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Forecasting Models of Spare Parts Consumption Based on Various Influence Factors

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Abstract. Considering the two kinds of conditions of the equipment after training next year, that the repair cycle is calculated by motor hour, on the basis of analyzing the factors which include components life distributions, maintenance strategies, the age of the equipment and next year's operation time, this paper established general models of spare parts consumption forecasting. At last, an example was taken to illustrate the applicability of these general models. These general models provide sufficient scientific basis for choosing spare parts application, storage and supply amount reasonably.

Key words. Motor hour, spare parts consumption, influence factors, forecasting models.

1. Introduction

In recent years, with the application of high-tech, there are more and more types of equipment, and the structure is more and more complex. Different units in the equipment in the preventive maintenance often take different maintenance strategies, resulting in that equipment spare parts consumption law of the current formed unit is more difficult to grasp and that the forecasting for the variety, quantity and amount of spare parts consumption is becoming more arduous. In order to meet the needs of equipment maintenance, it is necessary to realize the precision support of equipment spare parts, and all aspects of spare parts protection activities such as financing, storing and supply are closely related to the consumption of spare parts, and the consumption law of spare parts is considered as accordance. Therefore, it is of great practical significance to study the consumption law of equipment spare parts.

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According to the historical data, the US military establishes the availability of logistics model, the index smoothing model, the regression model [1], [2] to predict the consumption of spare parts, and provides a reference for the revision of the spare rate. The United States from the fifties of last century began to study the forecasting methods of aircraft spare parts consumption, and have established a number of models. The United States initially thought that the spare parts consumed by the aircraft engine were proportional to the number of flight hours and used a linear regression model to describe the spare parts consumption [3]; later the United States proved and found that spare parts consumption is also related to the number of flights. According to the characteristics of different equipment spare parts consumption statistics, the United States uses the exponential smoothing model, moving average method and other models [4], [5] to forecast spare parts consumption of different ships. Other authors have also done research on spare parts consumption forecasting [6].

The general forecasting models of spare parts consumption based on various influence factors are valuable for making a strategic decision of spare parts. No one has done research on them. So it is necessary to do research on the general forecasting models of spare parts consumption based on various influence factors.

Through the analysis of the literature on the consumption rules of equipment spare parts, it can be found that the factors influencing the consumption of equipment spare parts can be found, but the general models of spare parts consumption forecasting has not been established.

According to the repair cycle of different units, equipment can be divided into motor hours,

years, mileage, boot time, firing number and so on.

Equipment of a unit is in the normal training process. In case of failure, it can be overhauled. After the training, if the equipment goes into the interval of level maintenance, the level maintenance can be implemented. In this paper, the equipment, which takes the motor hours for the maintenance cycle measurement units, is used as the typical equipment, and the unit of the type equipment is taken as the study object, and the general forecasting method of equipment spare parts consumption is given.

2. Formulation of the problem

The equipment takes the motor hours for the repair cycle measurement units. The spare parts consumption generated by the equipment unit in the next year is closely related to the life distribution of the unit, the service time of the equipment, the use time of the equipment in the next year and the maintenance strategy of the unit.

When the spare parts consumption of the equipment unit is predicted, we should first determine whether the level maintenance will be done in the next year, by analyzing the total hours of motorcycle service of the ith $(i = 1, 2, \cdots, N)$ equipment, the motor hours of the ith equipment used in the most recent periodic maintenance, the average use time (motor hours) of the equipment in the following year.

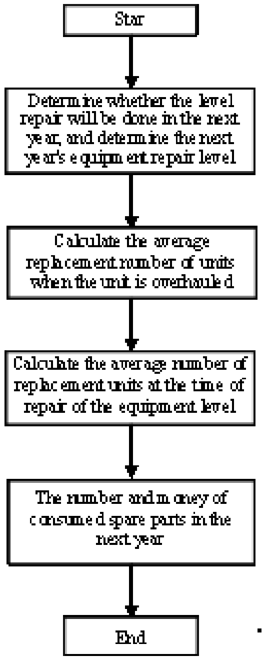

Fig. 1. The basic idea of spare parts consumption forecasting

If the equipment needs to be repaired, we determine the next year's equipment maintenance level. According to equipment, the motor hours of the ith equipment used in the most recent periodic maintenance, the average use time (motor hours) of the equipment in the following year. If the equipment needs to be repaired, we determine the next year's equipment maintenance level. According to the life distribution$f_{\theta_{ij}}(t)$ of the unit j on the equipment i, the cumulative use time $T_{ij}^{(1)}$ of the unit j on the equipment i after the last change, the training time $U_i^{(1)}$ of the equipment i in the next year, the maintenance level k_i and the maintenance strategy of the unit, the number of unit replacement in the next year can be obtained. On this basis, the spare parts consumed by the unit on each piece of equipment can be calculated one by one, and the total amount of spare parts consumed by the unit on all equipment in the next year can be obtained. The basic idea of spare parts consumption forecasting is shown in Fig.1.

Equipment takes motor hours as the measurement unit. There are two cases:

The cumulative service time of the equipment does not reach the level maintenance intervals, and the equipment need not the level maintenance.

The cumulative service time of the equipment exceeds the lower limit of the level maintenance interval, and the equipment level maintenance will be done after the completion of the training task.

Based on the above analysis of the problem, in the following, the number and money of spare parts consumption of the unit j on N pieces of equipment are forecasted in a year cycle.

3. The calculation of unit replacement count

As for equipment which takes the motor hours as measurement units, we need to calculate the number of replacement units in order to calculate the number of spare parts consumption of the same unit of all the equipment.

Case 1: The next year the equipment is not rated for maintenance. If the unit is replaced, it may only occur during overhaul. The number of unit replacement during overhaul is directly calculated, and then we can get the total number of replacement unit.

Case 2: The next year the equipment is rated for level maintenance, and the cumulative service time will not exceed the upper limit of the level maintenance interval. Replacement of units for the next year may occur during overhaul, may occur during the level maintenance, may be replaced during overhaul and the level maintenance, and may not be replaced during overhaul and the level maintenance. We need to first calculate the number of replacement units in the overhaul, and then calculate the number of replacement during the equipment level maintenance, and finally get the total number of unit replacement in the next year. In the following, two cases is discussed.

3.1. The number of unit replacement in case 1

When the equipment unit is overhauled, it may take no change or take change depending on situation.

(1)When no change is taken during overhaul, the replacement number of unit j on the equipment i is $q_{ij0}^{(1)} = 0$ in the next year.

(2) When change depending on situation is taken during overhaul, we assume that the initial remaining life of unit j on the equipment i is $\theta_{ij}^{(1)}$ in the next year and the service life before the lth replacement is $\theta_{ijl}^{(1)}$. According to the stochastic process theory, the average replacement number of unit j on the equipment i during overhaul in the next year is

$$\bar{q}_{ij0}^{(1)} = \sum_{x=0}^{+\infty} xP\left(q_{ij0}^{(1)} = x\right) = \sum_{x=1}^{+\infty} P\left(\theta_{ij}^{(1)} + \sum_{l=2}^{x+1} \theta_{ijl}^{(1)} < U_i^{(1)}\right) + P\left(\theta_{ij}^{(1)} < U_i^{(1)}\right) \quad (1)$$

Then, the general equation of the average replacement number of unit j on the equipment i during overhaul in the next year is

$$\bar{q}_{ij0}^{(1)} = 2L_{ij0}\left[\sum_{x=1}^{+\infty} P\left(\theta_{ij}^{(1)} + \sum_{l=2}^{x+1} \theta_{ijl}^{(1)} < U_i^{(1)}\right) + P\left(\theta_{ij}^{(1)} < U_i^{(1)}\right)\right] \quad (2)$$

3.2. The number of unit replacement in case 2

The average number of replacement during overhaul is calculated directly according to equation (2).

If the unit must change and does not change during the level maintenance, the replacement number is $q_{ijk_i}^{(1)} = 1$ and $q_{ijk_i}^{(1)} = 0$; if the unit is changed depending on situation, it is judged that $R(t)$ is smaller than the predetermined value w, and the unit is immediately replaced.

(1) When $T_0 \geq U_i^{(1)}$ and no change is taken during overhaul

If $\theta_{ij}^{(1)} \leq U_i^{(1)}$, the replacement number of unit j on the equipment i is $q_{ijk_i}^{(1)} = 1$ during the level maintenance in the next year;

If $\theta_{ij}^{(1)} > U_i^{(1)}$ and $T_{ij}^{(1)} + U_i^{(1)} \geq T_0$, the replacement number of unit j on the equipment i is $q_{ijk_i}^{(??)} = 1$ during the level maintenance in the next year;

If $\theta_{ij}^{(1)} > U_i^{(1)}$ and $T_{ij}^{(1)} + U_i^{(1)} < T_0$, the replacement number of unit j on the equipment i is $q_{ijk_i}^{(1)} = 1$ during the level maintenance in the next year;

Therefore, during the level maintenance in the next year, if $T_0 \geq U_i^{(1)}$ and no change is taken during overhaul, the general equation of the average replacement number of unit j on the equipment i is

$$\bar{q}_{ijk_i}^{(1)} = P\left(\theta_{ij}^{(1)} \leq U_i^{(1)}\right) + \delta'\left(T_{ij}^{(1)} + U_i^{(1)} - T_0\right) P\left(\theta_{ij}^{(1)} > U_i^{(1)}\right) \tag{3}$$

(2) When $T_0 \geq U_i^{(1)}$ and change depending on situation is taken during overhaul

If $\theta_{ij}^{(1)} < U_i^{(1)}$, unit j on the equipment i is not changed during level maintenance in the next year, and the replacement number is $q_{ijk_i}^{(1)} = 0$; if $\theta_{ij}^{(1)} = U_i^{(1)}$, unit j on the equipment i is changed during level maintenance in the next year, and the replacement number is $q_{ijk_i}^{(1)} = 1$.

If $\theta_{ij}^{(1)} > U_i^{(1)}$ and $T_{ij}^{(1)} + U_i^{(1)} \geq T_0$, unit j on the equipment i is changed during level maintenance in the next year, and the replacement number is $q_{ijk_i}^{(1)} = 1$.

If $\theta_{ij}^{(1)} > U_i^{(1)}$ and $T_{ij}^{(1)} + U_i^{(1)} < T_0$, unit j on the equipment i is not changed during level maintenance in the next year, and the replacement number is $q_{ijk_i}^{(1)} = 0$.

Therefore, if $T_0 \geq U_i^{(1)}$ and change depending on situation is taken during overhaul, the general equation of the average replacement number of unit j on the equipment i during the level maintenance in the next year is

$$\bar{q}_{ijk_i}^{(1)} = \delta'\left(T_{ij}^{(1)} + U_i^{(1)} - T_0\right) P\left(\theta_{ij}^{(1)} > U_i^{(1)}\right) \tag{4}$$

(3) When $T_0 < U_i^{(1)}$ and no change is taken during overhaul

If the cumulative use time of unit B on equipment A is more than C during overhaul after the failure or unit update in the next year, change is taken during level maintenance. So the average replacement number of unit j on the equipment i during the level maintenance in the next year is $q_{ijk_i}^{(1)} = 1$.

(4) When $T_0 < U_i^{(1)}$ and no change depending on situation is taken during overhaul

According to the stochastic process theory, the probability that unit j on the equipment i is not changed during overhaul and is changed during the level maintenance in the next year is $P\left(\theta_{ij}^{(1)} > U_i^{(1)}\right)$. The probability that the number of replacement is 1 and change is taken during the level maintenance is $P\left(\theta_{ij}^{(1)} < U_i^{(1)} - T_0, q_{ij0}^{(1)} = 1\right)$.

The probability that the number of replacement is x $x \geq 2$ and change is taken during the level maintenance is $P\left(\theta_{ij}^{(1)} + \sum_{l=2}^{x} \theta_{ijl}^{(1)} < U_i^{(1)} - T_0, q_{ij0}^{(1)} = x\right)$.

Therefore, if $T_0 < U_i^{(1)}$ and change depending on situation is taken during overhaul, the general equation of the average replacement number of unit j on the equipment i during the level maintenance in the next year is

$$\begin{aligned}\bar{q}_{ijk_i}^{(1)} =& P\left(\theta_{ij}^{(1)} > U_i^{(1)}\right) + P\left(\theta_{ij}^{(1)} < U_i^{(1)} - T_0, q_{ij0}^{(1)} = 1\right) \\ &+ \sum_{x=2}^{+\infty} P\left(\theta_{ij}^{(1)} + \sum_{l=2}^{x} \theta_{ijl}^{(1)} < U_i^{(1)} - T_0, q_{ij0}^{(1)} = x\right)\end{aligned} \tag{5}$$

4. General mathematical model

*iiii*The symbol λ_i is introduced to distinguish between two different situations.

$$\lambda_i = \tag{6}$$

The average replacement number of all units j on the same type equipment is summed up in the next year, and the total forecasting amount of spare parts consumed by the unit A can be obtained.

If $T_0 \geq U_i^{(1)}$,

$$\begin{aligned}Q_j^{(1)} = \sum_i \Bigg\{ & 2L_{ij0}\left[\sum_{x=1}^{+\infty} P\left(\theta_{ij}^{(1)} + \sum_{l=2}^{x+1} \theta_{ijl}^{(1)} < U_i^{(1)}\right) + P\left(\theta_{ij}^{(1)} < U_i^{(1)}\right)\right] + 4\lambda_i L_{ijk_i}^{(1)}\left(1 - L_{ijk_i}^{(1)}\right) \times \\ & \left[(1 - 2L_{ij0}) P\left(\theta_{ij}^{(1)} \leq U_i^{(1)}\right) + \delta'\left(T_{ij}^{(1)} + U_i^{(1)} - T_0\right) P\left(\theta_{ij}^{(1)} > U_i^{(1)}\right)\right] + \lambda_i L_{ijk_i}^{(1)}\left(2L_{ijk_i}^{(1)} - 1\right)\Bigg\}\end{aligned} \tag{7}$$

If $T_0 < U_i^{(1)}$,

$$\begin{aligned}& Q_j^{(1)} = \sum_i 2L_{ij0}\left[\sum_{x=1}^{+\infty} P\left(\theta_{ij}^{(1)} + \sum_{l=2}^{x+1} \theta_{ijl}^{(1)} < U_i^{(1)}\right) + P\left(\theta_{ij}^{(1)} < U_i^{(1)}\right)\right] + 8\lambda_i L_{ij0} L_{ijk_i}^{(1)}\left(1 - L_{ij}^{(1}\right. \\ & \left[P\left(\theta_{ij}^{(1)} > U_i^{(1)}\right) + P\left(\theta_{ij}^{(1)} < U_i^{(1)} - T_0, q_{ij0}^{(1)} = 1\right) + \sum_{x=2}^{+\infty} P\left(\theta_{ij}^{(1)} + \sum_{l=2}^{x} \theta_{ijl}^{(1)} < U_i^{(1)} - T_0, q_{ij0}^{(1)}\right.\right. \\ & +4\lambda_i L_{ijk_i}^{(1)}\left(1 - L_{ijk_i}^{(1)}\right)(1 - 2L_{ij0}) + L_{ijk_i}^{(1)}\left(2L_{ijk_i}^{(1)} - 1\right)\end{aligned} \tag{8}$$

If purchase price of the unit j is p_j, based on the unit price and the total forecast amount of spare parts consumption, the estimated total money of spare parts consumed by unit A on all equipment in the next year is

$$C_j^{(1)} = p_j Q_j^{(1)} \tag{9}$$

Year, the number of shooting, mileage and boot time is taken to measure the repair cycle of the equipment, whose the spare parts consumption forecast can refer to spare parts consumption forecast method which takes the motor hours as the measurement. Due to limited space, this article no longer explains.

5. Analysis of an example

A formed unit is equipped with a similar type of equipment whose number is 2. The first piece of equipment has been working 520 motor hours, and the second piece of equipment has been working 100 motor hours, 20 22 -55 60 -115 120 . The training time of the next year is 50 motor hours. The each number of three types of units on equipment is 1, and unit price, life distribution, the use of time, maintenance strategy and other basic information are shown in Table 1. When the equipment is in the level maintenance, if the working time of the unit depending on situation of has exceeded its average life, then the unit is changed, or not changed. Try to predict the number and money of spare parts consumed by the three types of units in the next year.

Table 1. The basic information of three types of equipment

Equipment	Unit	Price	Life distributed	Use of time	Maintenance strategy	
					Overhaul	Big maintenance
1	1	20000	$N(25, 0.6)$	0	change depending on situation	change depending on situation
	2	10000	$N(32, 0.4)$	60	change depending on situation	must change
	3	15000	$N(50, 0.8)$	80	no change	must change
2	1	20000	$N(25, 0.6)$	0	change depending on situation	must change
	2	10000	$N(32, 0.4)$	20	change depending on situation	no change
	3	15000	$N(50, 0.8)$	10	no change	must change

In the next year training hours are $U_1^{(1)}=U_2^{(1)}=5$ motor hours, so the cumulative use time of the two pieces of equipment will reach 570 motor hours, 150 motor hours. According to the equipment, in the next year the first piece of equipment after training is in the medium maintenance, $\lambda_1 = 1$; the second piece of equipment after training is not in the level maintenance, $\lambda_2 = 0$.

As is known from Table 1, the unit 1 has not been used, and the initial residual life of the unit is equal to its useful life,$\theta_{i1}^{(1)} = \theta_{i11}^{(1)}$. The lifetime density function of unit 1 is$f_{\theta_{11}}(t) = \frac{1}{\sqrt{1.2\pi}} e^{\frac{-(t-25)^2}{1.2}}$. Change depending on situation is taken during overhaul and change depending on situation is taken in the medium maintenance, so $L_{110} = L_{210} = 1/2$ $L_{11k_1}^{(1)} = 1/2$. In the medium the replacement time boundary of unit 1 replacement is $T_0 = 25$ motor hours. Due to A, it should be calculated according to equation (8). The correlation probability expression is shown in Table 2.

By programming, in the next year, the total number of spare parts consumed by unit 1 on the two pieces is expected to be $Q_1^{(1)} = 4.6$, and the total amount is estimated to be $C_1^{(1)} = 92000$; the total number of spare parts consumed by unit 2 on the two pieces is expected to be $Q_2^{(1)} = 4.4$, and the total amount is estimated to be $C_2^{(1)} = 44000$; the total number of spare parts consumed by unit 3 on the two pieces is expected to be $Q_3^{(1)} = 5.2$, and the total amount is estimated to be

$C_3^{(1)} = 780010$.

According to the number and money of spare parts consumption produced by the three types of units, equipment support personnel consider the support degree of spare parts, security costs and other factors, and then can develop the storage program of three types of spare parts. In addition, given the planned training time in the future years, it is possible to further obtain the number $Q_j^{(m)}$ and the money $C_j^{(m)}$ of spare parts consumption of the unit j on equipment in any future year (the mth year).

6. Conclusion

This paper deals with the forecasting of spare parts consumption which takes motor hours to measure maintenance cycle. According to the life distribution and the used time of the unit, the serious factors such as unit repair method, service time of equipment, working time of equipment, maintenance period of equipment and so on is considered, and a general model of spare parts consumption forecast is established. The general forecasting models of spare parts consumption based on various influence factors are very valuable and important for spare parts support. They are convenient to calculate and very practical. With reference to the general model, it is possible to further provide the forecasting method of spare parts consumption which takes year, the number of shooting, the mileage and the starting time as the repair period, so as to provide the theoretical basis of the scientific and reasonable spare parts support scheme for the equipment support department.

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