Research on Maintenance Material Supply Strategies

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***Abstract*— Considering two maintenance strategies of components applied to inspection and three maintenance strategies of components applied to regular maintenance, on the basis of analyzing five factors which include components lives, remaining lives of components, the age of the equipment, next year's operation time, and maintenance material storage amount, general models of maintenance material supply amount are established, using stochastic process theory, probability theory and mathematical statistics. At last, an example is taken to illustrate the applicability of these general models. These general models provide sufficient scientific basis for choosing maintenance material supply amount reasonably.**

***Index terms*—maintenance strategies, inspection, regular maintenance, maintenance material supply**

I. INTRODUCTION

In recent years, with the application of high-tech and information technology, equipment of formed units has become more and more complex with more and more species. Different maintenance strategies also tend to be applied for different components of equipment, making it difficult to grasp the law of equipment maintenance material supply and leading to heavier workload of maintenance material supply forecasting. To meet the needs of equipment maintenance, formed units need to store a certain variety and quantity of maintenance material in advance. If the storage capacity of each spare part is too small, the equipment's successful completion of the training mission cannot be guaranteed; if the storage capacity of each maintenance material is too much, it will cause overstock which affects economic benefit of the components. To ensure that maintenance material stored in the formed units is of reasonable quantity and good quality and can timely and reliably guarantee the equipment maintenance needs, a scientific and valid method of equipment maintenance material supply forecasting must be given.

Many scholars at home and abroad have conducted in-depth studies of methods of equipment maintenance material supply forecasting. Xu Yan-xue et al proposed the cruise missile maintenance material supply forecasting method based on rough sets and BP neural network, which gives full play to the advantage of rough set in handling of redundant data and improves the speed and effectiveness of forecasting. Yang mei et al proposed a combination forecasting method of aviation material maintenance material based on least squares support vector machines and information entropy in order to achieve precision support of aviation equipment, which solved the problems of the existing methods in difficulty in accurately predicting the aviation material maintenance material under conditions of small samples. Cheung KL et al analyzed the multiple failures of components, studied the component control model based on multi-tier technology, and established such maintenance material supply forecasting models as Mod-METRIC, Vari-METRIC, Dyna-METRIC through improvement. Through the analysis of the previous literature, it can be found there are few undertaken research work of method of equipment maintenance material forecasting based on a variety of maintenance strategies.

A certain type of equipment is maintained with a combination of inspection and regular maintenance. Within one year, in the normal training phase of the equipment, the equipment can be inspected and after the end of the training, regular maintenance of the equipment can be carried out. There may exists two maintenance strategies of "non-replacement" and "condition based replacement" in the inspection of the equipment component; there may exist three maintenance strategies of "non-replacement", "certain replacement" and "condition based replacement" at the regular maintenance of equipment. "Non-replacement" after inspection refers not the strategy not to replace components after failure or problem is found in inspection when the replacement condition is not available; "condition based replacement" after inspection refers to the strategy to replace components after failure or problem is found in inspection when the replacement condition is available; "non-replacement" after regular maintenance refers to the strategy not to replace components after failure or problem is found in regular maintenance when the replacement condition is not available; "certain replacement” after regular maintenance refers to the strategy to replace components no matter the component is damaged nor not during regular maintenance when the replacement condition is available; “condition based replacement” after regular maintenance refers to the strategy to replace components if the service time of the component exceeds a predetermined value during the regular maintenance when the replacement condition is available.

The determination of the storage capacity of equipment maintenance material should be based on the supply law of the equipment maintenance material. How to scientifically predict the maintenance material supply of the equipment under the circumstance of various maintenance is a key issue to be addressed by this text.

II. PROBLEM ANALYSIS

A. Influence Factors in Maintenance Material Supply

The maintenance strategy of equipment components determines how the component will be replaced in the next year, therefore closely associated with the maintenance material supply generated by the equipment in the next year. In addition, the four main factors including components lives, remaining lives of components, the age of the equipment and next year’s operation time have a direct impact on the maintenance material supply generated by equipment in the next year.

(1) Components lives. Components lives refer to the interval time from usage of components as new products (0 time) to occurrence of malfunction. Components lives are random variables, and hence the time when the component has malfunction is uncertain. However, under normal circumstances, the longer the average components lives, the fewer the maintenance material supply quantity and amount generated by the equipment in the next year.

(2) Remaining lives of components. Remaining lives of components refer to the interval time from the counting date after the component has been working for some time to occurrence of malfunction. Remaining lives of components are also random variables. If the component is replaced at the previous year’s regular maintenance, then when the equipment is trained in the next year, the component can be seen as a new product whose remaining life is equal to its life; if the component is replaced at the previous year’s regular maintenance, then in determination of the remaining lives of components, the period that the component has been used should be fully considered.

(3) The age of the equipment. The length of the age of the equipment decides the equipment maintenance level of the next year. When different levels of maintenance are undertaken for the equipment, the maintenance strategy adopted by the same component may not be the same. Therefore, determination of the component maintenance strategy for next year should be based on the age of the equipment.

(4) Next year’s operation time. Under the condition that the other factors that influence maintenance material supply are unchanged, the length of equipment operation time determines the quantity and amount of equipment maintenance material supply. The longer the next year’s operation time, the larger the quantity and amount of equipment maintenance material supply; the shorter the next year’s operation time, the smaller the quantity and amount of equipment maintenance material supply.

(5) Maintenance material storage amount. When the maintenance material storage amount is great, the maintenance material supply amount is small; when the maintenance material storage amount is small, the maintenance material supply amount is great.

B. Maintenance Material Supply Forecasting Process

Replacement of equipment components may occur during inspection or regular maintenance, possibly replaced at both inspection and regular maintenance, or not replaced at inspection and regular maintenance. Therefore, in forecasting of maintenance material supply generated by any equipment component in the next year, the number of components replacement at inspection and regular maintenance should be calculated first. The forecasting process of equipment maintenance material supply amoun tbased on various maintenance strategies are as follows:

Step 1: Enter the age of the equipment from its usage to the current time as well as inherent equipment maintenance cycle;

Step 2: Consider the two maintenance strategies that may be adopted for equipment inspection and the three maintenance strategies that may be adopted for regular maintenance of equipment;

Step 3 : Enter components lives, remaining lives of components and next year’s operation time;

Step 4: Count one by one the quantity and amount of maintenance material supply of equipment components in the next year;

Step 5: If for each equipment component, respectively establish a model to forecast the maintenance material supply generated in the next year, then the calculation amount is too large and the calculation process is cumbersome. Therefore, it is necessary to establish a general model for forecasting of equipment maintenance material under various maintenance strategies.

Step 6: Determine the equipment maintenance rating of the next year;

Step 7: Determine the component maintenance strategy;

Step 8: Calculate the number of component replacement at equipment inspection;

Step 9: Calculate the number of component replacement at regular maintenance;

Step 10: Forecast the maintenance material supply generated by the equipment in the next year.

III. GENERALIZED MODEL OF MAINTENANCE MATERIAL SUPPLY

A. Description of Symbols

θ_i ——Unit life span before the i time replacement in the next year, $i = 1,2,3\cdots$;

θ_1' ——Unit residual lifespan before the first replacement in the next year;

T_s ——Equipment service time;

T ——Equipment usage time in the next year;

x ——Level of equipment repair; $x=1$ minor repairs, $x=2$ medium repairs, $x=3$ major repairs;

L_0 ——Unit maintenance policy when equipment is under inspection;If non-replacement upon unit maintenance, $L_0=0$; If condition based replacement upon unit maintenance, $L_0=1/2$;

L_x ——Unit maintenance policy when equipment is under the x level repair;If non-replacement upon the x level equipment repair, $L_x=0$; If certain replacement upon the x level equipment repair, $L_x=1$; If condition based replacement upon the x level equipment repair, $L_x=1/2$.

B. Unit Replacement Number When the Equipment is Under Inspection

The equipment is repaired within the time period of $[0,T)$,(1)If the result is non-replacement i.e $(L_0=0)$,the unit replacement number $q_0=0$;(2) If the maintenance policy is condition based replacement i.e $(L_0=1/2)$,according to the theory of random processes, the probability of unit replacement number $q_0=0$ is $P(q_0=0)=P(\theta_1'>T)$;the probability of unit replacement number $q_0=1$ is $P(q_0=1)=P(\theta_1'<T)-P(\theta_1'+\theta_2<T)$;the probability of unit replacement number $q_0=k$ ($k=2,3,4\cdots$) is $P(q_0=k)=P\left(\theta_1'+\sum_{i=2}^{k}\theta_i<T\right)-P\left(\theta_1'+\sum_{i=2}^{k+1}\theta_i<T\right)$;The average value of unit replacement numbers when the equipment is under inspection can be obtained, so $q_0=\sum_{k=2}^{+\infty}P\left(\theta_1'+\sum_{i=2}^{k}\theta_i<T\right)+P(\theta_1'<T)$.

As a result,the generalized formula for unit replacement number when the equipment is under inspection can be expressed as

$$q_0=2L_0\left[\sum_{k=2}^{+\infty}P\left(\theta_1'+\sum_{i=2}^{k}\theta_i<T\right)+P(\theta_1'<T)\right] \quad (1)$$

C. Unit Replacement Number When the Equipment is Under Various Levels of Repair

Various levels of repair are given to the equipment at T moment, (1) If non-replacement policy is adopted, i.e $(L_x=0)$, the unit replacement number upon various levels of equipment repair $q_x=0$; (2) If the policy of certain replacement is adopt, i.e $(L_x=1)$,the unit replacement number $q_x=1$; (3) If the result is condition based replacement, i.e $(L_x=1/2)$,As it is stipulated that if the unit working time exceeds $T_0(T_0<T)$ when the equipment is under various level of repair, the unit should be changed with new maintenance material, otherwise no replacement is conducted, therefore when non-replacement policy is given, the unit replacement number upon various levels of equipment repair $q_x=1$;When the policy of condition based replacement is adopted, the average value of unit replacement numbers $q_x=P(\theta_1'>T)+P(\theta_1'<T-T_0,q_0=1)+\sum_{k=2}^{+\infty}P\left(\theta_1'+\sum_{i=2}^{k}\theta_i<T-T_0,q_0=k\right)$ Therefore, the generalized formula of unit replacement number upon various levels of equipment repair can be expressed as

$$q_x=2L_x(2-2L_x)\left\{2L_0\left[P(\theta_1'>T)+P(\theta_1'<T-T_0,q_0=1)+\sum_{k=2}^{+\infty}P\left(\theta_1'+\sum_{i=2}^{k}\theta_i<T-T_0,q_0=k\right)\right]-2L_0+1\right\}$$
$$+L_x(2L_x-1) \quad (2)$$

D. Forecasting Model for Maintenance Material Supply and Cost

By adding the next year unit replacement number upon equipment inspection q_0 and the next year unit replacement number upon various levels of equipment repair q_x , the predicted value of equipment maintenance material replacement in the year can be obtained as follow:

$$Y=2L_x(2-2L_x)\left\{2L_0\left[P(\theta_1'>T)+P(\theta_1'<T-T_0,q_0=1)+\sum_{k=2}^{+\infty}P\left(\theta_1'+\sum_{i=2}^{k}\theta_i<T-T_0,q_0=k\right)\right]-2L_0+1\right\}$$
$$+L_x(2L_x-1)+2L_0\left[\sum_{k=2}^{+\infty}P\left(\theta_1'+\sum_{i=2}^{k}\theta_i<T\right)+P(\theta_1'<T)\right] \quad (3)$$

Wherein: $x=1,2,3$,the specific value of x is determined according to the equipment service time T_s .

If the storage capacity of each maintenance material is Q , the predicted value of equipment maintenance material replacement in the year can be obtained as follow:

$$S = Y - Q \tag{4}$$

Suppose the unit purchasing price is P, the cost of spare part supply of the next year is

$$J = PS \tag{5}$$

The computer programming was conducted to the equation (4) and equation (5), and it is only needed to input the parameter of random unit, which will lead to an effective forecast for maintenance material supply of the units in the year. Beside easy operation and simple computing process, this method also greatly shortened the time cost in predicting the maintenance material supply by organization units.

IV. EXAMPLE OF MAINTENANCE MATERIAL SUPPLY FORECASTING

There is a certain type of equipment in certain organization unit with maintenance cycle of 1-3-6, which has been in service for 2 years. The 3 types of units of this equipment is uniformly 1, and the basic information including unit name, unit price, lifespan distribution, service time already spent and maintenance policy are shown in table 1. The storage capacity of the first type maintenance material is 1; the storage capacity of the second type maintenance material is 1; the storage capacity of the third type maintenance material is 1. It is stipulated that when the equipment is under various level of repair, if the working time of condition based replaced unit has already exceeded its average life span, unit replacement should be conducted; otherwise non-replacement of unit is adopted. In the next year the planed training time for this equipment is 0.6 year, after training, the equipment will be given with various levels of repair, now a trial of forecasting maintenance material supply and relevant cost of 3 types of units is conducted.

TABLE I
BASIC INFORMATION OF THREE KINDS OF COMPONENTS

No	Unit name	Unit price (yuan)	Lifespan distribution	Service time (year)	Maintenance policy			
					inspection	Minor repair	Medium repair	Major repair
1	First type	2000	$N(0.3,0.01)$	0	Condition based replacement	Condition based replacement	Condition based replacement	Certain replacement
2	Second type	1000	$N(0.4,0.01)$	0.7	Condition based replacement	Non-replacement	Non-replacement	Certain replacement
3	Third type	1500	$N(0.5,0.02)$	0.1	Non-replacement	Condition based replacement	Certain replacement	Certain replacement

According to the maintenance cycle of 1-3-6,it can be known that the level distribution for equipment repair is minor repair, minor repair, medium repair, minor repair, minor repair, major repair. Since the already spent service time $T_s = 2$ year, in the next the equipment should receive medium repair after finishing training task. The equipment use time for the next year $T = 0.5$ year. Hereby it firstly forecasts maintenance material supply of the first type unit

According to the known conditions in table 1, it can be seen that the already spent time for the first unit is 0,in this case, the remaining service time of the first unit equals its entire service time,i.e $\theta_1' = \theta_1$. The probability density function of the first unit life span is $f_\theta(t) = \frac{1}{0.1\sqrt{2\pi}} e^{-\frac{(t-0.3)^2}{0.02}}$, according to the probability theory and relevant statistical theorems,the probability density function of accumulated life span of k numbers of first units is $f_{\sum_{i=1}^{k}\theta_i}\left(\sum_{i=1}^{k} t_i\right) = \frac{1}{0.1\sqrt{2\pi k}} e^{-\frac{(\sum_{i=1}^{k} t_i - 0.3k)^2}{0.02k}}$. The maintenance polices for the first unit when the equipment is under inspection or under medium repair are both condition based replacement,so $L_0 = 1/2$, $L_2 = 1/2$;In the case of medium repair and condition based replacement,the time node for replacing first unit $T_0 = 0.3$ year.

Introducing the derived formula of table 2 as well as the values of L_0 and L_x into the equation (4). With MATLAB program software, it can compute the predicted value of maintenance material supply of the first unit in the next year $S = 1.3$;In addition, according to the unit price of the first unit,it can obtain the predicted value of spare part cost of the first unit in the next year, $J = 2600$.

Based on the prediction method of the first unit maintenance material supply, it can calculate the predicted values of next year maintenance material supply amount for the second unit and the third unit, which is 1.6 and 0, respectively; Meanwhile, the predicted values of next year maintenance material cost for the second unit and the third unit are 1600 and 0, respectively. Therefore, the predicted total cost of maintenance material for all types of units is 4200.

Based on the maintenance material supply amount and cost of the tree types of units, and with comprehensive consideration of equipment maintenance level and maintenance cost, the maintenance personnel can formulate a further plan to store the maintenance material for the three types of units.

V. CONCLUSIONS

Through analysis on various unit maintenance polices when the equipment is under inspection or under different levels of repair, and with the application of theory of random processes, probability theory and mathematical statistics method, the multi-maintenance policies based supply rule of equipment maintenance material was analyzed, in addition, the maintenance material supply for the next year was predicted, which solved practical problems. Through promoting the generalized model established in this paper, the multi-maintenance policies based maintenance material supply of equipments group can be further analyzed, resulting in solution to problems including prediction of equipments group maintenance material supply and the strategy optimization of maintenance material stock amount. On this basis, the military economic efficiency of equipments group maintenance material security.

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