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Article

Equipment Asset Management and Equipment Health Based on Fuzzy Algorithm Evaluation Model

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Abstract: In this paper, we addresses the growing importance of enterprise equipment asset management efficiency. Proposing an advanced approach rooted in combinatorial principles and scientific computing, the study introduces a comprehensive evaluation model for equipment value. Overcoming the limitations of traditional models, a fuzzy algorithm establishes a three-dimensional cross-compound element, encompassing equipment reliability, stability, and accuracy. Hierarchical analysis and the entropy power method determine weights for evaluation indexes, facilitating a quantitative assessment of measurement and production equipment health. Validation through a real energy meter production line demonstrates the model's effectiveness in comparison to real defect rates. This innovative evaluation model not only offers asset managers a new method for assessing equipment assets but also presents a forward-looking strategy for enterprises to enhance their asset management proficiency, emphasizing the synergies between combinatorics and scientific computing in addressing contemporary economic challenges.

Keywords: fuzzy algorithm, metering production equipment, health evaluation, hierarchical analysis, entropy weight method

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1. Introduction

With the continuous development of science and technology, China's economic vitality has undergone substantial growth with both technology and productivity increasing rapidly, and last year our annual GDP reached an unprecedented height [1]. This is inseparable from the prosperity of the manufacturing market, where not only the number of manufacturing enterprises is gradually increasing, but also the scale of production is getting larger and larger [2]. In the environment of increasingly fierce competition in manufacturing industry, how can an enterprise take the leading position in the market, how can it develop stably in the long run and maintain its core competitiveness is the problem that every enterprise needs to face.

There is no doubt that cost management is the core content of business management [3]. It is very important for a company to do the best cost management for this company's business management. Enterprise cost management covers numerous contents, which include direct labor cost, direct material cost, fixed asset management, etc. [4, 5]. In the process of enterprise production and operation management, if there is an omission in the management of fixed assets, it will not only reduce the productivity of the enterprise, but also increase the cost expenditure of the enterprise, which will further reduce the core competitiveness and economic efficiency of the whole enterprise. Therefore, for enterprises, it is necessary to do a good job of fixed asset management. And equipment asset management is one of the most important aspects of enterprise fixed asset management. Equipment asset management is important for the sustainable and healthy development of manufacturing enterprises, not only the management process is closely related to multiple links, but also involves the participation of several departments, such as planning, economic management, manufacturing, and procurement [6, 7]. Equipment asset management is a process management mode, which requires the tacit cooperation of relevant departments to achieve effective management.

In most manufacturing companies, equipment assets account for the majority of fixed assets. In many enterprises, the management of equipment assets still exists in the form of manual bookkeeping, and this management mode not only has unreasonable data information not easily kept, data information difficult to collect and easy to lose, but also consumes a lot of human and material resources in the management process [8, 9]. For customer direct supply equipment not found, idle equipment assets storage costs increase and a series of other details, from time to time in the process of the enterprise's equipment assets. In order to solve the problems encountered by enterprises in the process of equipment asset management, we should learn advanced management methods according to the actual situation of enterprises themselves, study the use of advanced information technology systems to build equipment asset network management system, and then improve the enterprise management process. At the same time, using the system management platform and business process optimization theory, each node of the life cycle of equipment assets will do process control, optimize the management process, do a good job of equipment asset management, and then achieve the goal of improving the business efficiency of the enterprise. At the same time, we should note that: 1) for enterprises, equipment assets are not only a large number of various types, is an important guarantee of normal production on site, and the value of equipment is very high, the daily management of equipment, inventory, etc., should be paid attention to in enterprise management; 2) equipment asset management is not a simple management project, from the purchase of equipment to idle scrap of all aspects involve multiple departments involved, and many areas between There are close relationships between many areas. Therefore, compared with the previous manual bookkeeping and other management methods, we need to optimize the management process, learn the advanced management mode, study the management methods suitable for the enterprise itself, break the original localized management mode, and the optimized equipment asset management will pay more attention to the overall management of equipment assets.

In recent years, the fuzzy comprehensive evaluation method has undergone greater development and optimization, including the improvement of the evaluation model, such as nonlinear function fuzzy comprehensive evaluation model, fuzzy comprehensive evaluation model with interference source, fuzzy object element comprehensive evaluation model; there is also the optimization of the method of determining weights, such as the use of optimal transfer matrix improved hierarchical analysis method to derive weights, geometric algorithm for weights, clustering power method for weights, etc. There are also optimizations in the judgment factor indicators such as the use of level eigenvalues as indicators for judgment; and many research results have also been developed in the practice of fuzzy comprehensive assessment method [10–12]. The fuzzy comprehensive assessment method takes into account both qualitative and quantitative analysis problems, and integrates the two, and is widely used in engineering, economic management and social life [13, 14]. How to reasonably and effectively combine the evaluation results of multiple factors and get the corresponding comprehensive evaluation results is one of the important problems that cannot be avoided in the practice of fuzzy comprehensive evaluation method, and the essence of the problem is how to determine the weighting relationship between these factors so that it can objectively reflect their true influence degree [15, 16].

In the new situation of continuous optimization of equipment asset management methods in modern enterprises, complete life-cycle value cost management of equipment is the way to modern asset-intensive enterprises [17, 18]. In China, the complete life cycle management of equipment is an innovative project of systematic, precise and scientific management [19, 20]. With the rapid development of modern management science, many problems in the traditional way of equipment asset management are gradually revealed, such as the short service life of equipment, low efficiency of use, large investment in overhaul or technical innovation, and high maintenance cost [21, 22]. In the face of this series of problems exposed in traditional equipment asset management, only by continuously changing management concepts, improving management methods, and taking into account the relationship between asset safety, practicality, and economy, can we achieve scientific management of the complete cycle of equipment [23–25].

In this paper, we focus on the value management of various types of equipment in the daily equipment asset management of asset-intensive enterprises. In this paper, we study and analyze the value management of various types of equipment in the daily equipment asset management of asset-intensive enterprises, and establish a new set of enterprise equipment asset valuation methods by combining the existing domestic and foreign advanced asset management methods and concepts. The paper focuses on the research and analysis of the value management of various types of equipment in the daily equipment asset management of asset-intensive enterprises. To provide effective reference data for enterprise equipment asset management decisions.

2. Model objectives

In the process of the complete life cycle of equipment, the management of its procurement, preventive maintenance, cost control, efficiency management and disposal management are the key elements of its management process, and the management of its value is also mainly reflected in the process of the above management process. In the existing enterprise asset value management, a comprehensive evaluation model that can objectively, truly, quantitatively and systematically reflect the actual value of the equipment has not yet been formed.

The establishment of a comprehensive evaluation model of equipment value based on a fuzzy algorithm will integrate the various index factors affecting the value of equipment, assign corresponding weighting ratios to them and form an objective and reasonable evaluation result. The fuzzy comprehensive evaluation model will provide an objective and comprehensive value reference platform for enterprises in the process of equipment asset value management in the future, and also serve as a reference for the establishment of other equipment asset fuzzy comprehensive evaluation models, forming a systematic equipment asset value management platform.

3. Model assumptions

This section will focus on the problems encountered by large production and construction enterprises in the management of equipment assets, and establish an asset management value model with reasonable structure, fast operation and intuitive conclusion. The model is based on the theory of fuzzy algorithm to make objective and comprehensive evaluation of the value of various types of equipment assets belonging to the company, so that the enterprise managers can reasonably grasp the enterprise asset structure and improve the efficiency of equipment asset utilization. This section will introduce the structure of the model and its specific calculation process in detail.

1. In the comprehensive evaluation of the value of equipment assets, one type of equipment asset is selected as the research object at a time and its comprehensive evaluation model is established. Through the successful establishment of this model, the modelling method of this evaluation model can be applied to the comprehensive evaluation of the value situation of individual equipment of this type of equipment asset.
2. In the process of establishing the model, each member of the equipment expert group has rich

Comparison of factors i and j	Meaning	a_{ij}	a_{ij}
i and j have the same status	i,j has the same impact on the target	1	1
i is slightly more important than j	The impact of i is slightly greater than that of j	3	1/3
i is obviously more important than j	The impact of i is significantly greater than that of j	5	1/5
i is more important than j	The impact of i is far greater than that of j	7	1/7
i to j is between the two adjacent	The impact is between adjacent judgments	2,4,6	1/2,1/4,1/6

Table 1. Elements of factor weight matrix

professional knowledge and experience in equipment assets, and has a more accurate judgment estimation of the value situation of the equipment.

3. The model was established mainly for the economic and technical indicators of a certain type of equipment in the past five years as a reference basis, and the indicators in the model will be adjusted accordingly as time passes by the improvement of technology level and changes in market value.
4. Some of the factors affecting the value of equipment in the model, such as the degree of market leadership, market demand and other qualitative indicators, will be entered into the enterprise asset management platform by the expert evaluation team after giving a qualitative evaluation based on the equipment and the market situation during the enterprise's annual year-end asset inventory assessment.
5. Evaluation model: In order to meet the requirements of enterprise equipment value management, the model can be widely applied to all types of large production and construction equipment of the enterprise. For a selected type of equipment, the steps for establishing the model are as follows.
   (a) For a selected type of equipment, list out the factors that affect the value of the equipment $x_1, l = 1, 2, ..., n$, Thus forming a factor set $U_o = x_1, x_2, ..., x_N$.
   (b) Classify the factor set $U_o = x_1, x_2, ..., x_N$ according to different attributes, let there be a total of S categories, then the main factor set is $U = U_1, U_2, ..., U_s$, Its subset of factors are

$$U_i = u_{i1}, u_{i2}, ..., u_{in}, i = 1, 2, ..., s \tag{1}$$

   and the conditions are met. $n_1 + n_2 + ... + n_s = n; U_1 \cup U_2 \cup ... \cup U_s = U_o$ $(\forall i, j) i \neq j \Rightarrow U_i \cap U_j = \Phi$.
   (c) Enumerate possible comments on the value of equipment based on the needs related to equipment asset value management $x_m, m = 1, 2, ..., p$, From where the evaluation set was formed.

$$V = v_1, v_2, ..., v_p \tag{2}$$

   (d) Using the binary comparative ranking method, weights were assigned to the elements in the main and sub-factor sets: the main factor layer was used as an example of a two-by-two comparative analysis of the factors in each factor set to quantify their relative importance in tabular form, (see Table 1)

$$a_{ij} = f(\cup_i, \cup_i), a_{ij} = 1/a_{ij} \tag{3}$$

Since when $W = (\omega_1, \omega_2, ..., \omega_s)^T$ is the weight vector of n elements of a layer, the n order discriminant matrix A corresponding to the elements of that layer has, if it satisfies consistency

$$A = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1s} \\ a_{21} & a_{22} & \cdots & a_{2s} \\ \cdots & \cdots & \ddots & \cdots \\ a_{s1} & a_{s2} & \cdots & a_{ss} \end{pmatrix} = \begin{pmatrix} 1 & \frac{\omega_1}{\omega_2} & \cdots & \frac{\omega_1}{\omega_s} \\ \frac{\omega_2}{\omega_1} & 1 & \cdots & \frac{\omega_2}{\omega_s} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{\omega_s}{\omega_1} & \frac{\omega_s}{\omega_2} & \cdots & 1 \end{pmatrix} = \begin{pmatrix} \omega_1 \\ \omega_2 \\ \cdots \\ \omega_s \end{pmatrix} \begin{pmatrix} \frac{1}{\omega_1} & \frac{1}{\omega_2} & \cdots & \frac{1}{\omega_s} \end{pmatrix} \tag{4}$$

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.59	0.92	1.11	1.25	1.31	1.42	1.44	1.48	1.52	1.48

Table 2. Table of average random consistency index values

and $\omega_1 + \omega_2 + ... + \omega_s = 1$ so the discriminant matrix A for the set of principal factors is summed by rows to give:

$$\sum_{j=1}^{n} a_{ij} = \omega_i \times \left(\frac{1}{\omega_1} + \frac{1}{\omega_2} + \cdots + \frac{1}{\omega_s}\right) \tag{5}$$

Since

$$S_i = \sum_{j=1}^{n} a_{ij} = \omega_i \times \left(\frac{1}{\omega_1} + \frac{1}{\omega_2} + \cdots + \frac{1}{\omega_s}\right), S = [S_i] = \left(\frac{1}{\omega_1} + \frac{1}{\omega_2} + \cdots + \frac{1}{\omega_s}\right) \cdot \begin{pmatrix} \omega_1 \\ \omega_2 \\ \vdots \\ \omega_s \end{pmatrix} \tag{6}$$

then when the discriminant matrix A satisfies consistency, normalizing the vector yields both the weight vector W.

(e) In order to test whether the weight judgment matrix A satisfies the consistency index, the size of the value of the consistency ratio $CR = \frac{CI}{RI}$ is used to judge, where $CI = \frac{\lambda_{max}(A)-n}{n-1}$ and the value of RI is related to its order, as shown in the following table 2:
When $CR \leq 0.1$, the weight discriminant matrix A is considered to satisfy the consistency requirement.
Similarly, the weight vector of each subfactor layer can be obtained, and it is judged whether it meets the consistency requirement.

(f) For each quantitative factor in each subfactor layer, the statistical method of using questionnaire survey equipment experts is used to determine the affiliation function of the quantitative element in each continuous interval, thus replacing the traditional fuzzy comprehensive evaluation method of directly evaluating the evaluation object. The specific method is as follows:
Each expert in the equipment expert group is required to be able to individually divide each quantitative factor into corresponding areas with respect to each element in the evaluation set. For example, for the quantitative factor $x_i \in [0, +\infty]$, the domain to which it belongs is divided into p intervals: $[0, y_1], [y_1, y_2], ..., [y_{p-1}, +\infty]$, corresponding to p elements in the evaluation set $V = \{v_1, v_2, ..., v_p\}$, respectively.
Through the questionnaire results of the expert panel, the frequency of each interval of the factor corresponding to each evaluation element of the evaluation set in the quantitative factor is counted, and the frequency of each interval of the quantitative factor is normalized to obtain the affiliation function of this quantitative factor.

(g) For each qualitative factor in each subfactor layer, its qualitative results are synthetically evaluated by the panel of experts at the end of the year, and the number of its qualitative evaluation results can be controlled to be consistent with the number of elements in the rubric set, then the comprehensive evaluation results of each qualitative element can correspond to the elements in the rubric set one by one. Let the set of evaluation results of qualitative elements be $D = \{d_1, d_2, ..., d_p\}$, then its affiliation function is

$$B(x) = \begin{cases} v_1 & x = d_1 \\ v_2 & x = d_2 \\ \cdots & \\ v_p & x = d_p \end{cases} \tag{7}$$

(h) After substituting each factor index of an equipment into the affiliation function corresponding to each factor, the judgment matrix $R_i, i = 1, 2, ..., s$ of each element in each subfactor layer can be obtained. Then, the fuzzy comprehensive judgment matrix $B_i = W_i \circ R_i = (b_{i1}, b_{i2}, ..., b_{ip})$ of each subfactor layer is calculated by using the evaluation model $M(\square, +)$.

(i) With the fuzzy integrated judgment matrix B_i of each subfactor layer to obtain the single-factor judgment matrix of the main factor layer:

$$R = \begin{pmatrix} B_1 \\ B_2 \\ \cdots \\ B_s \end{pmatrix} = \begin{pmatrix} W_1 \circ R_1 \\ W_2 \circ R_2 \\ \cdots \\ W_s \circ R_s \end{pmatrix} = \begin{pmatrix} b_{11} & b_{12} & \cdots & b_{1p} \\ b_{21} & b_{22} & \cdots & b_{2p} \\ \cdots & \cdots & \cdots & \cdots \\ b_{31} & b_{32} & \cdots & b_{3p} \end{pmatrix} \tag{8}$$

The evaluation model $M(\square, +)$ is then used again to obtain the integrated judgment matrix corresponding to the main factor layer:

$$B = W \times R = (\omega_1, \omega_2, ..., \omega_s) \times \begin{pmatrix} b_{11} & b_{12} & \cdots & b_{1p} \\ b_{21} & b_{22} & \cdots & b_{2p} \\ \cdots & \cdots & \cdots & \cdots \\ b_{31} & b_{32} & \cdots & b_{3p} \end{pmatrix} = (b_1, b_2, ..., b_p) \tag{9}$$

(j) Determine the result of the comprehensive evaluation of the value of the equipment by the principle of maximum affiliation.

3.1. Model Example

The weighting of the metering production equipment based on hierarchical analysis is based on the analysis of 1,000 unidirectional energy meters produced by a typical enterprise in October 2021, and the results of the calculation of the weighting factors at the criterion and decision levels are shown in Table 3.

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3.2. Determination of weighting factors based on the entropy weighting method

When determining the weights using the entropy weighting method, 1,000 devices from each of the three production lines were sampled in order to safeguard the sampling deviation and the average value was taken as the comprehensive weighting factor, the results of which are shown in Table 4.

3.3. Determination of comprehensive weighting factors based on improved information entropy

Based on the fusion evaluation method proposed in this paper, the results of the AHP and entropy weighting method were used to calculate the comprehensive weighting factors, and the results are shown in Table 5.

3.4. Evaluation results

Using decision-level indicators, a sample of 50 typical metering production equipment was evaluated and Standardized, and their superiority and inferiority degrees under 12 decision indicators were

Criterion layer	weight	Decision-making level	Relative weight	Absolute weight
B1	0.263	C1	0.135	0.036
		C2	0.276	0.073
		C3	0.313	0.083
		C4	0.280	0.074
B2	0.345	C5	0.422	0.146
		C6	0.262	0.091
		C7	0.196	0.068
		C8	0.124	0.043
B3	0.395	C9	0.233	0.092
		C10	0.279	0.150
		C11	0.292	0.116
		C12	0.100	0.040

Table 3. Weight determination based on AHP

Evaluating indicator	Sample 1	Sample 2	Sample 3	Average weight
C1	0.053	0.038	0.048	0.046
C2	0.079	0.078	0.076	0.078
C3	0.064	0.095	0.082	0.080
C4	0.070	0.067	0.076	0.071
C5	0.125	0.133	0.131	0.130
C6	0.088	0.111	0.079	0.093
C7	0.057	0.057	0.080	0.065
C8	0.030	0.068	0.055	0.051
C9	0.068	0.108	0.089	0.088
C10	0.171	0.134	0.159	0.0155
C11	0.105	0.095	0.099	0.100
C11	0.102	0.028	0.038	0.056

Table 4. Weight determination based on entropy weight method

distributed between 0 and 1. The results are shown in Figure 1. The results can reflect the absolute value and relative difference of the evaluation results among the bottom-level indicators for each typical sample, and reveal the types of indicators that have a greater impact on the final evaluation results from the perspective of distributed probability and range

Based on the advantages and disadvantages of the samples under 12 decision indicators, the health of 1000 samples is comprehensively evaluated by integrating the index weight factors. Its distribution characteristics are shown in Figure 2. It can be seen that the average value of its basic load is a partial normal distribution of about 0.75 p.u. Taking 100 defective products in the actual detection process as the detection target, compare the number of equal samples with the lowest health degree detected by the three methods of individual AHP, individual entropy weight method and improved information entropy fusion method, and verify the accuracy of the method according to its detection coincidence rate.

It can be seen from this that the improved information entropy fusion method can combine the advantages of the two methods to improve the accuracy of the evaluation, establish a sound enterprise measurement and production equipment health evaluation, and improve the completeness of the production line.

evaluating indicator	AHP	Entropy weight method	Comprehensive weight
C1	0.036	0.046	0.041
C2	0.073	0.078	0.076
C3	0.083	0.080	0.082
C4	0.074	0.071	0.073
C5	0.146	0.130	0.138
C6	0.091	0.093	0.092
C7	0.068	0.065	0.067
C8	0.043	0.051	0.047
C9	0.092	0.088	0.090
C10	0.150	0.155	0.153
C11	0.116	0.100	0.108
C12	0.040	0.056	0.047

Table 5. Comprehensive weighting factors

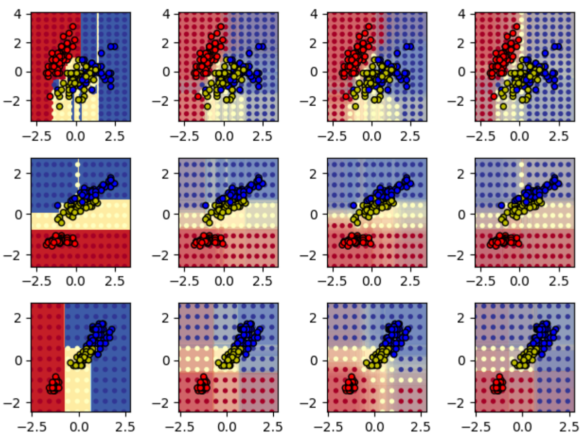

Figure 1. Evaluation score of various indicators of measuring production equipment

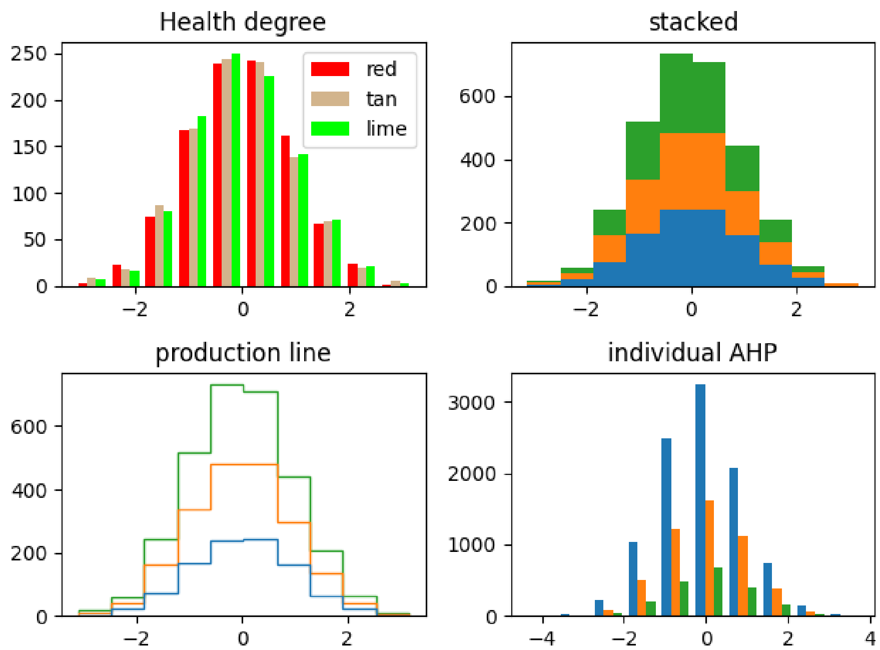

Figure 2. Distribution characteristics of comprehensive health degree of samples

Test cycle	Acquisition duration of traditional time series data acquisition test group	Collection duration of traditional big data cloud platform data collection test group	Collection duration of data collection test group of the Internet of Things
Acquisition cycle 1	2.06	2.12	0.98
Acquisition cycle 2	2.15	1.98	0.87
Acquisition cycle 3	2.42	1.87	0.92

Table 6. Comparison and Analysis of Test Results

3.5. Equipment declaration cycle assessment

A certain number of monitoring and collection nodes were deployed within the selected enterprise equipment and the corresponding data collection cycles were set. According to the actual situation the article set 3 cycles of 4 h each. Secondly, the enterprise equipment was switched on to collect the first cycle of data. Similarly, enterprise data is transformed using a preset format in a certain ratio to form 3 data packets, allowing them to be transmitted to the appropriate control location through the IoT channel. Finally, the remaining 2 cycles of application data are collected according to the data collection format described above. The formula for measuring the actual enterprise device data collection duration is:

$$U = n - \int \frac{\Im(b-1)}{0.2b+\mu^2} n\mu \tag{10}$$

Where: U is the length of data collection for the enterprise equipment, n is the total data collection limit, b is the unidirectional collection range, μ is the stacked collection range and $\Im$ is the data collection variance.

The combination of the above measurements ultimately leads to the final enterprise equipment data collection hours, as shown in Table 6.

As can be seen from Table 5, compared with the traditional time series data acquisition test set and the traditional big data cloud platform data acquisition test set, the designed IoT data acquisition test set eventually took a relatively short acquisition time, and all three cycles were better controlled under 1 min, with the advantages of better targeting and controllable acquisition error, which has certain practical application value.

4. Conclusion

This paper combines hierarchical analysis and fuzzy mathematics, and establishes a comprehensive evaluation model for equipment asset value management based on the traditional fuzzy comprehensive evaluation method, which is the first time in the field of enterprise equipment asset value management to use fuzzy mathematics to model the actual value status of equipment. By introducing the comprehensive evaluation model of equipment asset value established in this paper into the enterprise asset management platform, it not only simplifies the collection of statistics for the set of factors in the comprehensive evaluation model, but also the comprehensive evaluation results in the system will be updated in real time according to the changes of equipment information, in response to the shortcomings of the existing domestic enterprise equipment asset value management, which lacks an objective and quantitative evaluation system. Through the comprehensive evaluation results of equipment value within a certain period of time, it can forecast the direction of enterprise equipment asset value and provide an objective basis for enterprise asset management decisions.

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