HILL PUBLISHING

Engineering Advances, 2023, 3(6), 498-504
https://www.hillpublisher.com/journals/ea/
ISSN Online: 2768-7961

A Method for Determining the Requirements of Electronic Equipment Maintenance Personnel Based on FAHP and Queuing Theory

Zimeng Cheng[1], Bangchun Liu[1], Chen Xin[2,*]

[1]Space Engineering University, Beijing, China.
[2]Unit 73101 of the People's Liberation Army, Xuzhou, Jiangsu, China.

How to cite this paper: Zimeng Cheng, Bangchun Liu, Chen Xin. (2023) Mechanism of Influence of Sawtooth Interface Parameters on Shear Behavior of New and Old Concrete. *Engineering Advances*, 3(6), 498-504.
DOI: 10.26855/ea.2023.12.011

Received: November 30, 2023
Accepted: December 27, 2023
Published: January 19, 2024

[*]**Corresponding author:** Chen Xin, Unit 73101 of the People's Liberation Army, Xuzhou, Jiangsu, China.

Abstract

The high technological content of electronic equipment and the increased difficulty of failure maintenance make the battlefield emergency repair tasks of electronic equipment complex and heavy in wartime. It is very important for decision-makers to determine the wartime maintenance personnel requirements of electronic equipment to meet the task requirements and avoid the waste of maintenance resources. Based on the fuzzy analytical hierarchy process (FAHP), the relevance evaluation of maintenance professional types was first carried out, and then the degree of the professional type irreplaceability was evaluated, and the technical level for maintenance personnel was determined successfully. Based on accompanied maintenance and fixed points maintenance, the optimal maintenance personnel quantity model is established by the queuing theory model. Finally, taking a new electronic reconnaissance vehicle as an example, the maintenance requirements of the reconnaissance system of the vehicle are analyzed. The results show that the model proposed in this paper provides technical support and a quantitative analysis method for the determination of electronic equipment maintenance requirements during wartime. The paper also puts forward some interesting research directions for the future.

Keywords

Electronic equipment, Maintenance requirement, FAHP, Queuing Theory

1. Introduction

Electronic equipment refers to various military information systems, facilities, instruments, software, etc. characterized by electronic information technology [1]. It is an important part of military equipment, especially main battle equipment. Electronic equipment has penetrated into all aspects of weapon system of systems confrontation activities, running through the entire process of information acquisition, transmission, storage, processing, control, and other information flows [2]. This is a significant feature that distinguishes electronic equipment from traditional equipment [3-5].

The US military attaches great importance to the demonstration and analysis of equipment maintenance resources and proposes that the analysis and planning of equipment maintenance resources should be implemented from the demonstration and development stages, and attaches importance to laws and regulations, theoretical research, software development and other aspects [6, 7]. The US military proposes that "any professional maintenance personnel have the potential and talent to learn and master other professional knowledge in this field". The US military regards "multifunctional maintenance" as the core requirement for the transformation of the Army's maintenance system. Through the consolidation of maintenance professional categories, the number of ordnance specialties has been reduced from 43 to 35, which has to some extent improved the efficiency of maintenance [8]. Blond Kyle et al. put forward a maintenance scheduling method for the US Air Force adapting commercial best practices [9]. Zhou et al. provide configuration optimization ideas and solutions for complex equipment maintenance services [10].

The determination of the number of maintenance personnel has always been a focus of research in the field of maintenance decision-making. Li et al. estimated the number of maintenance personnel by analyzing the task size [11]. Zhu, et al. comprehensively considered various kinds of operation, shift preparation, and other factors, and obtained the standard staffing number of vehicle service systems, which provided a theoretical basis for operating enterprises to reserve personnel in advance [12]. Wang found that the reasonable allocation of the hospital's own medical equipment maintenance technical force is an important means to improve the comprehensive benefits of the hospital [13]. Ma et al. use the case-based reasoning method and introduce relevant principles and methods of BP neural network in the case retrieval process to calculate the demand for equipment maintenance personnel from past practical experience.

2. The process for the determination of equipment maintenance professional types

Due to the diverse professional types of maintenance personnel required for electronic equipment systems, which can generally reach over a dozen or even over twenty types, it is currently not possible to allocate enough maintenance professional positions in the military to meet the maintenance professional types' needs. Therefore, it is necessary to combine the professional types of maintenance personnel. The determination of the professional types of maintenance personnel mainly includes assessment of professional relevance, assessment of professional irreplaceability, and determination of the technical level of maintenance personnel. The specific determination process is shown in Figure 1.

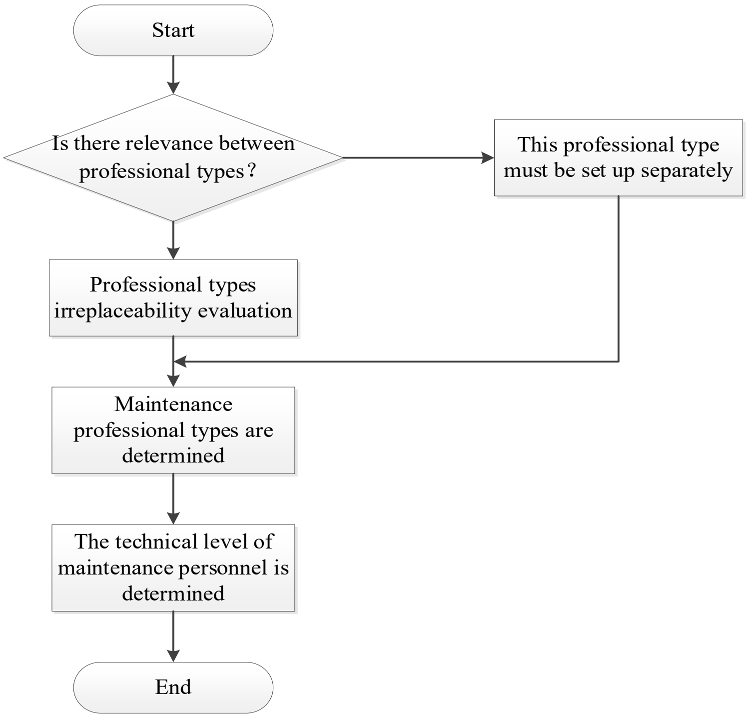

Figure 1. The specific determination process of the determination of equipment maintenance professional types.

3. The evaluation of the professional types relevance

The evaluation of professional types' relevance for maintenance personnel mainly involves inviting experts to determine whether there is relevance between the various professional types. If a certain professional type does not have relevance with all other professional types, then the professional type is relatively independent and should be directly set as a separate maintenance professional type; If there is relevance between a certain professional type and other professional types, the professional type may can be combined with certain professional types, and further determination is made by quantitatively evaluating the irreplaceability of the professional type to determine whether it need to be combined.

The evaluation of professional types' relevance can be divided into three steps:

(1) The evaluation table for the relevance of the professional types is designed, which is shown in Table 1.

(2) Several experts familiar with equipment maintenance were invited to conduct a pairwise evaluation of the relevance between various maintenance professional types. If there is relevance, mark "√" in Table 1. The professional type itself will not undergo relevance evaluation and will be distinguished by a grey box.

(3) The evaluation result analysis and professional types irreplaceability analysis are conducted.

Table 1. The evaluation table for the relevance of the professional types

Number	**Professional types**	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	...
1	Type 1								
2	Type 2								
3	Type 3								
4	Type 4								
5	Type 5								
6	Type 6								
7	Type 7								
...									
Number of the professional types with relevance									

4. The evaluation of the professional types irreplaceability

The quantitative evaluation steps for professional types' irreplaceability are as follows:

A professional type irreplaceable degree evaluation index system is established. The necessity of establishing maintenance professional types is usually evaluated from five aspects: the importance of professional types, the level of professional skills, the characteristics of the maintenance object, the matching degree of maintenance resources, and the progressiveness of maintenance technology. This is also the fundamental criterion for analyzing the professional types' irreplaceable degree. The indicator system of professional types' irreplaceability evaluation is shown in Figure 2.

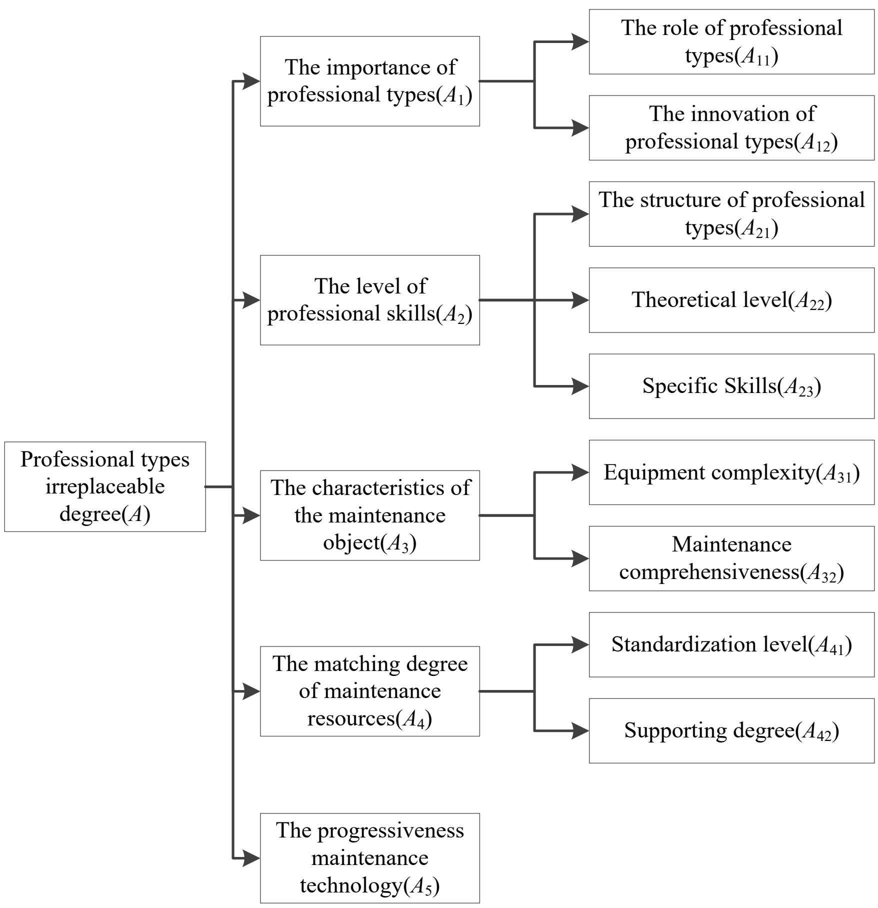

Figure 2. The indicator system of professional types irreplaceability evaluation.

Table 2. The professional types irreplaceability scoring rules

Irreplaceability degree level	Irreplaceability degree score								
	9	8	7	6	5	4	3	2	1
I (Seriously irreplaceable)	■	■	■						
II (Importantly irreplaceable)				■	■	■			
III (Generally irreplaceable)							■	■	■

The weight of each indicator is calculated. In order to determine the weight of the indicator of professional types irreplaceability evaluation, this study analyzes and quantifies the relative importance of maintenance professional types by using the index scale method. Through pairwise comparison among indicators in Fig. 2, the priority correlation judgment matrix A is established.

$$A=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mm} \end{bmatrix} \tag{1}$$

Where $a_{ij} \in (0, 0.5, 1)$, and:

$$a_{ij}=\begin{cases} 0 & \text{indicator } i \text{ is not as important as indicator } j \\ 0.5 & \text{indicator } i \text{ is as important as indicator } j \\ 1 & \text{indicator } i \text{ is more important than indicator } j \end{cases} \tag{2}$$

Twenty experts were invited to evaluate the pairwise relative importance of indicators, and the feedback and modification were carried out continuously until experts reached the same conclusion. After the results of the relative importance of the pairwise indicators were obtained, the priority correlation matrix was constructed. The priority correlation matrix can be viewed as a judgment matrix, and the judgment matrix is changed into a fuzzy consistent judgment matrix to solve the consistency problem of the judgment matrix. Firstly, A is summed in rows:

$$r_i=\sum_{k=1}^{m} a_{ik} \quad i=1,2,...,m \tag{3}$$

To ensure the fuzzy consistency of the matrix, formula (3) is transformed to:

$$r_{ij}=\frac{r_i-r_j}{2m}+0.5 \quad i,j=1,2,...,m \tag{4}$$

Thus, the fuzzy consistency judgment matrix can be obtained:

$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mm} \end{bmatrix} \tag{5}$$

By summing each row element of the fuzzy consistent judgment matrix, the importance l_i of indicator i relative to the upper indicator can be obtained as follows:

$$l_i=\sum_{j=1}^{m} r_{ij}-0.5 \quad i=1,2,...,m \tag{6}$$

After the normalization l_i, the weight W_i of each indicator is

$$W_i=\frac{l_i}{\sum l_i}=\frac{2l_i}{m(m-1)} \tag{7}$$

Assuming that the arrival rate of failed equipment is and the repair rate of the basic maintenance unit is μ . Then the service intensity of the whole system is:

$$\rho = \frac{m\lambda}{C\mu} \tag{8}$$

The idle probability of the basic maintenance unit is:

$$p_0 = \frac{1}{m!} \cdot [\sum_{n=0}^{C} \frac{1}{n!(m-n)!} (\frac{C\rho}{m})^n + \frac{C^C}{C!} \sum_{n=C+1}^{m} \frac{1}{(m-n)!} (\frac{\rho}{m})^n]^{-1} \tag{9}$$

where n is the number of failed equipment.

The probability of n equipment failure is:

When $1 \le n \le C$, then:

$$p_n = \frac{m!}{(m-n)!n!} (\frac{\lambda}{\mu})^n p_0 \tag{10}$$

When $C+1 \le n \le m$, then:

$$p_n = \frac{m!}{(m-n)!C!C^{n-C}} (\frac{\lambda}{\mu})^n p_0 \tag{11}$$

The average number of failed equipment is:

$$L_s = \sum_{n=1}^{m} np_n \tag{12}$$

The number of failed equipment waiting in the queuing system for repair is:

$$L_q = \sum_{n=C+1}^{m} (n-C)p_n \tag{13}$$

In wartime, accompanied maintenance is mainly to carry out rescue and repair with as little time as possible to restore the functions needed for the battle of the failed equipment. So that it can be put into the battle again. The maintenance efficiency of the queuing system can be measured by the continuous engagement rate, which is the ratio of the number of equipment meeting the operational requirements to the number of all equipment in a certain period of time.

The formula for calculating the continuous engagement rate is:

$$\alpha = \frac{m-L_s}{m} \times 100\% \tag{14}$$

The queuing system of fixed point maintenance refers to the system that sets maintenance points in fixed areas and uses multiple basic maintenance units to carry out equipment maintenance tasks in parallel. The customer source is the failed equipment sent by each combat unit, and the number of failed equipment can be considered infinite. Assuming that there are Z basic maintenance units serving independently and in parallel in the system, the queuing system of the fixed point maintenance can be regarded as an M/M/Z/∞/∞/FCFS type of queuing system. If the repair rate of the maintenance unit is μ and the arrival rate of the failed equipment is $\lambda^{'}$, then the service intensity of the system is:

$$\rho^{'} = \frac{\lambda^{'}}{Z\mu} \tag{15}$$

When the number of failed equipment in the system is n, the probability of the basic maintenance unit being empty is:

$$p_0^{'} = [\sum_{n=0}^{Z-1} \frac{1}{n!} (\frac{\lambda'}{\mu})^n + \frac{1}{Z!} (\frac{\lambda}{\mu})^Z (\frac{1}{1-\rho})]^{-1} \tag{16}$$

The number of failed equipment queued for repair is:

$$L_q^{'} = (\frac{\lambda'}{\mu})^Z \frac{\rho'}{Z!(1-\rho)^2} p_0^{'} \tag{17}$$

In wartime, combat units deliver equipment requiring repairs to designated locations, which requires avoiding congestion caused by long queues. Equipment maintenance during wartime requires a high degree of timeliness. The time spent waiting in the queue system for repair of failed equipment can be used to measure the efficiency of the queuing system. The formula for calculating the waiting time for the repair of failed equipment is:

$$w_q' = \frac{L_q'}{\lambda'} \tag{18}$$

5. Case analysis

The structure of a certain type of electronic reconnaissance vehicle is complex and the technical level is high. The maintenance professional types demand of single equipment is as many as 45, and the maintenance work is difficult. So many maintenance professional types make it difficult to have a sufficient number of maintenance personnel to match them, and some of the 45 maintenance professional types have relatively fewer maintenance tasks, so some professional types can be merged into other professional types. Therefore, it is not necessary to establish so many maintenance professional types separately, otherwise, it will cause a waste of maintenance resources. Taking the five maintenance professional types of the electronic reconnaissance vehicle reconnaissance system as an example, the method proposed in this study is used to carry out the evaluation of the professional types' relevance, the evaluation of the professional types' irreplaceability, the determination of the technical level for maintenance personnel and the determination of the number of maintenance personnel in turn. The results can provide a theoretical basis and technical support for the wartime maintenance of the electronic reconnaissance vehicle reconnaissance system.

The evaluation of the professional types' relevance to the reconnaissance system

Twenty experts familiar with the maintenance of the electronic reconnaissance vehicle were invited to conduct a pairwise evaluation of the relevance among various maintenance professional types, while the professional type itself will not undergo relevance evaluation. The results are shown in Table 3.

Table 3. The table for the relevance of the professional types

Number	**Professional types**	Chassis	Photoelectricity	Machinery	Hydraulic pressure	Electrical
1	Chassis			√	√	√
2	Photoelectricity			√	√	√
3	Machinery	√	√		√	√
4	Hydraulic pressure	√	√	√		√
5	Electrical	√	√	√	√	
Number of the professional types with relevance		3	3	4	4	4

This section mainly analyzes the electrical and photoelectricity professional types as examples. From Table 4, it can be seen that there is a relevance between the electrical and photoelectricity professional types. The scoring description in Appendix A is used to score according to the 10 indicators in Figure 2.

Table 4. The quantitative evaluation result of the professional types irreplaceability between Photoelectricity and Electrical

First-order index	Secondary index	Weight	Generally irreplaceable			Importantly irreplaceable			Seriously irreplaceable			Score
			1	2	3	4	5	6	7	8	9	
A_1	A_{11}	0.08			√							0.24
	A_{12}	0.09		√								0.18
A_2	A_{21}	0.08		√								0.16
	A_{22}	0.09			√							0.27
	A_{23}	0.06				√						0.24
A_3	A_{31}	0.15			√							0.45
	A_{32}	0.13			√							0.39
A_4	A_{41}	0.11	√									0.11
	A_{42}	0.10			√							0.30
A_5		0.11			√							0.33
Result			III (Generally irreplaceable)									2.67

6. Conclusions

This paper mainly studies the requirement determination of the maintenance personnel for electronic equipment. Based on the FAHP, the relevance evaluation of maintenance professional types was first carried out, and then the degree of the professional types' irreplaceability was evaluated, and the technical level for maintenance personnel was determined successfully. Based on accompanied maintenance and fixed point maintenance, the optimal maintenance personnel quantity model is established by the queuing theory model. Finally, taking a new electronic reconnaissance vehicle as an example, the maintenance requirements of the reconnaissance system of the vehicle are analyzed. The results show that the maintenance professional types required by the reconnaissance system are chassis, hydraulic pressure, machinery, and photoelectricity, and the technical levels of maintenance personnel matching each maintenance specialty are middle non-commissioned officer, assistant engineer, senior non-commissioned officer, and engineer. In the context of two combat units each unit equipped with 10 electronic reconnaissance vehicles, the optimal number of maintenance personnel is 168. The model proposed in this paper provides technical support and a quantitative analysis method for the determination of electronic equipment maintenance requirements during wartime.

References

[1] Chi L, Dong J J, Liu J G, et al. Analysis of The Reliability of Rasterized Electronic Information Equipment Maintenance [A]. Proceedings of 2013 International Conference on Quality, Reliability, Risk, Maintenance, and Safety Engineering [C]. Emeishan, Peoples R China: IEEE, 2013: 1646-1648.

[2] Chakravarthy SR, Dudin AN, Dudin SA, et al. Queueing System with Potential for Recruiting Secondary Servers [J]. Mathematics, 2023, 11(3): 624.

[3] Fedorova E, Lapatin I, Lizyura O, et al. Queueing System with Two Phases of Service and Service Rate Degradation [J]. Axioms, 2023, 12(2): 104.

[4] Ramesh A & Udayabaskaran S. Analysis of a Single Server Queueing System Controlled by a Random Switch [J]. Contemporary Mathematics, 2023, 4(2): 189-201.

[5] Samanta SK & Das K. Detailed Analytical and Computational Studies of D-BMAP/D-BMSP/1 Queueing System [J]. Methodology and Computing in Applied Probability, 2023, 25(1): 12.

[6] Oonsivilai A, Boribun B, & Pao-la-or P. Integration of Distributed Generation and Plug-in Electric Vehicles on Power Distribution System by Using Queuing Theory [J]. Energies, 2023, 16(7): 3146.

[7] Aliahmadi A, Ghahremani-Nahr J, & Nozari H. Pricing Decisions in the Closed-Loop Supply Chain Network, Taking into Account the Queuing System in Production Centers [J]. Expert Systems with Applications, 2022, 212: 118741.

[8] Ke H F, Zhu J L, & Zhang J Q. Framework of operational effectiveness evaluation index system for electronic equipment from a four-domain perspective [J]. Journal of Equipment Academy, 2016, 27 (03): 113-119. (Chinese)

[9] Matthew F. Bogdanos. Battlespace Management in Integrated Operations [J]. Joint Force Quarterly, Issue 37, 2007:8-9.

[10] Harris DH. Myths and Realities of Electronics Maintenance [J]. Human Factors, 2008, 50(3): 375-379.

[11] Jeremy D. Smith. A Proposed Modular Distribution Unit [J]. Army Logistician, 2006, 38(2): 26-28.

[12] Blond K, Himschoot A, Klein E, et al. Adapting Commercial Best Practices to US Air Force Maintenance Scheduling [J]. Aerospace, 2023, 10(1): 61.

[13] Zhou C L, Ye S, & Wang H J. Maintenance Service Configuration Optimization for Complex Equipment [J]. Systems, 2023, 11(1): 32.