Figure 2 Relation curve of sample size n and maximum deviation δ.

4.2 Binomial distribution- based comprehensive testability verification scheme

The risk values of the two parties determined by the experiment are α=β=0.1 and the detection rate required value is 80%, D=(1—R1)/(1—R0)=2. (n，c)=(61,16) can be obtained by table search. The fault injection test is performed according to sample size 61, and the results obtained are shown in Table 3.

Table 3 Binomial distribution- based comprehensive testability verification scheme.

sample size	number of successful samples	point estimate	unilateral lower confidence limit
61	49	80.33%	80.35%

4.3 Results Analysis

The value obtained in sample size calculation according to GJB2072-94 scheme is greatly different from that calculated according to binomial distribution-based comprehensive testability verification scheme. The value of the maximum deviation δ in GJB2072-94 scheme is a certain value between 0.01～0.05. For different δ, sample size difference is big, which causes a greater burden on test cost and sample distribution. In this paper, the object used in the experiment is only a subsystem. If the whole system is tested, the sample size will be too large to be feasible. Instead, binomial distribution-based comprehensive testability verification scheme specifies sample size calculation method, so that sample size selection can be done by searching the existing data table. In this way, sample size is reasonable, which can achieve full coverage of fault mode conveniently and fast, and also facilitate engineering operations.

In the two schemes, difference in point estimate result is 0.1%, and difference in confidence lower limit is 0.08%. The difference between the two schemes in this experimental verification mainly lies in sample size selection method. GJB2072-94 scheme holds that random variable follows lognormal distribution, and proceeds with sample size selection under this premise. However, binomial distribution- based comprehensive testability verification scheme considers that random variable follows binomial distribution. Whether the fault can be successfully detected in the test is a success-failure issue. The successful detection times of random variables obviously follows binomial distribution. It is proved in 2.2 that binomial distribution and normal distribution can be approximated under the premise of $0.1 \le p \le 0.9$. The experimental results show that the proposed method is feasible and has certain practical value under the engineering background.

5. Conclusion

Based on analysis of the existing testability verification scheme, this paper proposes a binomial distribution-based comprehensive testability verification scheme. By proving approximation of binomial distribution and normal distribution within the scope of specified testability indicator point estimate, it provides a theoretical basis for comprehensive verification scheme. Finally, experimental verification is done for the same test object. The experiment shows that the scheme is not only feasible, but also clarifies sample size calculation method and achieves sample size optimization. At the same time, this scheme realizes magnitude estimation of detection rate and isolation rate, which means more practical value. However, this solution is only applicable when $0.1 \le P \le 0.9$. When $P < 0.1$ or $P > 0.9$, binomial distribution has a poor approximation to normal distribution, which renders ineffectiveness of the method.

References

[1] Gairong Zhou.2004,Foundation of probability and mathematical statistics . Shanghai: Fudan University Press, : 67-71

[2] Junyou Shi . 2011: Testability Design Analysis and Verification Beijing: National Defense Industry Press, 277-280.

[3] Junyou SHI,Chao Ji , Li Haiwei.2012,Analysis of Testability Verification Technology and Its Application Status,Measurement & Control Technology,31 (5): 29-32

[4] Ran Chen, Guangyao Lian,i Baochen L.2014 Sequential regression-based experimental test scheme for small samples. Journal of Aerospace Power, ,29 (8): 1968-1974.

[5] Ran Chen.,2016 Research on Key Techniques of Equipment Testability Verification for LRM System. Shijiazhuang Ordnance Engineering College.

[6] Tianmei.Li Optimization Design and Comprehensive Evaluation Method for Equipment Testability Verification Test. Changsha: National University of Defense Technology, 2010

[7] Xishan Zhang.2015,A Study on Evaluation of Small Sample Sequences for Complex Electronic Equipment Shijiazhuang Ordnance Engineering College.

[8] Yang Yu.2008,Analysis of the relationship between binomial distribution, Poisson distribution and normal distribution . Enterprise Science and Technology & Development, (20): 108-200.

[9] Yin Xiang, Jiang Feng.2016, Overview of Equipment Testability Verification Technology,. Electronic Product Reliability and Environment Test, 34, (2): 65-67.

[10] Yong Zhang , Jing Qiu, Guanjun Liu, et al.2011, Comparison and prospect of testability models. Chinese Journal of Test and Measurement Technology, 26 (6): 504-514.

[11] Zhong Tian ,Junyou Shi. 2006,Analysis of ExistingTesting and Verification Methods and Suggestions .Quality and Reliability, (2): 47-51.