Analysis of the influence of the universality of aviation equipment parts on the probability of spare parts support and equipment availability

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Abstract. To study the impact of universal parts on spare parts support probability and equipment availability, first, the calculation method of spare parts support probability is given. According to the difference in equipment and spare parts number, the change of spare parts support probability is mathematically derived and proved, and then solved and verified by the Monte Carlo simulation method. Secondly, according to the calculation model of equipment availability of series systems, the influence of parts universality on equipment availability is calculated and compared. Through calculation and simulation, it is concluded that the spare parts support probability can be effectively improved, the deviation of support probability can be reduced, and the availability of equipment can be improved when the parts are common and the number of aircraft/spare parts is the same.

Keywords: Parts and components; Universality; Support probability; Availability

1 Introduction

Universality refers to a standardized form of expanding the scope of use of the same object (including parts, components, components, etc.) as far as possible based on interchangeability. Universality can reduce the duplication of labor in the design and manufacturing process of parts, achieve the purpose of reducing costs, and shorten cycles [1-4]. The universal design of equipment from two aspects of system efficiency and economy has been studied [5-8], but the research object is the universal design of different parts in the same type of equipment, and the research on the universal design of different types of equipment spare parts is insufficient. Especially for different types of aviation equipment, it is necessary to further study the impact of universal parts design on spare parts support probability and equipment availability.

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2 Mathematical Analysis

For the same type of aircraft, the same LRU (external field replaceable unit) between different aircraft can be used in tandem with each other. When the aircraft are of different types, the LRU between different aircraft should be determined according to the universal design of parts and components. The LRU guarantee situation of aviation equipment is shown in Figure 1.

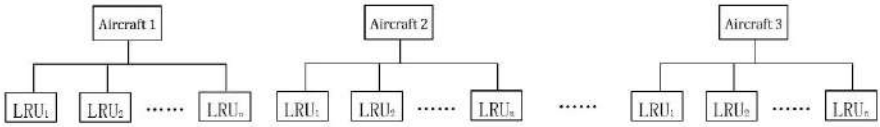

Fig. 1. LRU support situation of aviation equipment

2.1 When no spare parts are available

Assume that there are m_1 Model 1 and m_2 Model 2, and the task execution time is T. In each model, only one LRU of the same type is installed. In the case that there is no spare parts support for the existing model LRU1, assuming that the number of spare parts required for the equipment at the end of the task is ξ_1 and the variance is Var_1, then the mean probability of spare parts support for LRU1 at the end of the task is

$$\overline{\eta_1} = 1 - \frac{E(\xi_1)}{m_1} \tag{1}$$

On account of $Var_1 = E[\xi_1^2] - (E[\xi_1])^2$, therefore, the variance of the equipment support probability is

$$\delta_1 = \frac{Var_1}{m_1^2} = \frac{E[\xi_1^2]-(E[\xi_1])^2}{m_1^2} \tag{2}$$

Similarly, for a certain LRU2 of Model 2, in the absence of spare parts support, suppose that at the end of the task, the mean value of the required number of spare parts of the equipment is ξ_2 and the variance is Var_2, and the mean value of the spare parts support probability of LRU2 at the end of the task is

$$\overline{\eta_2} = 1 - \frac{E(\xi_2)}{m_2} \tag{3}$$

The variance of the support probability is

$$\delta_2 = \frac{Var_2}{m_2^2} = \frac{E[\xi_2^2]-(E[\xi_2])^2}{m_2^2} \tag{4}$$

If the equipment LRU1 of Model 1 and LRU2 of Model 2 can be common, and the equipment LRU2 of Model 1 and Model 2 are guaranteed at the same time, the number of spare parts required for Model 1 and Model 2 can be regarded as independent because there are no spare parts. Based on knowledge of mathematical statistics [9], as to conclusion:

①$E(\xi) = E(\xi_1) + E(\xi_2)$

②$\frac{E[\xi_1]}{E[\xi_2]} = \frac{m_1}{m_2}$

③$Var = Var_1 + Var_2$

Hence

$$\bar{\eta} = 1 - \frac{E(\xi)}{m_1+m_2} = 1 - \frac{E(\xi_1)}{m_1} = 1 - \frac{E(\xi_2)}{m_2} \tag{5}$$

The mean of the equipment support probability is unchanged, i.e.

$$\bar{\eta} = \overline{\eta_1} = \overline{\eta_2} \tag{6}$$

The variance of the support probability is

$$\delta = \frac{Var_1+Var_2}{(m_1+m_2)^2} \tag{7}$$

The following proves that when the devices are common, the variance of the support probability is smaller than that when the devices are not connected. When$m_1 < m_2$,we only need prove $\delta_1 > \delta_2$.

Suppose $m_2 = km_1$,where k is an integer greater than 1, then

$$\delta_2 = \frac{Var_2}{m_2^2} = \frac{kVar_1}{(km_1)^2} = \frac{1}{k} \cdot \frac{Var_1}{m_1^2} = \frac{1}{k} \cdot \delta_1$$

Namely

$$\frac{\delta_1}{\delta_2} = k > 1 \tag{8}$$

Certified.

Therefore, we have the following conclusions: when there is no spare parts support and the equipment can be used universally when the number of aircraft and the number of aircraft increases to k times, the mean value of the equipment support probability remains unchanged, and the variance of the equipment support probability decreases to 1/k times.

2.2 When Spare parts are supported

When spare parts support is available and the number of spare parts increases in the same proportion as the number of aircraft, the mean and variance of spare parts support probability are studied. We assume that the faulty equipment is irreparable, that is, only replacement parts can be carried out when the equipment fails.

Assume that the base number of spare parts is b and the base number of aircraft is m, that is, when the ratio of aircraft/spare parts is m/b, the corresponding spare parts shortage number is ξ at the end of the task, then the mean of the spare parts support probability is

$$\bar{\eta} = 1 - \frac{E[\xi]}{m} \tag{9}$$

The variance of the support probability is

$$\delta = \frac{Var}{m^2} = \frac{E[\xi^2]-(E[\xi])^2}{m^2} \tag{10}$$

When the number of aircraft is km and the number of spare parts is kb (k>1), the average value of the corresponding spare parts shortage number at the end of the mission is $\acute{\xi}$. When the number of aircraft and the number of spare parts increase in proportion, the space available for deployment of spare parts increases, therefore

$$E[\acute{\xi}] < kE[\xi] \tag{11}$$

From this, we can get the mean of spare parts support probability is

$$\acute{\bar{\eta}} = 1 - \frac{E[\acute{\xi}]}{km} > 1 - \frac{kE[\xi]}{km} = \bar{\eta} \tag{12}$$

It is shown below that when the number of aircraft and the number of spare parts increase proportionally, the variance of spare parts support probability decreases.

$$\delta - \acute{\delta} = \frac{E[\xi^2] - (E[\xi])^2}{m^2} - \frac{E[\acute{\xi}^2] - \left(E[\acute{\xi}]\right)^2}{k^2m^2}$$

$$= \frac{k^2E[\xi^2] - k^2(E[\xi])^2 - E[\acute{\xi}^2] + \left(E[\acute{\xi}]\right)^2}{k^2m^2}$$

$$\propto k^2E[\xi^2] - E[\acute{\xi}^2] + \left(E[\acute{\xi}]\right)^2 - k^2(E[\xi])^2$$

$$= E[k^2\xi^2] - E[\acute{\xi}^2] + \left(E[\acute{\xi}]\right)^2 - (E[k\xi])^2$$

$$= E\left[\left(k\xi - \acute{\xi}\right)\left(k\xi + \acute{\xi}\right)\right] - \left(E[k\xi] - E[\acute{\xi}]\right)\left(E[k\xi] + E[\acute{\xi}]\right)$$

$$= E\left[\left(k\xi - \acute{\xi}\right)\left(k\xi + \acute{\xi}\right)\right] - \left(E[k\xi - \acute{\xi}]\right)\left(E[k\xi + \acute{\xi}]\right)$$

$$= cov(k\xi - \acute{\xi}, k\xi + \acute{\xi}) \tag{13}$$

Set $f(k) = \frac{k\xi - \acute{\xi}}{k\xi + \acute{\xi}}$,Then its derivative is

$$\acute{f}(k) = \frac{2\xi\acute{\xi}}{\left(k\xi + \acute{\xi}\right)^2} > 0 \tag{14}$$

Therefore, $k\xi - \acute{\xi}$ is positively correlated with $k\xi + \acute{\xi}$ and its covariance is

$$cov\left(k\xi - \acute{\xi}, k\xi + \acute{\xi}\right) > 0 \tag{15}$$

Therefore

$$\delta > \acute{\delta} \tag{16}$$

Certified.

It can be concluded from the above that: in the case of spare parts support, when the number of aircraft and the number of spare parts increase proportionally, the mean value of the equipment support probability increases and the variance of the equipment support probability decreases.

3 Example Verification

There are two kinds of equipment, LRU1 and LRU2, which are the equipment on the Model 1 and Model 2 respectively, and the number of installations is 1 for each aircraft. The fault distribution types of the two devices all conform to the normal distribution with a mean value of 49 and a variance of 15 (the probability distribution is between 0 and 100). The mean value and standard deviation of the equipment support probability are obtained under the condition of a certain number of spare parts and task time. When the equipment is common, it can be considered as an increase in the number of aircraft and spare parts, so under certain aircraft/spare parts ratio conditions, increasing the number of aircraft and spare parts equivalent spare parts.

3.1 Steps of Simulation Calculation

The problem can be calculated by the Monte Carlo simulation method. The Monte Carlo simulation method is a statistical simulation method using random sampling technology. It is a statistical simulation or sampling by computer, and the approximate solution of the problem is obtained by probability and statistical theory methods.

The Monte Carlo simulation steps of this problem are as follows:

Step 1 Divide the time of the fault distribution type from 0 to 100 into 100 equal parts on average, perform discretization, and calculate the probability of device failure in each time interval.

Step 2 Based on the normal fault distribution type, select m randomly as the initial service time of the device from 1 to 100.

Step 3 Generate a random number between (0,1) from the uniform distribution of U (0,1) and compare it with the failure probability of each device within a certain time unit.

Step 4 If the failure probability is greater than or equal to a random number, the device is faulty. If spare parts are available, replace them (assuming that all spare parts are new products); Otherwise, it is directly transferred to the next time unit, and the next random number is compared with the failure probability of the device in the corresponding time unit. Until the task time T, the total number of failures is calculated, and a data simulation calculation is completed.

Step 5 Perform multiple simulations and calculate the probability and variance of the probability based on the simulation results.

3.2 Support probability simulation when no spare parts are available

For certain equipment, the LRU quantity is 10, 20, 30, 40, 50, 60, 70, and 80, the spare parts number is 0, and the task time T is 5. The equipment support probability is simulated 105 times, and the results are shown in Table 1.

Table 1. Simulation of support probability without spare parts

Number of equipment	The mean of the support probabilities	The variance of the support probabilities	Ratio of variance
10	0.79025	0.01657	1
20	0.79006	0.00834	1.99
30	0.78991	0.00555	2.98
40	0.79011	0.00414	4.00
50	0.78985	0.00333	4.97
60	0.79010	0.00279	5.95
70	0.79034	0.00237	6.99
80	0.79024	0.00207	8.02

According to the simulation results in Table 1, in the absence of spare parts support, when the number of aircraft in the fleet increases, the mean value of the equipment support probability remains unchanged, while the variance of the equipment support probability decreases, and the multiple of the variance reduction is equal to the multiple of the number of aircraft increase. Thus, it is verified that in the case of no spare parts support, the universal design of equipment has no impact on the mean value of the equipment support probability, but it will reduce the variance of the equipment support probability, that is, it can reduce the deviation range of the equipment support probability and make the prediction of the equipment support probability more accurate.

3.3 Support Probability when spare parts are available

Taking 10 pieces of equipment (number of aircraft) and 2 pieces of spare parts as the fixed aircraft/spare parts ratio, the equipment support probability of 10, 20, 30, 40, 50, 60, 70, 80, spare parts of 2, 4, 6, 8, 10, 12, 14, 16 and the task time T of 5 are simulated 105 times. The results are shown in Table 2.

Table 2. Support probability simulation when spare parts are available

Number of equipment	The mean of the support probabilities	The variance of the support probabilities	Ratio of variance
10	0.94565	0.00747	1
20	0.95942	0.00363	2.06
30	0.96558	0.00245	3.04
40	0.96933	0.00184	4.06
50	0.97199	0.00148	5.04
60	0.97384	0.00125	5.99
70	0.97546	0.00107	6.95
80	0.97643	0.00095	7.86

According to the simulation results in Table 2, in the case of spare parts support, when the number of aircraft in the fleet increases, the mean value of the equipment support probability gradually increases, and the variance of the equipment support probability significantly decreases. It is verified that the universal design of equipment can improve the mean value of equipment support probability and significantly reduce the variance of equipment support probability in the case of spare parts support, to improve the efficiency of fleet spare parts support.

4 Analysis of the impact on equipment availability

In Sections 1 and 2, we discussed the impact of parts universality on spare parts support probability. Under the given fault distribution model, the impact of spare parts universality design on the support probability of a single piece of equipment is not very large. Below, we further analyzed the impact of spare parts universality through the availability of equipment systems.

In the use management of aviation equipment spare parts, some equipment will be restricted from being used in tandem between different aircraft due to the limitation of disassembly times, life matching, and other factors. In this case, the equipment availability of a fleet can be equivalent to the reliability of a series system. Although the equipment cannot be shared on different aircraft, when the equipment is common, the support probability of the equipment will be affected because more spare parts can be deployed between more aircraft, as shown in Figure 2 and Figure 3. We assume that the availability of the equipment is only related to the equipment under study and that the equipment is not unavailable for other reasons.

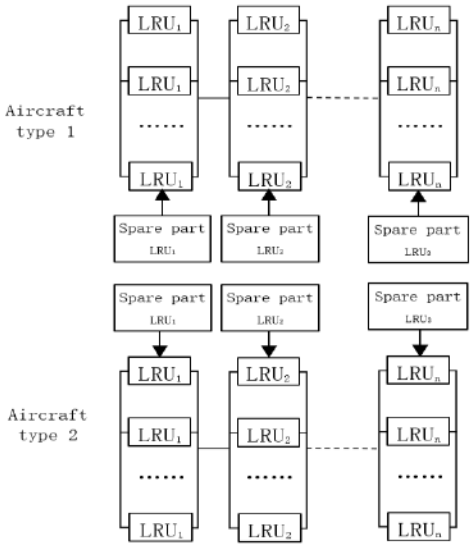

Fig. 2. Spare parts support when the equipment is not universal

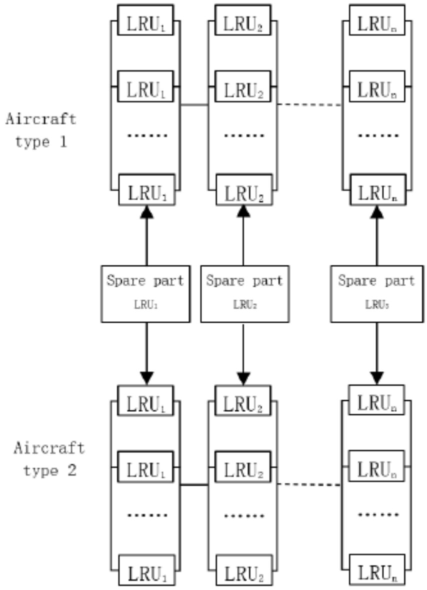

Fig. 3. Spare parts support when the equipment is universal

When the mean of the support probability of equipment LRU is $\bar{\eta_i}$ and the variance is δ_i, the mean of aircraft availability is [10]

$$\bar{\mu} = \prod_{i=1}^{N} \bar{\eta_i} \tag{17}$$

The variance in equipment availability is

$$\Delta = \prod_{i=1}^{N}\{\bar{\eta_i}^2 + \delta_i\} - \prod_{i=1}^{N} \bar{\eta_i}^2 \tag{18}$$

N indicates the type of devices that are common but cannot be used in series.

According to Formula (12) and Formula (17), there is

$$\bar{\bar{\mu}} = \prod_{i=1}^{N} \bar{\bar{\eta_i}} > \prod_{i=1}^{N} \bar{\eta_i} = \bar{\mu}$$

That is, when the device can be universal, the mean value of the device availability increases.

Assume that k is the type of equipment that is not allowed to be shared, the fault distribution type of each device is a normal distribution with a mean of 49 and a variance of 15, the number of Model I and Model II is 20, the number of spare parts for each device is 4, and the task time is 5. The influence of the universality of spare parts on the availability of the model is analyzed.

According to Section 2, when a device is unavailable, the mean support probability of a single device at the end of the task $\bar{\eta} = 0.95942$ with a variance of $\delta = 0.00834$.

When devices are common, the mean support probability $\bar{\eta} = 0.96933$ and variance $\acute{\delta} = 0.00184$ for a single device at the end of the task.

According to Formulas (17) and (18), when k changes from 1 to 10, the mean and standard deviation changes of aircraft availability are calculated, as shown in Figure 4.

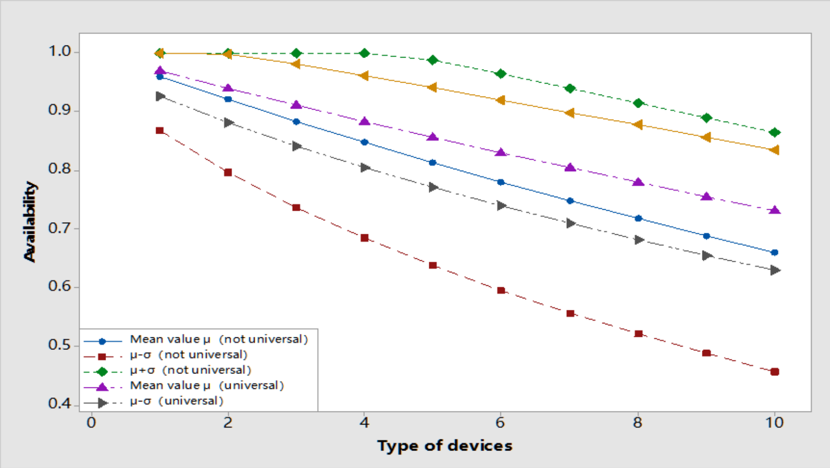

Fig. 4. Comparison of availability with the variation of equipment type

As can be seen from Figure 4, when the equipment can be universal, the aircraft availability increases, that is, the spare parts support efficiency increases, and the support efficiency increases with the increase of equipment types.

5 Conclusion

Through the above analysis, it can be seen that in the development of different types of aircraft, the accuracy of spare parts support of the aircraft fleet can be improved by improving the universality rate of parts of different models. In particular, the universality design of devices that cannot be shared can effectively improve the equipment availability of the aircraft fleet, which is of great practical significance for scenarios such as multi-models going out to perform tasks in the aircraft cluster mode. At the same time, we can also conclude that through the establishment of a parts centralized support center, the unified deployment of spare parts for similar equipment in different units and regions can improve the accuracy of spare parts support.

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