Research on optimization model of Equipment network maintenance Equipment

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Abstract: Aiming at the problem that the demand quantity of networked maintenance equipment is not accurate in the demand analysis results of networked maintenance equipment, an optimization model of maintenance equipment is established by using the principle of queuing theory and simulation method to describe the optimization problem of maintenance equipment quantity. According to the improved genetic algorithm, the established optimization model is solved, so as to get the optimal quantity of maintenance equipment.

1. The introduction
The optimization problem of networked maintenance equipment can be described as follows: on the basis of the analysis of the demand generation and use process of maintenance equipment in equipment maintenance, the optimization model of maintenance equipment is established and the optimal quantity of maintenance equipment is solved with the goal of maximizing the demand for equipment maintenance and the maximum use benefit of maintenance equipment.

The use of networked maintenance equipment is a complex process, each type of maintenance equipment to participate in the maintenance of many types of components, and the components obey different life distribution, maintenance time of components also obey different distribution. Therefore, the time between arrival and maintenance of faulty equipment is difficult to be described by a specific distribution. In addition, the influence of discontinuity in the use of military equipment training on the busy and idle state of maintenance equipment is also different from the queuing system in the usual sense. Therefore, it can be seen that the failure equipment and maintenance equipment constitute a kind of complex queuing system, which is difficult to be accurately described by mathematical analytical model. In view of this, this paper adopts the method of simulation to solve this problem.

The optimization model of maintenance equipment is based on the simulation of maintenance support process. Specifically, it is to obtain the configuration and use effect of the maintenance equipment through simulation of the use of the maintenance equipment in the support process. The configuration effect is used to measure whether the configuration quantity of the maintenance equipment reaches the optimal level.

2. Optimized simulation model
When building the model, in order to simplify the optimization model, combined with the actual use and configuration of maintenance equipment at each maintenance level in the current maintenance
system, when optimizing the number of equipment at a certain maintenance level, only simulation analysis is carried out for the equipment maintenance process at the corresponding maintenance level. The Monte Carlo method is used to simulate the fault (grass-roots level or relay level) and maintenance process of equipment in a certain training period. In the simulation, the accumulative working time and accumulative idle time of various maintenance equipment are recorded respectively, so as to get the average utilization rate of each kind of equipment. The satisfaction rate of the equipment can be obtained by recording the total working time of the equipment and the maintenance delay time caused by the equipment. Its simulation model framework is shown in Figure 1.

(1) Assumptions
   ① Training plans for known equipment;
   ② Spare parts and maintenance personnel are sufficient, and there is no maintenance delay caused by the lack of spare parts or maintenance personnel;
   ③ When a failure or preventive maintenance occurs, it is necessary to wait for all the required maintenance equipment to be idle before carrying out maintenance;
   ④ In the maintenance period, the required equipment has been in the state of occupation.

(2) Given conditions
   ① Equipment training time \( T_0 \);
   ② Maintenance time distribution of fault parts;
   ③ Life distribution function;
   ④ The type and quantity of maintenance equipment.

Figure 1 Sketch figure of simulation model for maintenance equipment optimization

(3) The advancing process of the simulation clock
   In the maintenance support system, the future event table is composed of the time when the equipment fails or the preventive maintenance event arrives. Therefore, the advance of the simulation clock is based on the physical state of the participating training equipment. The advance process of the
simulation clock is described as follows, as shown in Figure 2:

1. Define variables
   - $T$ — Simulation clock;
   - $T_{klm}$ — The time between failure or preventive maintenance of component $m$ in class $l$ of unit $k$;
   - $S_k$ — The working state of the $k_{th}$ equipment, where $S_k = 1$ means that the equipment is in working state and $S_k = 0$ means that the equipment is in maintenance state;
   - $T_{ks}$ — The clock of the $k_{th}$ device in a certain state, in which $T_{ks0}$ represents the clock in maintenance and $T_{ks1}$ represents the clock in working state after repair;
   - $Z_{ij}$ — The status of the $j_{th}$ maintenance device in Class $i$ maintenance equipment, where $Z_{ij} = 1$ means occupied and $Z_{ij} = 0$ means idle.
   - $T_{ij}$ — The idle clock of the $j_{th}$ maintenance device in class $i$ maintenance equipment
   - $T_{if}$ — The idle clock of the first idle service equipment in Class $i$ service equipment
   - $DT_i$ — Delay in maintenance due to waiting for equipment to be serviced
   - $TM_l$ — Random sampling of maintenance time for Class $l$ components
   - $FT_l$ — Random sampling of the life of Class $l$ components
   - $WT_k$ — Number of the $k_{th}$ equipment has been working
   - $MT_k$ — Total maintenance time for the $k_{th}$ piece of equipment
Start

All Training Subjects
Whether the training is complete

Yes
Completion of undergraduate training
No
All of this equipment
Whether to end the subject training

Yes
No

End of the simulation

No

Start again

No

Determine the training subjects and initialize the simulation

determine the corresponding training subject

The random residual life of the component

to determine the components and their clocks in the equipment that are the first to fail or require pre-repair;

Modify the state of the equipment, $S_k=0$, and calculate the working time, $W_{T_k} = W_{T_k} + T_{klm} - T$

Determine the type of equipment required for maintenance

Whether the equipment $k$ work is achieved Training time $T_0$

No

Yes

Determine the idle state for other equipment

$S=0$

No increase in working hours

$S=1$

Other equipment has been working hours plus $T_{klm} - T$

Yes

Determine the type of equipment required for maintenance

Line up and wait, recording the moment when the equipment begins to wait.

Update the next repair clock of the maintenance component $T_{klm} = T_{klm} + DT + TM_l$

Updated equipment $k$ status $S_k=1$

The maintenance clock of other parts of equipment $T_k$ is added $DT + TM_l$

The working time of the $j$th device $T_{W_j} = [0, T_{klm} + TM_l]$; the cumulative working time of the $j$th device $T_{W_{oscope}} = T_{W_j} + T_{klm}$

Determine if there is equipment State change

No

Yes

Changed equipment working time plus $T_{klm} + T$

Determine the busy and idle state of equipment

No

Yes

Figure 2 Simulation clock advancing of maintenance equipment optimization
Simulation clock advance steps

Step 1: Determine the training subjects of simulation, initialize the simulation system, etc. Initialize the simulation clock $T_{klm}^F$, system state, etc. Failure time sampling of all components involved in this training subject; The parts requiring preventive maintenance shall be given preventive maintenance clock $T_{klm}^P$.

$$T_{klm} = \min (T_{klm}^F, T_{klm}^P)$$

for components with preventive maintenance, and $T_{klm} = T_{klm}^F$ for components without preventive maintenance; Equipment working time $WT_k = 0$.

Step 2: Identify the first parts to break down or require preventive maintenance. Calculate $\min(T_{klm})$; Modify the state of the corresponding equipment of the component, denoted as in maintenance state, and set $S_k = 0$; Eg. The equipment has been in service for hours $WT_k = WT_k + T_{klm} - T$. If $T_{klm} \geq T_0$, then the equipment ends the training. If all the equipment has finished the training, then the training item ends the simulation. If $T_{klm} < T_0$ the fault is handled, proceed to the next step.

Step 3: Update the simulation clock to calculate the working time of other equipment. Judge the state of other equipment. When the equipment is in maintenance state, $S_k = 0$, its working time will not be increased. When the equipment is in working condition, $S_k = 1$, the working time of the equipment is plus $T_{klm} - T$. Update the simulation clock $T = T_{klm}$ to determine the last simulation clock and the current one. Whether the state of equipment changes between the simulation clock, the working time of equipment with the state change is added to $T_{klm}$, otherwise the working time will not be increased.

Step 4: Determine the type of equipment needed, judge the state of the equipment, and determine the actual maintenance delay time and the accumulative maintenance time of the equipment. Determine the type of spare parts needed for component maintenance. The state of all devices in this category is determined. If no devices are idle, queue up and wait, and record the clock $T_{klm}$ at which the device starts to wait. If any devices are idle, determine the idle clock $T_{ij} = \min(T_{ij})$ of the $j$th device in which the device of class $i$ is the first to be idle, and the accumulated idle time of the device $ST(j) = ST(j) + \max(0, T_{klm} - T_{ij})$, and modify the idle state of the device $Z_{ij} = 1$.

$DT = \max(0, T_{ij} - T_{klm})$ was determined to determine the maintenance delay time caused by the occupation of all kinds of equipment, and the longest time for the equipment to wait for all kinds of equipment was the actual maintenance delay time $DT_c = \max(DT)$. Determine the accumulative maintenance delay time of equipment $DT(k) = DT(k) + DT_c$ and accumulative maintenance time $MT_c = MT_c + DT_c + TM_c$, where $TM_c$ represents the random sampling of maintenance time of Class $l$ components.

Step 5: Determine the cumulative working time of the equipment, update the busy/idle clock and the busy/idle status of the equipment. To determine the clock $T_f$ of the latest idle state of all kinds of devices, calculate the working time of devices $TW_{ij} = \max(T_f, T_{klm}) - \max(T_{ij} - T_{klm}) + TM_c$, and the cumulative working time of Class $i$ devices $TW_{ij} = TW_{ij} + TW_{ij}$. Update device busy/idle clock $T_{ij} = \max(T_f, T_{klm}) + TM_c$; modify device busy/idle state $Z_{ij} = 0$. Update the next repair clock of the maintenance component $T_{klm} = T_{klm} + DT_c + TM_c + F T_c$, and update the equipment $k$ status $S_k = 1$; Add $DT_c + TM_c$ to the maintenance clock of other parts of equipment $k$. Back to Step 2.

Step 6: Determine whether the actual working time of all equipment reaches the specified time of this training course. If so, return to Step 1 for simulation of the next training course. Otherwise go back to step 2 and continue with the simulation for this training session.

3. Optimization model solving process based on genetic algorithm

The solution steps of the optimization model are as follows:

Step 1: genetic coding. Decimal integer coding is adopted to encode the configuration quantity of maintenance equipment into a row vector $(s_1, s_2, \cdots, s_M)$, where $s_i$ represents the configuration quantity of class $i$ maintenance spare parts, and the upper limit of its value is the quantity obtained from equipment demand analysis in Chapter 3.

Step 2: Generation of initial population. The random method is used to generate $M$ configuration
schemes that meet the cost constraints. As the initial population, each individual in the population meets
the cost constraints of maintenance equipment purchase, and the number of individuals in the population
is controlled between 20 and 200.

Step 3: Calculate individual fitness value. According to the maintenance equipment optimization
simulation model, the satisfaction rate and utilization rate of the individual were calculated, and the
fitness value of the individual was calculated according to the fitness calculation function of Equation
(4-2).

Step 4: Choose. Using the roulette wheel method, N individuals (N is even, M=2N) with higher
fitness value from the parent generation population were selected to be directly copied into the next
generation.

Step 5: Crossover and Mutation. According to Equations (4-3) and (4-4), cross probability \( p_c \) and
mutation probability \( p_m \) are calculated.

Crossover operation: the selected parental individuals are randomly paired with each other, and the
values of the same gene loci of the two individuals are crossed with the probability of \( p=p_c \) according to
Equation (4-5).

Conditions for individual crossover: firstly, a set of random number \( r_{nd} \) between \((0 \sim 1)\)
corresponding to each gene location of the individual is randomly generated. If \( r_{nd}\leq p_c \), crossover is
carried out; otherwise, no crossover is carried out. For example,

Parental individual 1 \( s_1, s_2, s_3, s_4 \)
Parental individual 2 \( s_1', s_2', s_3', s_4' \)

Intersection

Progeny individual 1 \( s_1, s_2, s_3, s_4 \)
Progeny individual 2 \( s_1', s_2', s_3', s_4' \)

Mutation operation: mutate the gene value of the cross-generated offspring with the probability of
\( p=p_m \).
The conditions for individual crossover: firstly, a set of random number \( r_{nd} \) between \((0 \sim 1)\)
corresponding to each gene location of the individual is randomly generated. If \( r_{nd}\leq p_m \), the mutation
operation is carried out; otherwise, no mutation is carried out.

The \( N \) offspring generated by crossover and mutation operations and \( N \) parent individuals form the
next generation population together.

Step 6: Determine whether the optimization criteria are met. If the genetic algebra reaches the
specified algebra or the maximum fitness value of the individual for 20 successive generations does not
increase, the search is stopped and the optimal solution is considered to be found. If the optimization
criteria are not met, go back to step 3 and continue.

4. Optimization of sample

4.1 Problem description

Taking a certain type of equipment in a regiment level unit as an example, the relay maintenance
equipment configuration of the equipment is optimized. Assume that the regiment is equipped with 20
pieces of this type of equipment, and set the proportion of equipment training as 30%, that is, the number
of equipment participating in the training as 6 pieces. The training plan for the equipment and the
relevant information for the components to be repaired at the relay level are shown in Table 1. To
complete the relay maintenance of the equipment, the maintenance equipment to be configured and the
equipment purchase cost are shown in Table 2.
Part 1: Weibull, $\lambda = 3200$, $\beta = 2$, driving 300h, type: Index, $\lambda = 8$

Part 2: Weibull, $\lambda = 1350$, $\beta = 1.8$, driving 300h, type: Normal, $\mu = 6$, $\sigma = 1$

Part 3: Weibull, $\lambda = 2240$, $\beta = 2.5$, driving 300h, type: Normal, $\mu = 6$, $\sigma = 1$

Part 4: Weibull, $\lambda = 3050$, $\beta = 3.1$, driving 300h, type: Index, $\lambda = 5$

| Part | Name of Maintenance Equipment | Unit price (ten thousand Yuan) |
|------|-------------------------------|--------------------------------|
| Part 1 | Equipment 1                   | 10                             |
|       | Equipment 2                   | 8.0                            |
|       | Equipment 3                   | 1.5                            |
| Part 2 | Equipment 4                   | 5.0                            |
|       | Equipment 5                   | 4.0                            |
| Part 3 | Equipment 6                   | 2.5                            |
|       | Equipment 7                   | 10                             |
|       | Equipment 8                   | 7.5                            |
| Part 4 | Equipment 9                   | 5.5                            |

Set the total cost of equipment purchase to be 1 million yuan and equipment working time to be 200 hours. Solve how to configure relay maintenance equipment under the premise of meeting the equipment purchase cost, so that the comprehensive effect of satisfaction rate and utilization rate of maintenance equipment for equipment maintenance can be optimized.

4.2 Optimization results and analysis

According to the optimization method of networked maintenance equipment introduced in Part 3, relevant programs were written with MATLAB to obtain the fitness curve corresponding to the optimal individual in each generation of the population, as shown in Fig. 3. It can be seen from the figure that the genetic algebra tends to be stable from about the 8th generation, so it can be considered that the optimal solution has been searched at this time.

![Figure 3 The dynamic curve of fitness value in optimization](image)
The satisfaction rate of maintenance equipment corresponding to the optimization results is 0.9320 and the utilization rate of maintenance equipment is 0.9239. Table 3 shows the optimal configuration scheme of maintenance equipment.

| Equipment 1 | Equipment 2 | Equipment 3 | Equipment 4 | Equipment 5 | Equipment 6 | Equipment 7 | Equipment 8 | Equipment 9 |
|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| Quantity of demand analysis | 2          | 2          | 2          | 1          | 2          | 2          | 2          | 1          | 2          |
| Optimize number | 1          | 1          | 1          | 2          | 1          | 1          | 1          | 2          | 1          |

5. **The summary of this chapter**

In this paper, the maintenance equipment optimization simulation model based on equipment satisfaction rate and utilization rate is established by analyzing the support process of networked maintenance equipment, and the solution method based on genetic algorithm is designed for the optimization model. The optimization process of maintenance equipment quantity is described by an optimization example, and the correctness and effectiveness of the optimization method are proved by an example.

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