Reliability system engineering capability evaluation of equipment contractor based on combination weighting cloud model

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Abstract. In order to reasonably evaluate the reliability system engineering capability of equipment contractor, a reliability system engineering capability evaluation method based on combination weighting cloud model is proposed. Firstly, a set of scientific evaluation system of reliability system engineering capability of equipment contractor is summarized. Then, an evaluation model based on combination weighting cloud model is established around the system. Then, AHP method and entropy weight method are used to calculate the weights of two layers of indicators. Based on the cloud model, the standard cloud map of the evaluation system and the comprehensive cloud map of each dimension are formed. Finally, the method is effectively applied through case analysis, which can provide reference for equipment contractor to improve equipment production efficiency.

Keywords: reliability system engineering capability; cloud model; AHP method; entropy method

1 Introduction

Reliability System Engineering (RSE) is an engineering technology that studies the struggle against failures during the life cycle of products. Reliability system engineering capability refers to the ability to organize and implement the working process of fighting against faults during the product life cycle.[1]。

The reliability of equipment is an important part of equipment quality, which directly affects the operational use of equipment. At present, the research work on equipment reliability evaluation has achieved rich results. For example, literature [2] sorts out the research status of equipment reliability evaluation at home and abroad, and puts forward some suggestions from the perspective of intelligent operation and maintenance and health management. Literature [3] studies the reliability of radar

A. Rauf et al. (eds.), *Proceedings of the 3rd International Conference on Management Science and Software Engineering (ICMSSE 2023)*, Atlantis Highlights in Engineering 20,
https://doi.org/10.2991/978-94-6463-262-0_45

equipment, and literature [4] explores the reliability of armored equipment. However, the above research mostly focuses on the reliability of the equipment itself, ignoring the influence of the engineering manufacturing capacity of the equipment contractor on the reliability of the equipment.

Based on this, in order to control the quality from the source of equipment production, this paper evaluates its reliability system engineering capability from the perspective of equipment manufacturing units. Based on the existing research results, the main idea is to absorb and summarize the opinions of the industry field, extract and summarize a set of systematic evaluation index system of reliability system engineering capability of equipment manufacturing units, establish a combined weighting cloud model to quantitatively analyze it, and prove the rationality of the proposed index system through case analysis, which can effectively promote the efficiency of equipment construction.

The evaluation system of reliability engineering capability of equipment manufacturing units is mainly divided into three dimensions, namely basic capability, process management and use effect.

The basic ability mainly reflects the quality system operation, personnel and technical strength of the contractor ; the process management mainly combines the quality problems and rectifications found by military representatives in the contract supervision process, the implementation of reliability-related standards and requirements, and reliability tests, etc., to reflect the standardization and effectiveness of the reliability work carried out by the contractor in the product development and production process; the use effect mainly reflects the actual embodiment of the reliability system engineering ability of the contractor through the use reliability level and continuous reliability improvement of the equipment and products in the actual use process of the army. The specific evaluation index division is shown in Figure 1.

It can be seen from the figure that there are four evaluation indexes in the basic ability dimension, which are human resource management A_1, tooling equipment management A_2, department organization management A_3 and technical management A_4. Among them, human resource management refers to the equipment manufacturing unit has a set of hierarchically empowered reliability professional human resource management system, that is, reliability professional construction, configuration, development, full empowerment reliability work implementation, professional development planning, and professional management system continuous optimization and innovation practice ; tooling equipment management refers to the equipment manufacturing unit with mature and high-quality equipment and experimental equipment, and the implementation of strict and standardized daily management work, with the realization of reliability test, reliability growth, reliability standard test and other functions ; department organization management refers to the establishment of reliability professional institutions in equipment manufacturing units. It has clear reliability professional intelligent institutions and relatively independent departments, which can realize management evaluation and improvement, and can realize system innovation and optimization. Technical management refers to the integrated management of reliability technology of equipment manufacturing units, which has the methods and applications of reliability design and reliability prediction. It establishes the development and application of reliability technology, tools and methods, and can clarify the objectives, such as technology development, knowledge application transformation and technology integration management to achieve system optimization and innovation.

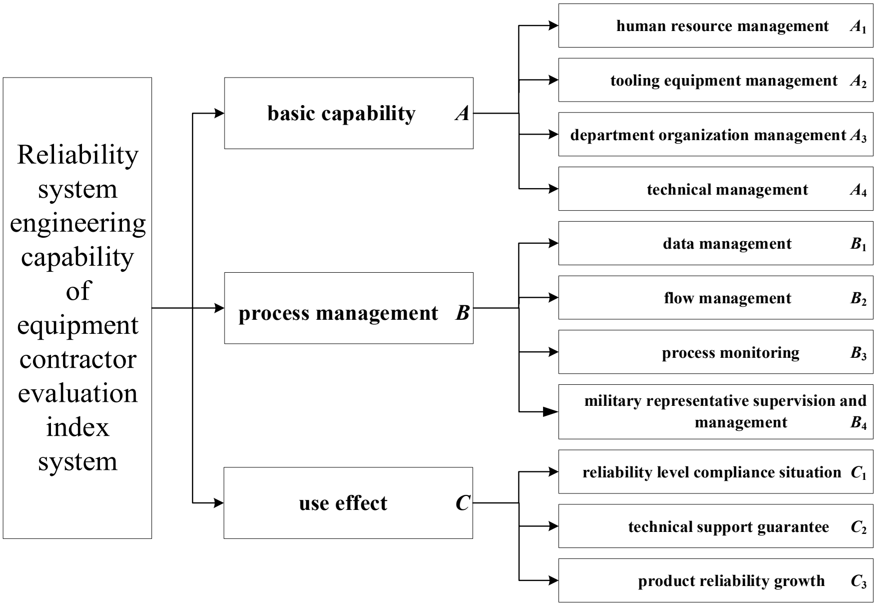

Fig. 1. Reliability system engineering capability of equipment contractor evaluation index system

There are four evaluation indexes in the process management dimension, namely data management B1, flow management B2, process monitoring B3 and military representative supervision and management B4. Among them, data management refers to the reliability data management of equipment manufacturing units, which can establish a product knowledge base dominated by reliability and realize the innovation and optimization of data system. Flow management refers to the reliability workflow management of equipment manufacturing units, that is, to establish a management system for planning, application, evaluation and assessment of reliability work standard management, as well as to plan the workflow system for the whole profession, the whole level and the whole life cycle, with the ability to evaluate and improve flow management; process monitoring refers to the reliability work process monitoring of equipment manufacturing units. It can clarify the process monitoring objectives, such as risk identification rate, process monitoring results, product failure rate, etc. It can publicize and implement internal and external training, effectively control the inspection and supervision of key projects, and clarify the process monitoring evaluation and improvement. In order to improve the overall efficiency, the cost and resource use in the process are optimized and controlled. The supervision and management of military representative means that the equipment manufacturing unit has the military representative institution in the factory (institute, room), which can carry out the whole process quality supervision of the whole life cycle of equipment design, production and delivery. It can supervise and manage the rework rate, reliability index compliance, failure frequency and consequences, and quality problem zeroing in the equipment development and production. It can review the reliability design and support situation, and can also coordinate the product support situation after the equipment is delivered to the army.

There are three evaluation indexes in the dimension of use effect, which are reliability level compliance situation C1, technical support guarantee C2 and product reliability growth C3. The reliability level compliance refers to whether the equipment manufacturing unit needs to verify whether the reliability level of the product is up to the standard in the actual environment. In view of the reliability level compliance of the product of the manufacturing unit in the combat test and in-service assessment, including whether the qualitative requirements and quantitative requirements meet the requirements of the contract. In addition, according to the index compliance, it is necessary to distinguish one-time pass, pass after rectification and non-pass, and comprehensively consider the ability of the equipment manufacturing unit. Technical support support means that the equipment manufacturing unit has the service support ability in the actual use environment after the equipment leaves the factory, and the manufacturing unit provides technical support; support support is carried out in combination with the daily maintenance and combat training tasks of the army, and the maintenance support capability of the undertaking unit after the failure of the equipment can be tested. According to the needs of the military, the service and technical support can be provided after the equipment is delivered. Product reliability growth refers to the ability to increase the reliability of the product if the product delivered by the equipment contractor does not meet the specified indicators in the actual use environment ; it has the ability of system upgrading and transformation. In view of the feedback problems in the use of the army, it can be rectified and implemented in time. From the aspects of timeliness and effectiveness of implementation, it reflects the reliability system engineering ability of the manufacturing unit. In addition, it should also realize the whole process life cycle management, provide technical feedback, make the products continuously improve and upgrade, and form a “feedback-improvement” dynamic virtuous cycle mechanism, so as to promote the continuous improvement of the reliability system engineering ability of the equipment manufacturing unit.

2 Determine the weight based on the combination weighting method

2.1 Based on AHP method to determine the subjective weight

AHP analytic hierarchy process is a research method that combines quantitative and qualitative methods to calculate decision weights to solve multi-objective complex problems[5].The steps are as follows:

1) The evaluation matrix is constructed according to the expert scoring situation $X=\left(x_{ij}\right)_{m\times n}$. Among them, m is the number of indicators, n is the number of experts. Then, the scores of the indexes under each expert are averaged, and the importance of each index in the evaluation index system is compared in pairs. And construct the judgment matrix $A=\left(a_{ij}\right)_{m\times m}$ .Among them, a_{ij} indicates the importance of the i index relative to the j index.

2) The maximum eigenvalue $\lambda_{\max}$ and eigenvector α of the judgment matrix A are calculated, and the weight vector $\boldsymbol{w}$ is obtained after normalization.

Then, the consistency test is performed to determine whether the obtained weight vector is reasonable. The formula is as follows:

$$CI=\frac{\lambda_{\max}-m}{m-1} \tag{1}$$

Among them, CI is the consistency index and m is the order of matrix A .

3) Calculate the consistency ratio CR by looking up the table. The formula is as follows:

$$CR=\frac{CI}{RI} \tag{2}$$

Among them, RI is the random consistency index.

4) If the value of CR is less than 0.1, it shows that the weight obtained by the consistency test is reasonable. If the value of CR is greater than 0.1, it indicates that the consistency test is not passed, and the random consistency index needs to be re-established.

Determine the objective weight based on entropy method

The entropy value method is based on the information entropy in the index to calculate the weight[6].If the information entropy of the index is smaller, the amount of information it contains is larger, and the weight is larger. On the contrary, the greater the information entropy of the index, the smaller the amount of information it contains, and the smaller the weight. The steps are as follows:

1) The evaluation matrix $X=\left(x_{ij}\right)_{m\times n}$ constructed in Section 2.1 is dimensionlessly processed to obtain $\hat{X}=\left(\hat{x}_{ij}\right)_{m\times n}$. The formula is as follows:

$$\hat{x}_{ij}=\frac{x_{ij}}{\sum_{i=1}^{m}x_{ij}} \tag{3}$$

2) Calculate the entropy E_j of each index in the matrix $\hat{X}=\left(\hat{x}_{ij}\right)_{m\times n}$, the formula is as follows:

$$E_j = -\frac{1}{\ln m}\sum_{i=1}^{m}\hat{x}_{ij}\ln\left(\hat{x}_{ij}\right) \tag{4}$$

3) Calculate the index weight $\boldsymbol{\omega}$， the formula is as follows:

$$\omega_i = \frac{1-E_j}{\sum_{i=1}^{m}\left(1-E_j\right)} \tag{5}$$

2.2 Based on the linear weighting method to determine the combined weight

The combination weight $\boldsymbol{W}$ can be obtained by linear combination of subjective weight determined by AHP method and objective weight determined by entropy method. The formula is as follows:

$$\begin{cases} W_i = k_1 w_i + k_2 \omega_i \\ k_1 + k_2 = 1 \end{cases} \tag{6}$$

Among them, $0 \le k_1 \le 1$， $0 \le k_2 \le 1$, the specific value should be determined according to the actual.

3 Based on cloud model, the reliability system engineering capability evaluation of equipment contractor is constructed.

3.1 The digital features of the cloud model

The cloud model represents a concept by three digital features: expectation Ex ,entropy En and superentropy He , $T\left(Ex, En, He\right)$ [7]. Among them, expectation Ex refers to the expectation of the distribution of cloud droplets in the discussion domain space, which is the best value to represent the qualitative concept. Entropy En refers to the uncertainty measure of qualitative concept, which is used to describe the span of cloud model and reflects the dispersion degree of cloud droplets. Superentropy He is an uncertainty measure of entropy En , representing the degree of entropy dispersion, which is jointly determined by the randomness and fuzziness of entropy.

3.2 Build a standard cloud

Firstly, the reliability system engineering capability evaluation level of the equipment contractor was divided into "no implementation, no effect", "preliminary implementation, no obvious effect", "partial implementation, acceptable effect", "partial implementation, good effect", and "all implementation, excellent effect" according to the

5-level scale method. Assuming that the evaluation interval is [0,100], the digital feature calculation formula of the evaluation standard cloud is:

$$Ex = \frac{d_{\min} + d_{\max}}{2} \tag{7}$$

$$En = \frac{d_{\max} - d_{\min}}{6} \tag{8}$$

$$He = k \tag{9}$$

Among them, $d_{\min}$ and $d_{\max}$ are the upper and lower bounds of the evaluation interval corresponding to each evaluation level, and k is a constant with a value of 0.1.

After calculation, the numerical characteristics of the evaluation standard cloud are shown in table 1:

Table 1. Digital characteristics of evaluation standard cloud

order of evaluation	evaluation interval	digital characteristic
no effect	(0, 20]	（10, 3.33, 0.1）
no obvious effect	(20, 40]	（30, 3.33, 0.1）
acceptable effect	(40, 60]	（50, 3.33, 0.1）
good effect	(60, 80]	（70, 3.33, 0.1）
excellent effect	(80, 100]	（90, 3.33, 0.1）

According to the above data, using Matlab software and forward cloud generator, the evaluation standard cloud of reliability system engineering capability of equipment contractor is established, as shown in figure 2:

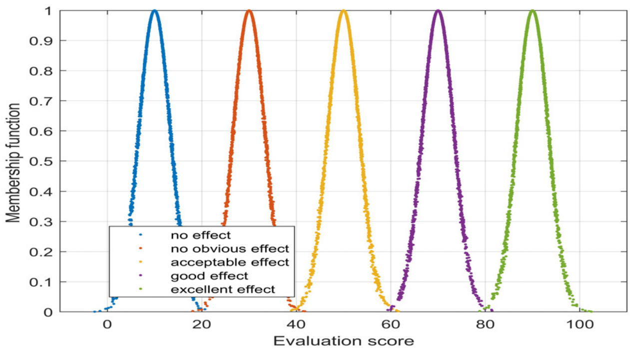

Fig. 2. Standard cloud image

3.3 Computing Evaluation Cloud

According to the evaluation level of reliability system engineering capability of five types of equipment manufacturing units, n experts are invited to score m evaluation indexes, and the evaluation cloud of each evaluation index is calculated by using Matlab software and reverse cloud generator. The calculation formula is as follows:

$$Ex_i = \overline{x} = \frac{1}{n}\sum_{j=1}^{n} x_{ij} \tag{10}$$

$$En_i = \sqrt{\frac{\pi}{2}}\frac{1}{n}\sum_{j=1}^{n}\left|x_{ij} - Ex_i\right| \tag{11}$$

$$He = \sqrt{\frac{\sum_{j=1}^{n}\left(x_{ij} - Ex_i\right)^2}{n-1} - En_i^{\,2}} \tag{12}$$

Among them, x_{ij} is the score given by the j expert for the i index.

3.4 Computing integrated cloud

Based on the combination weight coefficient of each evaluation index obtained in Section 2, the evaluation cloud of each evaluation index is weighted to obtain a comprehensive cloud. The formula is as follows:

$$Ex = W_i \sum_{i=1}^{m} Ex_i \tag{13}$$

$$En = W_i \sqrt{\sum_{i=1}^{m} Ex_i^{\,2}} \tag{14}$$

$$He = W_i \sum_{i=1}^{m} He_i \tag{15}$$

4 Case study

4.1 case background

Taking the optimization of key components required by a certain type of domestic equipment as an example, there are three ABC manufacturers in China producing the key components required for the equipment. According to the comprehensive evaluation of the reliability system engineering capability of the equipment manufacturing unit, the selection is carried out, and the optimization purpose is finally realized. In order to facilitate the introduction, only a certain manufacturer is selected as the research object. The purpose is to provide a feasible and common method to solve this kind of problem and better serve the equipment production.

4.2 experimental analysis

In order to reasonably evaluate the reliability system engineering capability of equipment manufacturing units of key component manufacturers. Seven experts in related fields were invited to score the manufacturer based on the reliability system engineering capability evaluation index of the equipment manufacturing unit. According to the steps in Section 2.1 and 2.2, the AHP method and the entropy method are used to process the expert scoring. The subjective weight w and objective weight ω of the index can be obtained, and the combined weight W of each index is calculated according to Formula (6). The results are shown in Table 2:

Table 2. Reliability system engineering capability evaluation index weight of equipment contractor

First level index	Second level index	subjective weights w		objective weights ω		combination weight W	
		First level index	Second level index	First level index	Second level index	First level index	Second level index
basic capability A	human resource management A_1	0.324	0.248	0.306	0.219	0.315	0.233
	tooling equipment management A_2		0.245		0.222		0.233
	department organization management A_3		0.243		0.163		0.203
	technical management A_4		0.264		0.396		0.331
process management B	data management B_1	0.335	0.244	0.343	0.154	0.339	0.199
	flow management B_2		0.242		0.175		0.209
	process monitoring B_3		0.248		0.242		0.245
	military representative supervision and management B_4		0.266		0.429		0.347
use effect C	reliability level compliance situation C_1	0.341	0.333	0.351	0.333	0.346	0.333
	technical support guarantee C_2		0.337		0.326		0.331
	product reliability growth C_3		0.330		0.341		0.336

According to the expert scoring results and equations (10) to (12), the characteristic values of cloud model of the second layer evaluation index are calculated, and the results are shown in Table 3:

Table 3. The second layer index cloud model digital characteristics

Evaluation index	Numeral characteristic		
	E_x	E_n	H_e
A_1	84.71	3.48	0.04
A_2	84.29	3.48	0.04
A_3	83.43	3.33	0.73
A_4	91.00	4.15	0.40
B_1	84.00	3.43	0.94
B_2	83.29	3.48	0.04
B_3	85.29	3.84	0.77
B_4	91.29	4.56	0.24
C_1	91.00	4.15	0.40
C_2	92.00	4.15	0.40
C_3	90.00	4.15	0.40

According to the data in Table 3 and equations (13) to (15), the characteristic values of the cloud model of the evaluation index of the first layer are calculated, and the results are shown in Table 4:

Table 4. The first layer index cloud model digital characteristics

Evaluation index	Evaluation index		
	E_x	E_n	H_e
A	86.43	1.912	0.199
B	86.70	2.094	0.279
C	91.00	2.396	0.231

According to the data in Table 4, a comprehensive cloud map of the first layer of indicators can be generated, as shown in Figure 3 to Figure 5:

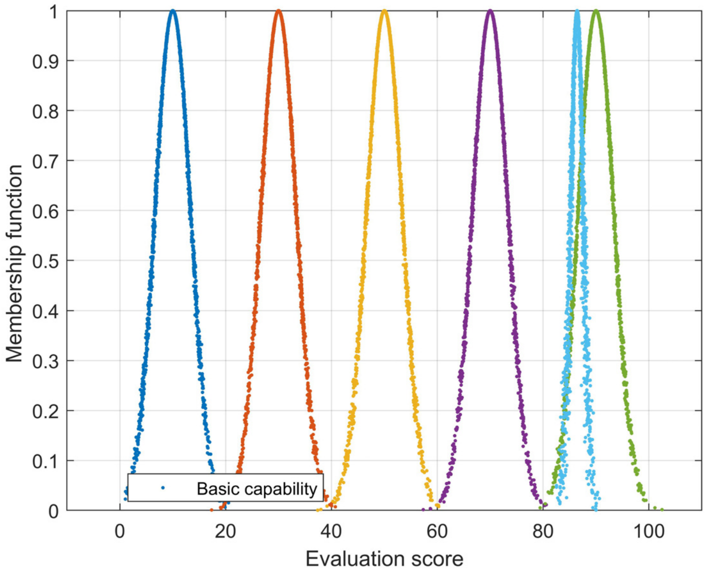

Fig. 3. Basic capability cloud image

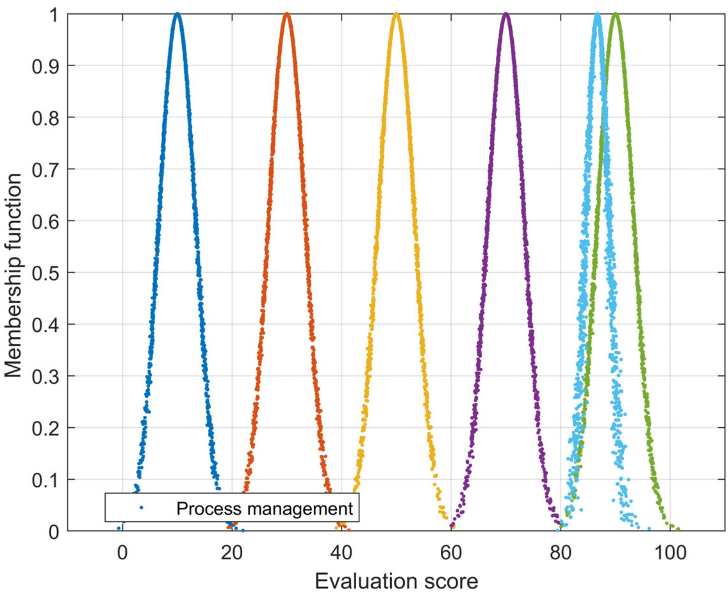

Fig. 4. Process management cloud image

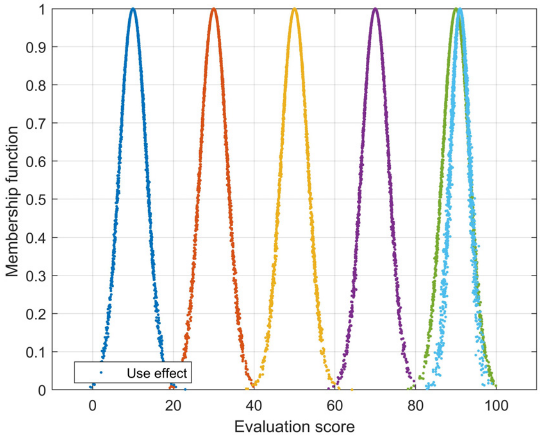

Fig. 5. Use effect cloud image

According to the data and formulas (13) to (15) in table 4, the numerical characteristics of the comprehensive cloud model of the reliability system engineering capability of the equipment contractor of the manufacturer are calculated as (88.1,1.24,0.23). According to the characteristics, the corresponding comprehensive cloud map can be generated, as shown in figure 6:

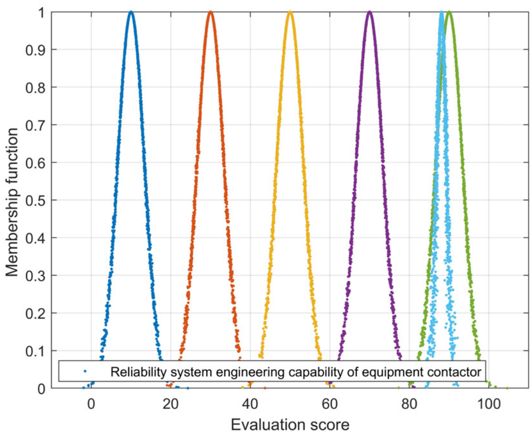

Fig. 6. Reliability system engineering capability cloud map of equipment contactor

4.3 interpretation of result

It can be seen from Section 4.1 that the comprehensive cloud model digital characteristics of the reliability system engineering capability of the equipment contractor of this manufacturer are (88.1, 1.24, 0.23), that is, the expected Ex=88.1. It can be seen from the evaluation interval in Table 1 that the reliability system engineering capability of the equipment contractor of this manufacturer is at the level of good effect. It can also be seen from the close degree of the comprehensive cloud image and the standard cloud image that its reliability system engineering capability is good, and it can be concluded that the equipment produced by the manufacturer is in line with the requirements.

In addition, as can be seen from the cloud map in Figure 3 to Figure 5, although the manufacturer has met the requirements for equipment production and use, it still has some deficiencies in basic capabilities and process management. Therefore, in the subsequent production activities, investment in these two aspects can be appropriately increased.

5 Conclusions

This paper focuses on the reliability system engineering capability evaluation of equipment contractor based on the combinatorial weighting cloud model. Firstly, a set of scientific and perfect evaluation index system is summarized through the absorption and reference of existing achievements, and then the combinatorial weighting cloud model is established for quantitative evaluation. Finally, the rationality and reliability of this method is demonstrated through case analysis. It can provide reference for equipment contractor to improve equipment production efficiency.

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