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Research on the Optimization Method of Maintenance Support Unit Configuration with Queuing Theory

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Abstract

Beginning with the conception of maintenance support unit, the maintenance support flow is analyzed, so as to confirm the relation between damaged equipment mean-time-to-repair and the number of maintenance support units. On that basis, the maintenance support unit configuration optimization model is found aiming at the minimum cost of maintenance support resources, of which the solution is given. And the process is explained at the last with a example.

Keywords: maintenance flow; queuing; Maintenance Support Unit; Configuration

1 Introduction

In order to satisfy the recent development of army's modular redesign and the request of precise support in war time, the structure of the equipment support power is on the development of modular assembling[1,2,3]. Maintenance support unit is the aggregate of some different kinds of maintenance support resources and the executant of maintenance support tasks. To allocating maintenance support units reasonably is not only help to reduce the cost and increase the using efficiency of maintenance support units, but also decrease the response time of maintenance support system, as well as the velocity of maintenance.

The conventional method to allocate maintenance support units is evaluation method of man-hour and the formula is[4],

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$$s = \frac{NW}{T} \tag{1}$$

In the formula, N is the number of need to be maintained equipments, W is the standard maintaining time of equipment, T is the available maintaining time of equipment. Conventional method does not consider the logic relationship between maintenance support units and the waiting time because of the maintenance support units be used. So queuing theory is more suitable to deal with the problem of maintenance support units optimization allocation. Practical maintenance process contains queue configuration in series, in parallel connection, and in cycle, but only the series queue configuration is discussed in [5]. In order to do some further more precise analyze on maintenance support units allocation, a method based on queuing theory was researched.

2 Conception of maintenance support units

The conception of maintenance support units has been accepted extensively, but there is not a common definition. The explanation of the unit in the book of CiHai is the unit mad up of some things similar in the characteristic. Accordingly, the maintenance support units was defined as: maintenance support unit is a combination of indispensable maintenance support resources that required by special maintenance support tasks. Consult the known references, the common character description of maintenance support units was given as follows[4,6],

- Maintenance support units must have some particularly specific functions. That means maintenance support units should contain the ability to finish at least one task independently.
- Maintenance support units should be a aggregation of maintenance resources that combines maintenance support personnel, maintenance support facilities, pertinent equipments and maintenance support hardware, etc.
- Maintenance support unit is a combination of the least resources that needed to satisfy the function requests. That means it can only finish one task at once. If we found a maintenance support unit finished two tasks at the same time, then we can plot out it into two maintenance support units.

So, we can find out that maintenance support units can only finish one task at once, this characteristics is the similar to server's. The different maintenance activities in the maintenance process are defined as maintenance task in this paper, which is assigned to maintenance support units to accomplish.

3 The analysis of maintenance support units optimization allocation

3.1 Analysis of maintenance support flow

Equipment maintenance flow contents a series maintenance activity which executed by maintenance support units.

Usually the same kind of maintenance support units can complete at least one kind of maintenance tasks. With the foundation of maintenance flow and the function of the maintenance support units, we can get the maintenance support flow.

In the maintenance support flow, each kind of maintenance support units may be several. For example, s_i is the number of No.i kind of maintenance support unit, the service velocity of the kind maintenance support unit is u_i, the velocity that broken-down equipment arrival is obey poisson distribution whose key parameter is λ_i, then we get a queuing system express as *M/M/s*. Assuming $\rho_i = \lambda_i / s_i u_i$, the mean time, which is expressed as $w_i(\lambda_i, u_i, s_i)$, that broken-down equipment stay in maintenance support units i can be calculated as,

$$w_i(\lambda_i,u_i,s_i)=\frac{1}{\lambda_i}\frac{(s_i\rho_i)^{s_i}-\rho_i}{s_i!(1-\rho_i)^2}\left[\sum_{i=0}^{s_i-1}\frac{(s_i\rho_i)^i}{i!}+\frac{(s_i\rho_i)^{s_i}}{s_i!(1-\rho_i)}\right]^{-1}+\frac{1}{u_i} \tag{2}$$

In the maintenance support process, there is three main queuing net structure composed by maintenance support units, which are select structure, tandem structure, and cycle structure. It is showed as figure 1. Any complex maintenance flow can be constructed in the three structure. In order to get the maintenance ability of the whole maintenance flow model, we firstly analyze these structures.

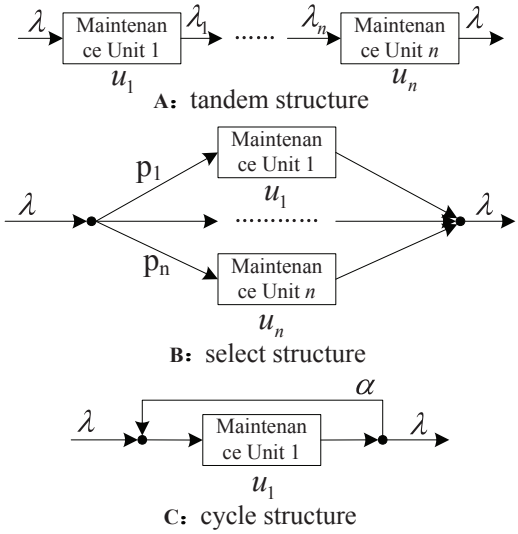

Figure 1. The basic structure of maintenance flow

In the figure 1, λ is the velocity that broken-down equipment arrives, which obeys poisson distribution. There are n maintenance support units in the structure. $w_i(\lambda_i,u_i,s_i)$ is the mean time of broken-down equipments through the No.i kind of maintenance support unit. W_s is mean time broken-down equipments through the queuing structure.

- Tandem structure queuing system

λ_i is the velocity of broken-down equipments arrive to the No.i kind of maintenance support units, which equals to λ. The mean time broken-down equipments through the queuing structure is,

$$W_s=\sum_{i=1}^{n}w_i(\lambda_i,u_i,s_i) \tag{3}$$

- Select structure queuing system

λ_i is the velocity of broken-down equipments arrive to the No.i kind of maintenance support units, which equals to $p_i\lambda$. p_i is the probability that broken-down equipment select No.i kind of maintenance support units. The mean time broken-down equipments through the queuing structure is,

$$W_s=\sum_{i=1}^{n}p_iw_i(p_i\lambda,u_i,s_i) \tag{4}$$

- Cycle structure queuing system

λ_i is the velocity of broken-down equipments arrive to the No.i kind of maintenance support units, which equals to $\lambda/(1-\alpha)$. α is the probability that broken-down equipment need to be maintained again. The mean time broken-down equipments through the queuing structure is,

$$W_s = w_i(\frac{\lambda}{1-\alpha}, u_i, s_i) \tag{5}$$

According to the analysis above, the equipment maintenance queuing flow can be analyzed and the queuing model can be built up. Then the mean time that broken-down equipment stay in the queuing system and the relationship between the mean time and the number of maintenance support units can be got.

3.2 Maintenance support units collocation modeling

Usually, there are some district time requirements in war time. In order to meet the integrality requirements of the equipment, the mean time of broken-down equipments maintained by one maintenance support force is required to up to some value, which can be get by analyzing of equipment maintenance queuing flow. The devotion in the maintenance support is huge and so do the cost to execute, and the cost is one of the most concerned parameters by decision-maker. Therefore, the problem of maintenance support unit optimization allocation is researched under the restriction of the mean time that broken-down equipments maintained, which is less than given value, and aiming at the lowest cost of maintenance support units devotion.

The cost of each maintenance support unit No. *i* kind is assumed to be C_i. The amount of No. *i* kind of maintenance support unit is s_i, when the mean time W of broken-down equipments maintained is less than given value W'. The whole cost C,

$$C = \sum_{i=1}^{n} s_i C_i \tag{6}$$

The $\min C$ and its s_i are final results of the problem of maintenance support unit optimization allocation.

4 A demonstration of maintenance support units allocation

The maintenance steps of certain equipment are as follow: damage localization, rough disassembly, parts maintenance and whole assembly. Based on steps' different resource requirement, setting up damage localization units answer for going to the equipment's blooey part; setting up disassembly and assembly units answer for disassembling and assembling; setting up three kinds of parts maintenance units answer for maintaining every parts. Hereby, the kind equipments' maintenance support flow can be expressed as flow.

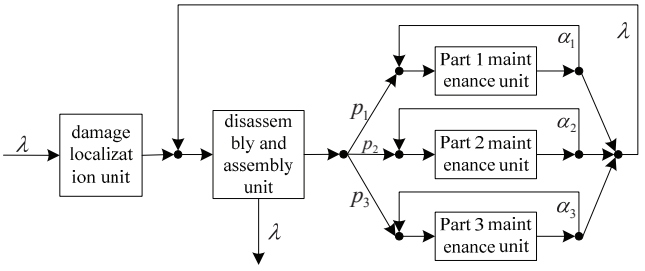

Figure 2. Maintenance support flow

In the maintenance support queuing process, there are 5 kinds of maintenance support units. It's know that the velocity that broken-down equipments arriving λ =3 per hour, the probability that the part

1 maintenance units, part 2 maintenance units and part 3 maintenance units are selected are p_1=0.3, p_2=0.5, p_3=0.2. The re-maintain probability of each parts is α_1=0.1, α_2=0.1, α_3=0.2. The cost and maintenance velocity of each maintenance support units are showed as table 1.

Table 1. The cost and maintenance speed of maintenance support unit

Maintenance support unit	Cost(ten thousand Yuan)	Maintenance velocity
damage localization units	1	0.5
disassembly and assembly units	4	1
part 1 maintenance unit	3	0.2
part 2 maintenance unit	2	0.25
part 3 maintenance unit	5	0.3

The problem is to calculate the least cost and the number of each kind of maintenance support units, when the mean time of broken-down equipments maintained is less than 15 hours.

The steps to solve the problem are showed as figure 3.

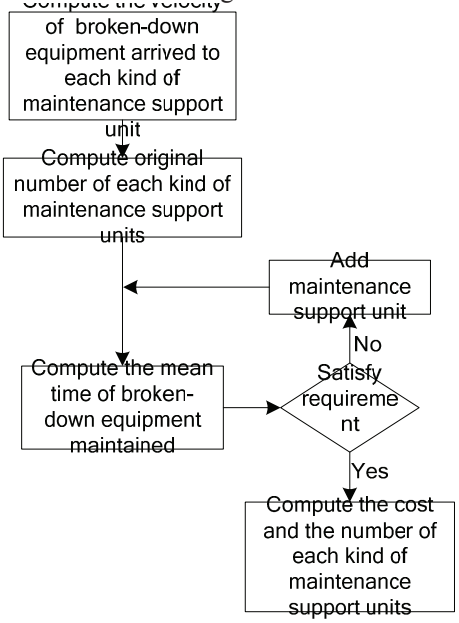

Figure 3. The flow of Maintenance Support Unit Configuration Optimization

Step 1: The velocity of broken-down equipments arrived to each kind of maintenance support units is computed.

$$\lambda_d=\lambda=3,\quad \lambda_{da}=2\lambda=6,\quad \lambda_{p1}=\frac{p_1\lambda}{1-\alpha_1}=1,\quad \lambda_{p2}=\frac{p_2\lambda}{1-\alpha_2}=1.67,\quad \lambda_{p3}=\frac{p_3\lambda}{1-\alpha_3}=0.75。$$

Step 2: Original number of each kind of maintenance support units is computed, according to the velocity of broken-down equipments arrived to each kind of maintenance support units, which equals to the number that assure broken-down equipments queue won't augment unlimitedly. According to $\lambda_i/s_iu<1$, s_i can be get.

s_d=7, s_{da}=7, s_{p1}=6, s_{p2}=7, s_{p3}=3.

Step 3: The mean time of broken-down equipments maintained is computed, based maintenance support flow predigested.

(1) There are re-maintain rate in part 1 maintenance units, maintenance units, and part 3 maintenance units. Based on the cycle queuing model, the mean queuing time of broken-down equipment through each kind of maintenance units can be computed.

W_{p1}=8.46, W_{p2}=7.99, W_{p3}=8.72

(2) Three kinds of parts maintenance units are regarded as one select queuing structure, the mean queuing time W_p of broken-down equipment through the structure is,

$W_p = p_1 W_{p1} + p_2 W_{p2} + p_3 W_{p3}$ =8.28

(3) In maintenance process, broken-down equipments need pass disassembly and assembly units twice. The resources and time requirements of disassembly and assembly are the same. So they can be seemed as the same activities. The mean time of broken-down equipments maintained is,

$W = W_d + 2W_{da} + W_p$ =4.93+4.93+8.28=19.14

Step 4: Adding maintenance support units. The mean time of broken-down equipments maintained W can not up to the requirement value, the number of maintenance support units must be increased.

When No.i kind of maintenance support units was increased one, the mean maintaining time decreases ΔW. Then the kind of maintenance support units is chosed, which ensure a maximum $\Delta W / C_i$, and let its number plus 1. Details are showed in table 2.

Table 2. the relationship of maintenance support unit number and cost per unit time

	ΔW	$\Delta W / C_i$
Adding one damage localization units	2.39	2.39
Adding one disassembly and assembly units	2.39	0.6
Adding one part 1 maintenance unit	2.2	0.73
Adding one part 2 maintenance unit	3.04	1.52
Adding one part 3 maintenance unit	1.56	0.31

Obviously, to add a damage localization unit can get the maximum $\Delta W / C_i$. So the number of damage localization units will be increased one.

Back to step 3, mean time of broken-down equipment maintained will be computed again . It get W =15.75 hours, which is also unsatisfied to the required value.

Step 5: Work out the number of maintenance support units and the whole cost. After calculation, the mean time of broken-down equipments maintained W =12.71 hours, which satisfies the requirement, when s_d=8, s_{da}=7, s_{p1}=6, s_{p2}=8, s_{p3}=3. And the whole cost are 850 thousands Yuan.

5 Conclusion

The relationship of the number of maintenance support units and the mean time of broken-down equipments maintained is analyzed based on queuing theory and equipment maintenance process. The model of maintenance support units optimization allocation is built and the process to solve the model is given with a demonstration. The method is helpful to compute the optimal number of maintenance support units, so as to decrease the whole cost and mean time of broken-down equipments maintained and improve the ability of maintenance support.

References

[1] Congressional Research Service, Washington, DC, U.S. Army's Modular Redesign: Issues for Congress. CRS Report for Congress (ADA436231/XAB), 2006.2.6.

[2] ZHANG Yong-xing, ZHANG Meng-peng, WANG Yun-cheng, Analysis Army Modularized Development Based on Models Combination regulation[J], Shijiazhuang Mechanized Infantry Academy Transaction, 2005, (3), P36-37.

[3] XU Lin-ping, The Conception of Army Tactics Corps Block-based Design[J], Military Art, 2003, (1), P74-75.

[4] PAN Quan, HUANG Shan-hui, The Method to Compute Wartime Maintenance Man Hour Based on Maintenance Unit[J], Research of Ordnancemaintenance Engineering, 2005, (2), P1-4.

[5] LIU Guang-jun, ZUO Xiao-yong, TAI Zhong-kui, LONG Zhao-fei, Research on the Models of Damaged Equipments Maintenance Based on Serial Queuing System[C], Proceedings of Academy of System Simulation Technology & Application, 2009, P65-68.

[6] YE Zhan-wu, Equipment Maintenance Unit Block-based Design[D], Shijiazhuang: Ordnance Engineering College, 2005.

[7] LU Chuan-lai, Queuing Theory[M], Beijing: Beijing University of Post and Telecommunications Press, 2009.

[8] TIAN Nai-shuo, XU Xiu-li, MA Zhan-you, Discrete-time Queuing Theory[M], Beijing: Science Press, 2009.

[9] SUN Rong-heng, Stochastic Process and Their Applications[M], Beijing: Tsinghua University Press, 2004.

[10] LIN Chuang, TIAN Li-qin, WEI Ya-ya, Performance Equivalent Analysis of Workflow Systems[J], Journal of Software, 2002, (8), P1472-1480.