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A method for estimation of exponential component storage life distribution parameter

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Abstract. With regard to the problem of storage reliability in the long-term storage of weapon equipment including torpedo, mine and missile, this paper analyzes the practical dilemma of difficultly in accurately determining the storage life of existing equipment and points out that the storage life of components is crucial to the storage life of equipment. For this reason, this paper proposes a method for estimating the exponential component storage life distribution parameter by utilizing the test results during the actual storage period. As revealed in the example design and numerous results of simulation verification, this proposed estimation method brings satisfying results, and overcomes the shortcoming of conventional storage test in its demand for a large number of samples, so it has very high value for practical application.

Key words. Exponential distribution, storage life, parameter estimation.

1. Introduction

Most civil and military products are put into service or commission as soon as they are delivered from factory, and basically operate till the end of their full lifecycle. Hence, people often care about the indicators for their operational reliability and overlook the indicators for their storage reliability. Nevertheless, it is worth noting that some products, especially military weapon equipment such as missile, mine and torpedo, must be stored in the shore-based warehouse, ship warehouse, and even launch or carrying component for a long time after being delivered from factory, and may be put into service and enter into the battle status after receiving the mission [1-3]. With regard to these weapon equipment, we should not only pay attention to the indicators for their operational reliability, but also attach more importance to

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the indicators for their storage reliability. Among them, storage life is an important parameter for the reliability of equipment storage.

Generally, storage life refers to the time taken for ammunition to reach its given reliability after its storage starts under the given storage conditions. In this paper, we define storage life as the time when a product fails after it is stored. Predicting the storage life of weapon equipment accurately can not only help reduce the storage cost of weapon equipment and conserve the resources, but also provide the basis for correct decision on the inspection and repair of equipment and reduce the cost of logistics guarantee while enhancing the perfectness of storage equipment [4]. This paper introduces a method for estimating the exponential component storage life distribution parameter by utilizing the test results during the actual storage period. Based on the estimation of storage life distribution regularity, we can answer such questions as "how possible is that at least 80 out of 100 torpedoes are still intact after they are stored for 3 years", so as to accurately assess the effect of storage.

2. Description of exponential component storage life

Torpedo, mine and missile belong to the weapon equipments that are stored in most cases, so they are called long-term stored equipment. Taking torpedo as an example, torpedo is often stored for years, and its unit cost is very high, so it is difficult to accurately determine its storage life distribution parameter through the theoretical storage test (requiring enough test duration and number of samples) due to time and economic costs. Moreover, it is impossible to carry out the real-time and online continuous test for a torpedo or its components during its full storage life, but we can only judge whether the torpedo (or its component) is "intact" or "failed" at a discrete test time T_c. If keeping the storage life of weapon equipment as T_0, the discrete test can only find out the storage life $T_0 > T_c$ (the test result is "intact") or $T_0 < T_c$ (the test result is "failed", but cannot obtain the accurate value of the storage life T_0). The failure to obtain the accurate time of failure during the storage period is an important reason why it is difficult to accurately find out the storage reliability of weapons including torpedo.

A storage batch normally involves a large number of torpedoes, so sampling test is periodically carried out during the storage period, and able to locate the failure at a certain level of component. After a long storage period, a certain amount of storage test results will be accumulated. The storage life of components including elements is a key factor affecting the storage life of equipments such as torpedo, mine and missile. For instance, the statistical data of more than 1,000 missiles stored for 12 years revealed that more than 90% of missiles failed the test due to their elements and components. Hence, component storage reliability directly affects the storage stability of equipment. General speaking, the life of electronic parts is subject to exponential distribution, e.g. printed circuit board plug-in, electronic part, resistor, capacitor and integrated circuit, etc. In this paper, the component with the life X subject to exponential distribution is called exponent component, which is represented by $X \sim Exp(\lambda)$. Among them, the failure rate is $\lambda > 0$; the physical meaning of $\frac{1}{\lambda}$ is average life; and the distribution function of X is

$F(x) = 1 - e^{-\lambda x}$.

3. Estimation model of exponential component storage life distribution parameter

If the average storage life of exponential component is t_0, and there are m batches of test results, the results of the ith test are represented by $[cT_i \quad N1_i \quad N0_i\ ]$. Among them, cT_i stands for the time that sample components in the batch are stored till this test; $N1_i$ is the number of components that are intact in the test results; and $N0_i$ is the number of components that are failed in the test results. Hence, the estimation model of exponential component storage life distribution parameter is formed in the following steps:

1) Generate n candidate failure rates $\lambda_j, 1 \le j \le n$.

Based on the past experience, the upper limit $T_{\max}$ and lower limit $T_{\min}$ of the average storage life for the components are estimated, and should satisfy $T_{\max} > T_0 > T_{\min}$ ($T_{\max}$ and $T_{\min}$ are not required to get close to the average storage life of components T_0). After taking the step length $dT = \frac{T_{\max} - T_{\min}}{n}$, we obtain $\lambda_j = \frac{1}{T_{\max}} + (j-1)\frac{1}{dT}, 1 \le j \le n$. The value of n depends on the requirement for the estimation accuracy of T_0.

2) With regard to n failure rates λ_j in 1), give the corresponding weight parameters $W_j, 1 \le j \le n$. Initiate the weight coefficient W_j, and let $W_j = \frac{1}{n}$.

3) After checking the test results of each batch, modify the weight coefficient W_j.

3.1) Let $i = 1$.

3.2) Based on the results $[cT_i \quad N1_i \quad N0_i\ ]$ of the ith test, calculate $P1_j = e^{-\lambda_j \bullet cT_i}$, $\quad P0_j = 1 - P1_j$, $\quad P_j = P1_j^{N1_i} \bullet P0_j^{N0_i}$ for all candidate failure rates λ_j. Among them, P_j quantitatively describes the likeliness of test results $[cT_i \quad N1_i \quad N0_i\ ]$; cT_i stands for the time that sample components are stored till the ith test; $N1_i$ indicates the number of components whose result in the ith test is intact; and $N0_i$ is the number of components whose result in the ith test is failed.

3.3) Modify the weight coefficient W_j, and let $W_j = \frac{W_j \bullet P_j}{\sum_{k=1}^{n} W_k \bullet P_k}, 1 \le j \le n$.

3.4) Let $i = i + 1$. If $i \le m$, execute the step in 3.2). If not, execute the step in 4). Among them, m stands for the results of m tests in total.

4) Let $\hat{\lambda} = \sum_{j=1}^{n} W_j \bullet \lambda_j$ be the estimated storage life failure rate of the exponential component. Hence, $\frac{1}{\hat{\lambda}}$ is the estimated average storage life t_0 of exponential components.

4. Example design

For convenience of expression, it is assumed that the total number of samples in each test is 10. Assuming that the average storage life of an exponential component is 120 months, a test is carried out every 6 months, and 10 sample tests are carried out. The test results are given in Table 1.

Table 1. Test results

Test Time	6	12	18	24	30	36	42	48	54	60
Number of Intact Components	10	10	7	10	8	8	6	5	6	7
Number of Failed Components	0	0	3	0	2	2	4	5	4	3

The exponential component storage life distribution parameter is estimated in the following process:

1) Estimate the average storage life of the component. If it is between 12˜240 months, and the estimation accuracy is 12 months, 20 candidate failure rates are generated, i.e. $\lambda_j, 1 \leq j \leq 20$,$\lambda_j = \frac{1}{12 \bullet j}$.

2) Initialize the weight coefficientW_j, and let $W_j = \frac{1}{20}$.

3) Check the test results of each batch, and modify the weight coefficientW_j. The calculation results are given in Table 2.

4) Let $\hat{\lambda} = \sum_{k=1}^{20} W_k \bullet \lambda_k$ be the estimated storage life failure rate of the exponential component. There is$\frac{1}{\hat{\lambda}} = 131.7$, which the estimated average storage life of exponential unit isT_0.

5. Simulation analysis

The following simulation model can be employed to simulate the storage process for the total number of samples S as well as the results of the ith test.

1) Generate a set of random numbers $X_s, 1 \leq s \leq S$ following the law$Exp(\frac{1}{t_0})$;

2) Find out all the random numbers larger than cT_i from this group, and let the total number be$N1_i$. Let$N0_i = S - N1_i$.

Fig. 1 presents the box plot of results in the extensive simulation of parameters with the proposed method for the above example. Based on the simulation results, the estimated average storage life of the exponential component is 133.2, and the root mean square error is 26.4. This means that the simulation result of average storage life is consistent with the average storage life of 120 months given in the example.

Table 2. Adjusted results of weight coefficient based on batch tests in the example

Batch No.	$\mathbf{W}_1$	$\mathbf{W}_2$	$\mathbf{W}_3$	$\mathbf{W}_4$	$\mathbf{W}_5$	$\mathbf{W}_6$	$\mathbf{W}_7$	$\mathbf{W}_8$	$\mathbf{W}_9$	$\mathbf{W}_{10}$	$\mathbf{W}_{11}$	$\mathbf{W}_{12}$

6. Conclusion

Considering the problem of storage reliability in the long-term storage of weapon equipments including torpedo, mine and missile, this paper analyzes the test mechanism in the existing equipment storage management process as well as the difficulty

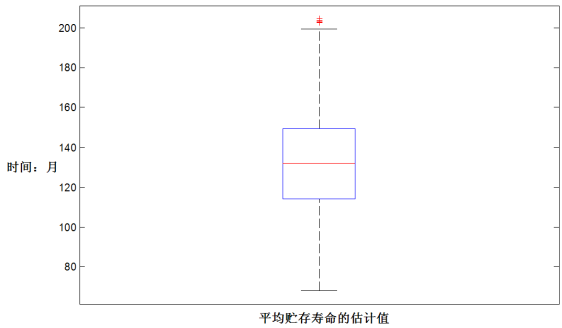

Fig. 1. Box plot of simulation results for average storage life based on the parameters in the example

in determining the storage life of equipment. Based on the censored data accumulated from a large number of tests, a method is proposed to estimate the exponential component storage life distribution parameter. With the example design and numerous results of simulation verification, it is revealed that this proposed method can accurately estimate the storage life distribution regularity of exponential components within the acceptable confidence interval. With this method, the estimation results are rarely affected by the sample size, and any accurate setting of initial interval is not required for storage life. On the contrary, the estimation will be more accurate if the initial interval is set wider.

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