SIMULATION MODEL FOR SPARE PARTS REQUIREMENT OF COMPONENTS IN SERIES SYSTEM

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Abstract

The general simulation method for spare parts requirement of components in series system is discussed in this paper. Considering the working components and spare parts as a cold storing system is the theory basis for simulation model. When the system reliability is equal to the required reliability, the number of the spare parts in this system is just the required number for the components. The simulation step and flow and result is offered. The calculation result proves the necessity of considering the used time of components. The model is instructive for determining the number of spare parts.

Keywords: spare parts; life distribution; reliability; simulation

Reasonable spare store is one of important factors for mission success probability of ship. Equipment system of ship is very complicated. And it is composed of many systems in series with same components. Through considering each component as independent unit and calculating its spare parts requirement, spare parts requirement is gained by multiplying number of same components and their own spare parts requirement, but it isn't reasonable. Therefore, it's necessary to construct spare parts requirement model for system in series with same components. About parts life obeying exponential distribution, the parsing calculation model is constructed because exponential distribution unremembered speciality. And for Weibull distribution and normal school, it's very difficult to construct parsing calculation model, so the simulation technical is needed.

1 Theory gist and hypothesis

The spare parts requirement model discussed in the paper is constructed on the basis of mission reliability. Spare parts store aims to make the system mission reliability required reliability equal. Here system is composed of working parts and their own spare parts.

System spare parts sufficiency rate is a probability whether system could gain its own spare parts once each replaceable component conks out. Except component replacing time and other factors affecting mission success, the mission reliability that both former working component and its replacing spare part have achieved equals to its spare parts sufficiency rate. Besides, confirming spare parts reciprocal operation is to forecast spare parts requirement on the condition of required mission reliability.

Both equipment components and their spare parts compose a cold storing system. Supposed that former component residual life equals x_0, and its spare parts' life is respective x_1, x_2, …, x_n, and they are separated each other. $P(X_0>t)$ represents a probability that equipment components don't conk out during the mission period while ship execution mission time is t. when the probability is above required value, this kind of component need not spare parts during the mission period; and $P(X_0+X_1>t)$ represents a probability that equipment component with only one spare part continue its work to end time of mission; similarly $P(X_0+X_1+\ldots+X_n)$ represents a probability that equipment component with n spare parts continue working to the end time of mission. From the definition of reliability we know that the probability is just the system reliability. When failure happens to the working units and could be solved by replaced parts, $P(X_0+X_1+\ldots+X_n>t)$ is the probability of system mission success too. Therefore in the antecedent of the following hypotheses, system mission reliability equals to the spare parts sufficiency rate, and their calculation formulation is current, and when system mission reliability is just bigger than required reliability, spare parts requirement is n namely, so spare parts sufficiency rate and spare parts requirement is equivalent.

Hypotheses about spare parts sufficiency rate is established as following:

(1) Life distribution of same type spare parts is same, and they don't conk out during the store time;

(2) Equipment fault can be solved by replacing parts, and the replacing time can be neglected;

(3) Don't consider climate, environment and man-made factors etc affecting mission success;

(4) During mission time all components are regarded as unrepairable.

2 Simulation idea and flow

Take double parameter Weibull life distribution as example, the problem is described as follows: The system is composed of two work components and n spares. The work component is replaced by one spare when failed until no more available spare. Thus, simulation idea is: Firstly, the life samples of two work components are calculated. The component whose life sample is smaller is considered failed and is replaced by spare. Secondly, the life samples of the remained component and the new spare are calculated. Same, the component whose life sample is smaller is considered failed and is replaced by spare. Then, repeat the process until no more spare spares. The sum of every smaller life equals the life of system of components and spares. If the life of system exceeds the mission time, the number of stored spares is satisfied to mission requirement. Take the simulation process with N times, suppose the times of success is K, then the system reliability approximately equals K/N.

The simulation steps as follows:

Step 1: Determining the known condition such as number of spares, called as n, and mission time, called as *TT*, and simulation times, called as *SIMtotal*.

Step 2: Initializing the mission success, called as *Sucnum*, and current simulation times, called as *SIMnum*.

Step 3: Comparing *SIMnum* to *SIMtotal*. If *SIMnum* ⩽ *SIMtotal*, go on next steps. If *SIMnum*>*SIMtotal* , go to step 7.

Step 4: Calculating the life samples of the two work component, noted as t_{01} 、 t_{02}. $t_0=\min(t_{01}、t_{02})$, then calculating the life samples of the replaced spares and the remained component. $t_1=\min(t_{01}、t_{02})$. Repeatedly, t_2 until t_n can be calculated. Therefore, the life of system of components and spares, noted as *T*, can be calculated by following equation:

$$T = t_0 + \sum_{1}^{n} t_i$$

Step 5: if *T*⩾*TT*, then *Sucnum*=*Sucnum*+1, *SIMnum*=*SIMnum*+1, go to step 3.

Step 6: if *T*<*TT*, then *SIMnum*=*SIMnum*+1, go to step 3.

Step 7: Finishing the simulation and calculating the mission success probability: *P*=*Sucnum*/*SIMtotal*.

The simulation tactic and step is same for series system with multi-component and for other life distribution.

3 Calculating example

Take double parameter Weibull life distribution as example, the distribution function and probability density function as follows:

$$F(t) = 1 - e^{-(\lambda t)^{\alpha}}$$

$$f(t) = \lambda\alpha(\lambda t)^{\alpha-1} e^{-(\lambda t)^{\alpha}}$$

The life and residual life sampling equation is:

$$t_F = \left(-\ln(1-\eta)\right)^{\frac{1}{\alpha}} \Big/ \lambda$$

$$t_{0F} = \left(1/\lambda\right)\left[(\lambda t_0)^{\alpha} - \ln(1-\eta)\right]^{1/\alpha} - t_0$$

Supposed the distribution parameter as: λ=1/1000, α=2.The result is given in table 1.

Table 1: the result of series system

Spare number	3	9	15	18	21	30	36	45
Series number	1	3	5	6	7	10	12	15
reliability	0.867	0.9042	0.931	0.9342	0.9533	0.9724	0.982	0.99

The algorithm can calculate the spare requirement of component with different worked time. Table 2 gives the result for system of 3 components with 10 spares.

Table 2: the result for mission of 2400 hour when considering worked time

Worked time	2,2.5,3	6,2.5,3	2,8,3	6,8,3	6,8,7	6,8,10	9,8,10	0,0,0
reliability	0.9524	0.942	0.9358	0.9121	0.893	0.8846	0.8796	0.9796

4 result analysis

4.1 validating of simulation algorithm

Parse model could be done for system in series and their components natural life obeys exponential distribution. Here is a system in series which is composed of k components, and there are n spare parts in store. Its reliability calculating formulation is as following:

$$R_S(t) = e^{-k\lambda t}\left[1 + k\lambda t + \frac{(k\lambda t)^2}{2!} + \frac{(k\lambda t)^3}{3!} + \cdots + \frac{(k\lambda t)^n}{n!}\right]$$

Annotation: λ means the fault rate of exponential distribution.

Supposed the distribution parameter λ equals to 1/1000, and mission time is 2000, then system reliability would be calculated by parse model and simulation model respectively on the condition of different numbers of spare parts and components in series (see Table 3).

Table 3 system reliability of two components in series

Spare number	2	3	4	5	6	7	8
Parse algorithm	0.2381	0.4335	0.6288	0.7851	0.8893	0.9489	0.9786
Simulation algorithm	0.239	0.4314	0.6232	0.7838	0.8934	0.95.	0.9798

Reliability comparison indicates that both algorithms appear well. Also the simulation algorithm based on numbers of same components in series is in point.

4.2 meaning of spare parts requirement model for multi-components in series

In order to prove the spare parts requirement num1 not always equals to the product num2 of single component spare parts requirement and series number, we compare num1 with num2 by different kind of components whose life obeys exponential distribution and weibull distribution respectively. But their parameters are same, and results are as following (see Table 4 and 5).

Table 4 result of exponential components in series (mission time is 2000h)

Series number	1	2	4	6	7	10	16	25
Spare number	4	7	13	18	20	27	42	62
reliability	0.9489	0.9042	0.931	0.9342	0.9533	0.9724	0.982	0.99

Seeing from table 4, when required mission reliability is 0.95, the gap between num1 and num2 of the exponential components becomes bigger gradually along with components numbers in series added. When series numbers is 25, num1 equals to 62 and num2 equals to 100. That is, for system in series composed of 25 components, to achieve same goal, num2 is 38 more than num2, and this case results in biggish waste.

Table 5 result of weibull components in series (mission time is 3000h)

Series number	2	3	4	5	8	10	16	25
Spare number	8	12	15	19	29	35	55	84
reliability	0.9528	0.9662	0.9534	0.969	0.9648	0.9456	0.9526	0.9568

Seeing from table 5, when required mission reliability is 0.95, the gap between num1 and num2 of the exponential components becomes bigger gradually along with components numbers in series added. When series numbers is 25, num1 equals to 84 and num2 equals to 100. That is, for system in series composed of 25 components, to achieve same goal, num2 is 38 more than num2, and this case results in biggish unnecessary waste.

4.3 Working time's affection on spare parts requirement

If working time don't affect spare parts requirement, and the process of every sample is from new component. Then based on the same parameters, we compare single component with system in series composed of numbers of components, and its mission time is 2400h. Considering convenience, working time of components in series is same (see Table 6 and 7).

Table 6 comparison of single weibull component（3 spares）

Working time	200	400	600	800	900	1000	1200
不考虑时的 R	0.89734	0.89734	0.89734	0.89734	0.89734	0.89734	0.89734
考虑时的 R	0.862	0.82134	0.80042	0.77994	0.76858	0.75472.	0.74686

Table 7 comparison of many weibull components（16 spares and 5 series）

Working time	200	400	600	800	900	1000	1200
不考虑时的 R	0.9846	0.9846	0.9846	0.9846	0.9846	0.9846	0.9846
考虑时的 R	0.9592	0.9302	0.8978	0.8528	0.8418	0.832.	0.784

5 Conclusions

The paper establishes numbers of models solving spare parts requirement of system in series composed of unrepairable components, tests the correctness of algorithms. Models deal with working time affection on spare parts requirement, results is creditable, model applicability is better and could solve spare parts requirement of any distribution components, also it is instructive to forecast spare parts requirement for different equipment and their same components in series with different working time.

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