TELKOMNIKA, Vol.11, No.2, February 2013, pp. 599~606
ISSN: 2302-4046

Equipment maintenance support capability evaluation using cloud barycenter evaluation method

Hongqiang Gu*[1], Cheng Zhang[2], Quan Shi[3]
[1,2,3]6th deptartment, Shijiazhuang Mechanical Engineering College, Shijiazhuang, 050003, China
*Corresponding author, e-mail: zcflysky@163.com

Abstract

Maintenance support is the most important measures to keep equipments having high operational capabilities. Equipment maintenance support capability is an important part of operational capability and the evaluation of equipment maintenance support capability is very important to the establishment of battle effectiveness. The evaluation index system of equipment maintenance support capability is established according to the evaluation index establishing principles. Cloud barycenter evaluation method is applied to equipment maintenance support capability evaluation on basis of the established evaluation index system. The application steps of cloud barycenter evaluation method to equipment maintenance support capability evaluation are analyzed. A calculating example for equipment maintenance support capability using the proposed algorithm is presented and the evaluation results are achieved using the weighted deflection degree which is used to demonstrate the deflection degree between equipment maintenance support capability and its perfect state. The correctness and validity of the proposed method is verified by the calculating results, which provide an efficient method for equipment maintenance support capability evaluation.

Keywords: *Equipment maintenance support, capability evaluation, cloud barycenter evaluation*

1. Introduction

Equipment maintenance support is an indispensable oprational element in information war. With the fast development of science and technology, more and more modern hi-tech weapons appeared and equipped, which puts forward higher requirements for equipment maintenance support. Equipment maintenance support capability is an important part of operational capability and the evaluation of equipment maintenance support capability is very important to the establishment of battle effectiveness [1]. Performing equipment maintenance support capability evaluation timely and accurately can provide reliable information for equipment support commander to adjust equipment support plan as well as make decisions timely and correctly. The prime aim of equipment maintenance support capability is to manifest the objective characteristics of equipment maintenance support capability actually and comprehensively. The evaluation of equipment support includes many uncertain factors, in which some are quantitative factors while others are qualitative factors. Moreover, the relationship between these factors and equipment maintenance support capability is complex and nonlinear. Many algorithms has been investigated in literature at present to perform the evaluation process. Neural network evaluation method is used in [2] to evaluate euquipment amintenance support capability in wartime, in which a neural network model about the maintenance support capability is established after constructing the evaluation index system. The concept of state space and matched degree of maintenance supposing resources are presented and the main method and basic approach to establish the ideal state space are specified in [3].

The evaluation index system model of maintenance support capability is established and the weight and calculation of every evaluation index are also provided. The least squares support vector machine (LS-SVM) is used in [4] to perform equipment support capability evaluation, in which a method of robust LS-SVM is proposed to make the established model be free of the influence of singular point. But all these evaluation methods can not deal with the relationship between qualitative concept and quantitative description perfectly, which confines their practical applications.

Received October 2, 2012; Revised December 21, 2012; Accepted January 10, 2013

Cloud theory is a kind of mathematical model, which describes the mapping relationship between quality and quantity through synthesizing fuzzy and stochastic relation completely [5,6]. Cloud barycenter evaluation method developed from cloud theory is a comprehensive evaluation method dealing with uncertified and ambiguous knowledge. It is a qualitative and quantitative method and can realize the transformation between conception and data. It has wide use in evaluating complex system in military domain. Against the problem of the traditional operational effectiveness evaluation of air-attack targets threat, the establishment of guide lines of the air target threat is ascertained in [7] and based on the cloud theory, the theory of membership cloud, concepts of multidimension synthetic cloud and its gravity centre (GC) are proposed, which helps the operation commander of air defense to make a fast and accurate decision. The number characters, forward cloud, reverse cloud and weighted sum algorithm which are applied in the efectiveness evaluation of aviation EW system are introduced in [8]. Through the forw ard cloud algorithm, the qualitative weight and evaluative description are transformed to number characters and the quantitative evaluation value is transformed to qualitative evaluation conclusion through the reverse cloud algorithm, which coincides with people's custom. Cloud barycenter evaluation method is suit for dealing with comprehensive evaluation problem with fuzzy and uncertain characteristics. So it is feasible to use cloud theory in equipment maintenance support capability evaluation.

This paper discusses the application of cloud barycenter evaluation method in evaluating equipment maintenance support capability. The evaluation model and index system is established based on the analysis of the composing of equipment maintenance support capability. The basic theory of cloud barycenter evaluation method is introduced as the theoretic basis. Then the general steps of the proposed evaluation method are expatiated to evaluate equipment maintenance support capability level. The correctness and effectiveness of the proposed method are verified by evaluation results.

2. Research Method

Cloud barycenter evaluation method based on cloud model is used in this paper to evaluate equipment maintenance support capability. Cloud model is a transformation model between a concept and a quantified value, which is presented based on the traditional fuzzy set and probability statistics. In other words, it can realize the transformation between a concept described in words and its numerical representation. The evaluation index system of equipment maintenance support capability is established and the basic theory of cloud barycenter evaluation method is discussed in this section as the basis of the applicaiton of cloud barycenter evaluation method.

2.1. Evaluation Index

The key problem of evaluating the capability of equipment maintenance support is analyzing the main influence factors and establishing the evaluation index system. The general principle of establishing evaluation index is that the established index must accord with scientificity, feasibility, systematization, independence and flexibility. Furthermore, the following three principles must also be considered. Firstly, the maintenance capability in peacetime as well as in wartime must be considered simultaneously. Equipment training and operation are implemented according to plan in peacetime, in which equipment support has some general rules to follow. But in waretime equipment support tasks are changed from time to time and the requirements of different tasks to equipment support are various. As result, equipment support demands in peacetime and in waretime must be considered simultaneously in the process of establishing index system. Secondly, dynamic characteristic of equipment support must be considered. Equipment support is a developing dynamic system, so the index system reflecting its work is also a dynamic system to guaranteeing the sensitivity. Lastly, criterion is also an important aspect that must be considered in establishing index system in order to let the established index system has currency, which is in convenient of data collecting.

According to above evaluation index establishing principle the evaluation index system of equipment maintenance support capability established in this paper is illustrated as follows.

The total index: the overall equipment maintenance support capability U . First level index: U ={Maintenance support forces U_1 , Maintenance support equipment U_2 , Maintenance support spare parts U_3, Maintenance support facility U_4, Maintenance support technical information U_5}.

Second level index: U_1={Personnel technical level U_{11}, Personnel number U_{12}, Personnel utilizing rate U_{13}}.

U_2={Support equipment intact rate U_{21}, Support equipment quantity satisfaction rate U_{22}, Support equipment parts variety rate U_{23}}.

U_3={Spare parts satisfaction rate U_{31}, Spare parts inventory U_{32}, Spare parts reliability U_{33}, Spare parts intact rate U_{34}}

U_4={Aupport facility utilizing rate U_{41}, Average support facility area utilizing rate U_{42}, Support facility area delay rate U_{43}},

U_5={Technical information utilizing rate U_{51}, Technical information maturity rate U_{52}, Technical information practicality U_{53}}.

2.2. Cloud Barycenter Evaluation Method

Cloud barycenter evaluation method is based on cloud model which describes the uncertain transition between a linguistic term of a qualitative concept and its quantitative description. In other words, it is the model of the uncertainty transition between qualitative concept and quantitative description. In the discourse universe, the cloud mainly reflects two uncertainties: the first on is the fuzziness (the boundary character of both this and that) and the second one is the randomness (occurrence probability). The cloud model completely integrates the fuzziness and randomness, researches the uncertain rules which have contained by basic linguistic term (or linguistic atom) in natural language, that not only is possible to obtain the scope and distribution rule of quantitative data, but also may effectively transform precise number to qualitative linguistic term.

Suppose *T* is the language value of domain *U*, *U*={*x*}, $\mu(x)$ refers to the membership grade of *x* in *T*, that is:

$$\mu(x):\rightarrow[0,1],\ \forall x\in U,\ x\rightarrow\mu(x) \tag{1}$$

The distribution of $\mu(x)$ in *U* is called membership cloud of *T*, or cloud for short, *x* is called cloud drop. Cloud is represented by three digital characteristics including expected value E_x, entropy E_n and super-entropy H_e, where E_x is the central value of the fuzzy concept in the defined domain, E_n is the fuzzy measurement of the qualitative concept which reflects the random of the degree of membership to a qualitative concept, and H_e is the fuzzy measurement and the entropy of E_n, which reflects the cloud drop's dispersive degree.

The most important cloud model is the normal one because of its universality [9]. If the distribution of $\mu(x)$ is normal, it is called normal cloud model. Its mathematical expected curve is described as:

$$\mu(x) = e^{-\frac{(x-Ex)^2}{2(En')^2}} \tag{2}$$

where $x \sim NORM(Ex, En')$, $En' \sim NORM(En, He^2)$, *NORM* is a function to generate random number which satisfies normal distribution.

Cloud generator includes forward cloud generator and backward cloud generator. The former realizes the mapping fromqualitative concept to quantitative data while the latter generates cloud drops that satisfiy the normal distribution according to E_x, E_n and H_e. The algorithm of generating cloud is illustrated as follows:

Firstly, generate a normal random number $E_{n_i}{}'$ with the expected value E_n and standard deviation $H_e{}^2$. Secondly, generate a normal random number x_i with the expected value E_x and standard deviation $E_{n_i}{}'$ Thirdly, compute:

$$\mu(x) = e^{-\frac{(x_i - Ex)^2}{2(En_i')^2}} \tag{3}$$

Fourthly, repeat the above steps untile N cloud drops are generated.

The cloud barycenter can be denoted as $T = a \times b$, where a is the location of cloud barycenter, b is the height of cloud barycenter. Expected value reflects the information center value of corresponding fuzzy concept. That is the so called cloud barycenter location and is changed with the expected value. The height of cloud barycenter is generally selected as 0.371. The importance of various cloud with the same expected value can be differentiated from their barycenter height, that is to say, the cloud barycenter height reflects the importance of corresponding cloud and the change of system information can be reasoned from the change of cloud barycenter.

Cloud barycenter evaluation method is a system evaluation method realized by establishing cloud model of each index and the corresponding multi-dimensional synthesized cloud barycenter expression. To the giving system index set, there are quantitative variables and the qualitative variables as well. Select *n* group of samples to compose decision matrix, then these indexes with precise numerical value can be described by a cloud model, where:

$$E_x = (E_{x1} + E_{x2} + \cdots + E_{xn})/n \tag{4}$$

$$E_n = (\max(E_{x1} + E_{x2} + \cdots + E_{xn}) - \min(E_{x1} + E_{x2} + \cdots + E_{xn}))/6 \tag{5}$$

At the same time, every qualitative index expressed by linguistic value can also be described by a cloud model, and all qualitative index can be described by a synthesized cloud, where:

$$E_x = (E_{x1}E_{n1} + E_{x2}E_{n2} + \cdots + E_{xn}E_{nn})/(E_{n1} + E_{n2} + \cdots + E_{nn}) \tag{6}$$

$$E_n = (E_{x1}E_{n1} + E_{x2}E_{n2} + \cdots + E_{xn}E_{nn})/(E_{n1} + E_{n2} + \cdots + E_{nn}) \tag{7}$$

where, $E_{x1}, E_{x2}, \cdots, E_{xn}$ denote the index value when these indexes are precise numbers while $E_{x1}, E_{x2}, \cdots, E_{xn}$ denote the expected value of cloud model when these indexes are qualitative value, $E_{n1}, E_{n2}, \cdots, E_{nn}$ are the entropy of cloud model.

The cloud barycenter of p dimension synthesized cloud can be expressed by p dimension vector, that is, $\boldsymbol{T} = (T_1, T_2, \cdots, T_p)$, where:

$$T_i = a_i \times b_i \, , i_i = 1, 2, \cdots, p \tag{8}$$

when system condition changes, it's barycenter becomes $\boldsymbol{T}' = (T_1', T_2', \cdots, T_p')$.

Generally, system index value in ideal conditions is known. Suppose p dimension synthesized cloud barycenter location vector in ideal conditions is $\boldsymbol{a} = (E_{x1}^0, E_{x2}^0, \cdots, E_{xp}^0)$, and cloud barycenter height vector is $\boldsymbol{b} = (b_1, b_2, \cdots, b_p)$, where:

$$b_i = 0.371 w_i \tag{9}$$

where w_i is the index weight. Then, cloud barycenter vector in ideal conditions is

$$\boldsymbol{T}^0 = a \times b^T = (T_1^0, T_2^0, \cdots, T_p^0) \quad (10)$$

Using the same method, p dimensional synthesized cloud barycenter vector in a certain condition is $\boldsymbol{T} = (T_1, T_2, \cdots, T_p)$. Normalize the synthesized cloud barycenter vector result in the vector $\boldsymbol{T}^G = (T_1^G, T_2^G, \cdots, T_p^G)$, where:

$$T_i^G = \begin{cases} (T_i - T_i^0)/T_i^0, & T_i < T_i^0 \\ (T_i - T_i^0)/T_i, & T_i \geq T_i^0 \end{cases}, i = 1, 2, \cdots, p \quad (11)$$

After normalization, the synthesized cloud barycenter vector in ideal condition becomes $(0, 0, \cdots, 0)$.

Define the weighted deflection degree $\theta (0 \leq \theta \leq 1)$,

$$\theta = \sum_{i=1}^{p} w_i T_i^G, i = 1, 2, \cdots, p \quad (12)$$

where w_i is the ith single index weight. The difference between these two synthesized cloud barycenter in ideal and a certain condition can be described by the weighted deflection degree.

3. Results and Analysis

Equipment maintenance support capability method is proposed using the discussed cloud barycenter evaluation method, which can deal with fuzzy and uncertain characteristics well. The basic evaluation process is detailed as follows.

Step 1: Establish the index system of equipment maintenance support capability.

Using the index system established method of equipment maintenance support capability discussed in section 2, we can get the index system as indicated in figure 1.

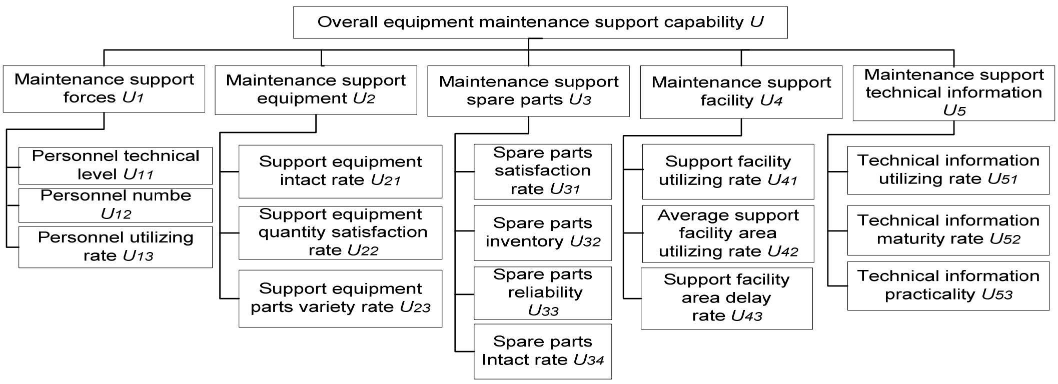

Figure 1. The Index System Of Equipment Maintenance Support Capability

Step 2: Extract each index conditional value.

The conditional value can be derived from the evaluation results of experts. Invite n experts to evaluate the capability of each lowest index results in n assessment conditions according to equipment maintenance support capability information. For convenient consideraten, the maintenance support spare parts U_3 is considered firstly and four conditions are extracted from the n evaluation condition. Each index evaluation condition of maintenance support spare parts U_3 is illustrated in table 1.

Table 1. Each Index Condition of U_3

Condition	U_{31}	U_{32}	U_{33}	U_{34}
1	mild good	very good	mild good	moderate
2	good	slight good	mild bad	slight good
3	moderate	good	moderate	very good
4	slight good	very good	mild good	mild good
Ideal condition	maximum good	maximum good	maximum good	maximum good

Step 3: Construct cloud model description for each index.

According to cloud theory, E_x can be seemed as the quantitative express for each index after quantifying these three qualitative characteristics (E_x, E_n, H_e). So the qualitative expression of linguistic evaluation results (maximum bad, very bad, bad, slight bad, mild bad, moderate, mild good, slight good, good, very good and maximum good) can be quantified as numeric expressions (0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1). From table 1 we can get the decision matrix:

$$\boldsymbol{B} = \begin{bmatrix} 0.6 & 0.9 & 0.6 & 0.5 \\ 0.8 & 0.7 & 0.4 & 0.7 \\ 0.5 & 0.8 & 0.5 & 0.9 \\ 0.7 & 0.9 & 0.7 & 0.6 \end{bmatrix} \tag{13}$$

Step 4: Calculate weight for each index.

According analysis hierarchy process (AHP) theory, the weight of each index can be derived from calculating the largest eigenvalue and the corresponding eigenvector of the judgement matrix which is constructed by comparing the importance of two factors in the same level [10]. The commonly used in AHP of the comparison of stimuli A and B is the nine scales method as showed in Table 2.

Table 2. Nine Scales Method in AHP

Condition	A	B
A is extremely preferred to B	9	1/9
A is much preferred to B	7	1/7
A is considerably preferred to B	5	1/5
A is little preferred to B	3	1/3
A and B are equally preferred	1	1
B is a little preferred to A	1/3	3
B is considerably preferred to A	1/5	5
B is much preferred to A	1/7	7
B is extremely preferred to A	1/9	9

Consider paired comparison matrix as:

$$\boldsymbol{M} = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \tag{14}$$

where $m_{11} = m_{22} = m_{33}$, $m_{12} = m_{21}$, $m_{13} = m_{31}$, $m_{23} = m_{32}$.

Construct the judgment matrix is:

$$A = \begin{bmatrix} 1 & 1/2 & 2 & 1/4 \\ 2 & 1 & 3 & 1/2 \\ 1/2 & 1/3 & 1 & 1/4 \\ 4 & 2 & 4 & 1 \end{bmatrix} \quad (15)$$

The normalized eigenvector can be seemed as the weighting vector. The largest eigenvalue $\lambda_{\max}$ and the corresponding eigenvector $\boldsymbol{E}$ are respectively: $\lambda_{\max} = 4.0458$, $\boldsymbol{E} = (0.2490,0.4585,01598,0.8380)$. As $CI = 0.015<0.1$, $CR = 0.0167<0.1$, where CI is the coherence test index, which shows how much a subject's answers are consistent, CR is the stochastic coherence rate, so the judgment matrix satisfied the coherence requirement. Normalize $\boldsymbol{E}$ we can get the weighting vector $\boldsymbol{W} = (0.1460,0.2689,0.0937,0.4914)$.

Step 5: Calculate the expected value and entropy of each index cloud model.

The expected value and entropy of each index cloud model can be calculated from decision matrix according to equation (4) and (5), which is listed in Table 2.

Table 2. The Expected Value And Entropy For Each Index of U_3

index	C_{31}	C_{32}	C_{33}	C_{34}
E_x	0.6500	0.8250	0.5500	0.6750
E_n	0.0500	0.0333	0.0500	0.0667

Step 6: Calculate the weighting synthesized cloud barycenter vector.

From cloud barycenter vector $\boldsymbol{T} = a \times b^T$, we can get four dimensional weighting synthesized cloud barycenter vector $\boldsymbol{T} = (0.0352, 0.0823, 0.0191, 0.1231)$. The weighting synthesized cloud barycenter vector in ideal conditions is $\boldsymbol{T}^0 = (0.371, 0.371, 0.371, 0.371)$. Normalize the synthesized cloud barycenter vector, we can get $\boldsymbol{T}^G = (-0.5385, -0.2121, -0.8182, -0.4815)$.

Step 7: Calculate the weighted deflection degree θ.

From equation (12), we can get the weighted deflection degree θ, that is $\theta = -0.4489$, that is to say, the weighted deflection degree deflected from the ideal conditions is 0.4489.

Step 8: Realize linguistic words evaluation set using cloud model.

The linguistic words evaluation set is realized using cloud model. Put linguistic words evaluation set to the continuous linguistic value ruler and every linguistic word evaluation value is realized by cloud model, which constructs a quanlitive evaluation generator as showed in Figure 2. The generator showed in Figure 2 is the socalled cloud generator model.

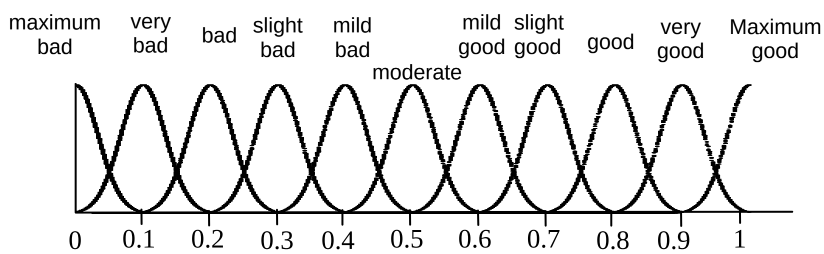

Figure 2. Cloud Generator Model

Input the weighted deflection degree into the evaluation cloud generator model and two cloud objects of “moderate” and “mild good” will be activated, in which the activation degree of the latter is larger than the former. So the ultimate equipment maintenance support capability of maintenance support spare parts is 0.5511 and the maintenance support capability level is classified as mild good.

Using the same method, we can achieve the damage level of other first level indexes. Then the overall index level of equipment maintenance support capability can be derived using all these first level indexes, which is the final equipment maintenance support capability level.

4. Conclusion

Equipment maintenance support is a kind of complex systematic engineering. The evaluation of equipment maintenance support capability is an important part of operational capability evaluation and is very important to the establishment of battle effectiveness. Cloud theory is used to deal with equipment maintenance support capability evaluation and an effective evaluation method based on cloud barycenter evaluation method is proposed in this paper. The evaluation index system is established according to the general principles and the basic cloud theory is introduced. Then the evaluation steps are illustrated according to cloud barycenter evaluation method. The fuzziness and uncertainty of equipment maintenance support capability is considered completely in the proposed evaluation method and the transmitting between qualitative and quantitative variables is settled effectively. The correctness and effectiveness of the proposed method are verified by the presented evaluation results, which provides an efficient evaluation method for equipment maintenance support capability evaluation.

References

[1] Yuan Yi, Zhao Hongyu. Application of BP neural network in evaluation about the maintenance support capability. *Computer and Information Technology.* 2009; 17(5): 28-31.
[2] Li Xiaoyu, Wang Xinge, Huang Yong, etal. Evaluation of equipment maintenance support capability based on neural network in wartime. *Aircraft Design.* 2011; 31(3): 63-65.
[3] Yang Xiaosong, Zhang Jianhua, Liao Lingping. Research on maintenance support capability evaluation of mlitary vehicle equipment based on AHP. *Journal of Academy of Military Transportation*. 2010; 12(5): 29-33.
[4] He Naiqiang, Hui Xiaobin, Zhang Ping, et al. A RLS-SVM based model for equipment support capability evaluation. *Electronics Optics & Control.* 2011; 18(11): 53-56.
[5] Li Deyi, Meng Haijun, Shi Xuemei. Membership cloud and membership cloud generator. *Journal of Computer Research and Development*. 1995; 32(6): 15-20
[6] Han Guozhu, Fan Ningjun, Cheng Li, et al. Performance evaluation of neutralizing weapon system based on cloud theory. *Computer Measurement & Control*. 2011; 19(2): 338-340.
[7] Chen Chen, Wang Qiang, Wang Xiao’en. Air-attack targets threat evaluation on MCGC. *Computer Measurement & Control*. 2009; 17(2): 354-356.
[8] Shi Yanbin, Gao Xianjun, Zhang An. Application of cloud theory on aviation EW system efectiveness evaluation. *Computer Engineering and Applications*. 2009; 45(22): 241-243.
[9] Li Pengfei, Wang Minle, Wang Zhengyuan, et al. Evaluation of M issile Combat System Survivability Based on Cloud Theory. *Modern Defence Technology.* 2012; 40(3): 39-43.
[10] Shi Jiangping, Li Xin. Water environment carrying capacity in Dianchi Lake basin and its dynamic variation characteristics. *Acta Scientiae Circumstantiae*. 2012; 32(7): 1777-1784.