Research on Green Quality Management System Based on AHP Fuzzy Comprehensive Evaluation Method

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Abstract: Against the background of the increasing importance of green development and sustainable development, the quality management of enterprises is gradually developing in a green and healthy direction. To a certain extent, traditional quality management with enter-prise product quality as the core is difficult to adapt to the form in which enterprises focus on green quality management. Based on this, this study will use the fuzzy analytic hierarchy process to build a green quality management system that conforms to the current enterprise development from the entire process of enterprise quality management: planning, production, management, sales and feedback. The results show that the green quality management system constructed in the study takes production as the core. At the same time, the study uses Company A as an example to investigate the effectiveness of the model, and also proposes corresponding solutions for Company A to improve green quality management.

1. Introduction

In recent years, the development of science and technology and the reform of enterprises have not only brought convenience to human life, but also brought huge impacts and changes to human living environment. Environmental issues such as the greenhouse effect, atmospheric pollution, endangered species, marine ecological crisis, and sharp decline in green barriers remind humanity of the importance of environmental protection at all times, and also cause human beings to rethink the unreasonable problems brought about by the sustainable development of economic production. The original meaning of the economy is to develop and save resources. Irrational development and use will definitely cause damage to the green environment, which will trigger a green crisis. Developing the economy needs to abide by the laws of green and the principles of green economy. At the same time, people need to recognize that if people want to prevent environmental degradation, they must maintain a virtuous circle of economic activity. The enterprise is the main "source" of manufacturing environmental pollution, and the enterprise is also the main body of the modern economic cycle. Therefore, in order to govern the environment, we must govern the enterprise first. Being able to complete green construction and management has become one of the important signs of an enterprise's international competitiveness. Because the economic and technological development levels of developed and developing countries in the world are not the same and based on international management standards such as ISO9001 and ISO14000, a unified green trade standard has not yet been formed in various countries. The standards of developed countries are now used as the unified standards of all countries in the world, which is commonly referred to as "green trade barriers". For developing countries, including China, this restricts products from entering the market. From the perspective of developed countries, higher green environmental protection quality standards are considered to be a sign of social progress, and the WTO agreement has also formulated various rules and procedures to coordinate green quality standards. Based on such an environment that pursues green development, this research is to carry out related research on green quality management.

2. Overview of Green Quality Management

Traditional quality management focuses on improving product quality, meeting consumer demand, and ensuring production economy. This organizational goal often leads to rough economic development, causing environmental problems of "polluting first, then treating". Green quality management will, based on traditional theories, integrate into more green environmental protection functions, and emphasize the coordination and unification of internal production and external environmental protection, so as to change from the original profit uniqueness to the combination of business operation and ecological development. The concept of green quality management is of great significance for expanding the connotation of quality management, changing the concept of quality management, and ultimately implementing green standardized management and control. In such a change in the concept of quality management, more and more scholars are also studying green quality management and trying to build a green quality management system. As early as 2006, Perrini and Tencatiz proposed that green quality management is the fifth largest management core after production management, financial management, quality management, and logistics management. Subsequently, in 2009, Baharum and Pitt analyzed the green strategic choices of enterprise quality management from a management perspective. Around 2012, scholars such as Zhang Yanqing proposed that green management is the main form of management for enterprises to achieve sustainable development. In 2013, scholar Sui Lihui proposed to build a green quality management system by using neural network analysis methods. Scholar Yao Tao used the quality function (QFD) to explore the construction of a green quality management system.

Based on the relevant research results of previous scholars, this study defines green quality management as: the company runs the idea of green environmental protection throughout the entire production process from product planning to after-sales information feedback. Based on this, this research will start from the entire process of enterprise production, build a green quality management system from five aspects of production planning, product production, comprehensive management, product sales, and product feedback to conduct a comprehensive evaluation of enterprise production and quality management.

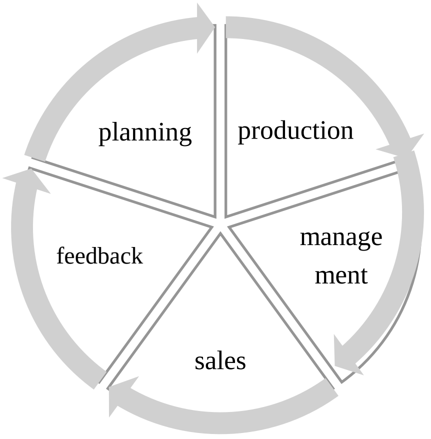

Figure 1 Green Quality Management Process

3. Research methods

3.1 Analytic hierarchy process (AHP method)

Analytic Hierarchy Process (AHP) is a convenient method for quantitative analysis of non-quantitative events. The method first hierarchizes the target problem, and establishes three layers: a target layer, a criterion layer and an indicator layer. Secondly, relevant factors that affect the achievement of goals are summarized into a three-level hierarchy according to the affiliation between the factors. Finally, according to the judgments and decisions of the target group, the relationship between the factors and the importance of the factors, the importance of each factor against the indicators at all levels and the overall goal is determined, and the final plan is clear.

The basic ideas of the analytic hierarchy process is to construct a hierarchical model, construct a comparison matrix, hierarchical ranking, and consistency test. Constructing the indicator system is the most critical part of the entire process. In the research, it was determined through the literature research method that the green quality management system should include first-level indicators such as planning and production. Secondly, based on related management system formulation standards such as the national standard GB / T19000, set secondary indicators such as product rejection rate.

On this basis, the research invited relevant experts to evaluate the indicators. The evaluation method adopts the scoring form of 1-9 points. The higher the score, the greater the weight of the indicator. After obtaining expert scores, the study uses weighted average method to synthesize multiple expert scores. Then based on the analytic hierarchy process, the membership of each indicator is obtained according to the importance of the indicator scale, and then a judgment matrix $A=(a_{ij})_{n\times n}$ is constructed.

$$A=\begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix}$$

After the construction of the judgment matrix indicator is completed, the maximum eigen-value $\lambda_{\max}$ of the judgment matrix A will be used to calculate the consistency test indicator CI:

$$CI=\frac{\lambda_{\max}-n}{n-1}$$

Finally, CR will be used to test the judgment matrix $A=(a_{ij})_{n\times n}$

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

In general, when CR <0.1, it can be considered that the judgment matrix has passed the consistency test, and the feature vector weights are reasonable and can be used.

3.2 Fuzzy comprehensive evaluation

Fuzzy comprehensive evaluation is based on fuzzy mathematics, and by establishing an appropriate membership function quantifies the non-linear evaluation value to obtain a comparable quantitative evaluation result. Fuzzy comprehensive evaluation can effectively deal with subjective problems and fuzzy objective problems. Using this method and analytic hierarchy process to conduct empirical research on related issues to ensure the objectivity and accuracy of evaluation results.

Generally, the fuzzy comprehensive evaluation is performed according to the following steps:

(i) Determining the evaluation indicator set of the evaluation object $U=(u_1,u_2,\cdots,u_n)$

The set $U=(u_1,u_2,\cdots,u_n)$ constitutes the framework of the evaluation indicator, where $u_i(i=1,2,\cdots,n)$ is the evaluation indicator factor and n is the number of factors on the same indicator level.

(ii) Determining the judging set $V=(v_1,v_2,\cdots,v_m)$

The evaluation set $V=(v_1,v_2,\cdots,v_m)$ limits the evaluation range of the evaluation result of an indicator factor, where $V_j(j=1,2,\cdots,m)$ refers to the evaluation result, each level corresponds to a fuzzy subset, and m indicates the number of evaluation levels. The evaluation elements in the judgment set $V=(v_1,v_2,\cdots,v_m)$ can be either qualitative evaluation or quantitative evaluation.

(iii) Establishing membership degree matrix R (fuzzy relation matrix)

The membership degree matrix R represents that from a single factor perspective, the degree of membership of the evaluated indicator factor to the hierarchical fuzzy subset. It can be interpreted as a fuzzy vector $R_i = (r_{i1}, r_{i2}, \dots, r_{im})$ relative to v_j (j=1,2,3…,n) obtained by single-factor evaluation of the i-th (i=1,2,3…,n) evaluation factor n_i, that is:

$$R = \begin{pmatrix} r_{11} & \cdots & r_{1m} \\ \vdots & \ddots & \vdots \\ r_{n1} & \cdots & r_{nm} \end{pmatrix}$$

The entire matrix contains all the information obtained by the evaluation set V evaluating the evaluation indicator set U, Where r_{ij} is the degree to which factor u_i has v_j ($0 \le r_{ij} \le 1$).

(iv) Determining the evaluation factor weight vector $W = (w_1, w_2, \cdots, w_n)$

In the evaluation factor weight vector $W = (w_1, w_2, \cdots, w_n)$, $w_i, (i = 1, 2, \cdots, n)$ indicates the importance of $u_i\,(i = 1, 2, \cdots, n)$, that is, Wi（i=1，2,…，n）indicates the weight of $u_i\,(i = 1, 2, \cdots, n)$, and the weight vector W is required to satisfy $\sum_{i=1}^{n} w_i = 1, 0 \le w_i \le 1$.

(v) Obtain fuzzy comprehensive evaluation result S

The result S of fuzzy comprehensive evaluation of things is composed of weight vector W and membership degree matrix R, that is:

$$S = W \cdot R = (w_1, w_2, \cdots, w_n) \cdot \begin{pmatrix} r_{11} & \cdots & r_{1m} \\ \vdots & \ddots & \vdots \\ r_{n1} & \cdots & a_{nm} \end{pmatrix} = (s_1, s_2, \cdots, s_m)$$

Among them, $s_j = \sum_{i=1}^{n} w_i \cdot r_{ij}, j = 1, 2, \cdots, m$ represents the degree of membership of the evaluated things to the v_j hierarchical fuzzy subset as a whole.

4. Construction of Evaluation System by Fuzzy Analytic Hierarchy

There is no clear evaluation indicator system for green quality management. This study attempts to construct a green quality management system from the five aspects of planning, management, production, sales, and feedback by studying previous research results and interpreting the latest environmental policies.

4.1 Selection of green quality management indicators

The green quality management system is a relatively complex comprehensive evaluation system. It is a complete quality management evaluation system that covers products from production to sales to feedback. In the research process of this study, the green quality management system will be constructed from five aspects of enterprise production: produc-tion planning, product production, comprehensive management, product sales, and product feedback. The planning process indicators are mainly reflected in the quality policy and strategy and product design. In this regard, we will set three secondary indicators: product rejection rate, product out of tolerance rate, green design and development. The production process indicators mainly include seven three-level indicators: development utilization rate of abandoned sites, green building industry ratio, site energy-saving design standards, green equipment adoption rate, environmental protection material utilization rate, energy-saving equipment penetration rate, and centralized waste treatment rate. The comprehensive management process indicators include the training rate of green production personnel and low-carbon operation coverage rate. The sales process indicators mainly include green marketing cost, green product value, green product storage and sales rate, and green product return rate. The feedback process indicators mainly include the quality target achievement rate and customer information feedback.

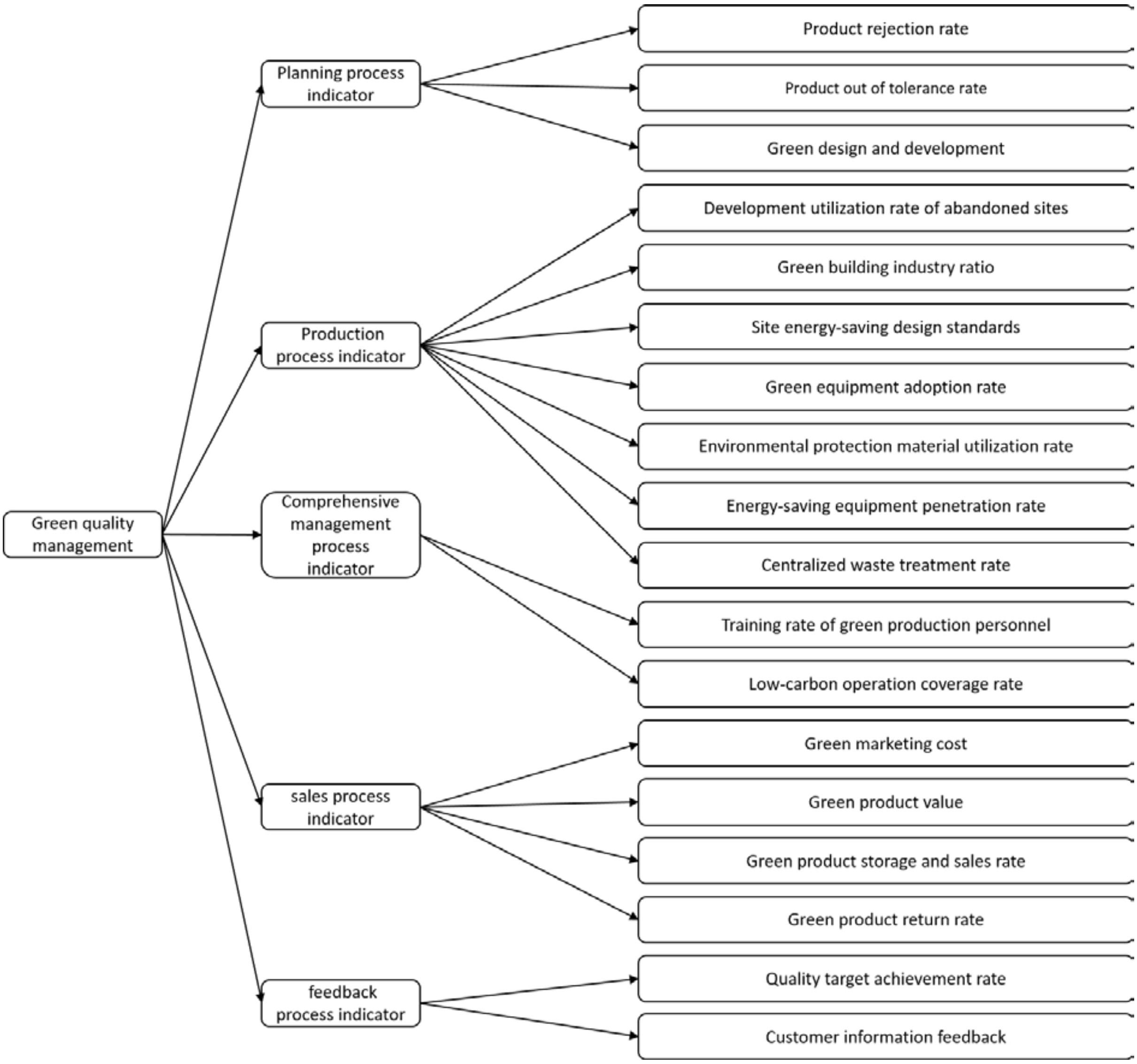

Figure 2 Construction of a green quality management system

4.2 Determining indicator weights through AHP

In the study, it was determined through the literature research method that the green quality management system should include first-level indicators such as planning and production. And, second-level indicators such as product scrap rate based on related management systems such as ISO9001. On this basis, the research invited relevant experts to evaluate the indicators. The evaluation method was conducted in the form of 1-9 points. The higher the score, the greater the weight of the indicator. Based on the expert scoring and evaluation, and combined with many literatures read by researchers, the first-level indicator decision matrix is finally constructed as shown in Table 1.

Table 1 Judgment matrix for first-level indicators

	Planning	Producing	Management	Producing	Feedback
Planning	1	1/3	2	5	3
Producing	3	1	3	5	4
Management	1/5	1/3	1	3	2
Sales	1/5	1/5	1/3	1	3
Feedback	1/3	1/4	1/2	1/3	1

Matrixing the evaluation results gives:

$$A=\begin{pmatrix} 1 & 1/3 & 2 & 5 & 3 \\ 3 & 1 & 3 & 5 & 4 \\ 1/5 & 1/3 & 1 & 3 & 2 \\ 1/5 & 1/5 & 1/3 & 1 & 3 \\ 1/3 & 1/4 & 1/2 & 1/3 & 1 \end{pmatrix}$$

Using Matlab to perform matrix operations can be obtained:

Table 2 Related weights for first-level indicators

Indicators	Planning	Producing	Management	Producing	Feedback
Weight	0.254	0.445	0.142	0.091	0.069
CI			0.078		
CR			0.070		

Consistency test indicator CR=0.070<0.10, the consistency test passes, and the indicator weight conforms to the calculation rules. According to the weight distribution of the first-level indicators, the construction of green quality management system by researchers and experts mainly focuses on planning, production and management, of which the production accounts for the largest proportion. It can be seen that the company's green quality management is also in line with the research proposed: green quality management is the expansion and supplement of comprehensive quality management.

The study uses the same method to calculate the weight of each second-level indicators, and the calculation results are shown in the table:

Table 3 Weights of secondary indicators

First-level indicator	Weight	Second-level indicator	Weight	Consistency test
		Product rejection rate	0.105	
Planning	0.254	Product out of tolerance rate	0.258	CR= 0.037
		Green design and development	0.637	
		Development utilization rate of abandoned sites	0.211	
		Green building industry ratio	0.167	
		Site energy-saving design standards	0.261	
Producing	0.445	Green equipment adoption rate	0.077	CR=0.099
		Environmental protection material utilization rate	0.044	
		Energy-saving equipment penetration rate	0.057	
		Centralized waste treatment rate	0.184	
Management	0.141	Training rate of green production personnel	0.500	/
		Low-carbon operation coverage rate	0.500	
		Green marketing cost	0.288	
		Green product value	0.532	
Sales	0.091	Green product storage and sales rate	0.068	CR=0.008
		Green product return rate	0.112	
Feedback	0.0689	Quality target achievement rate	0.500	/
		Customer information feedback	0.500	

According to the weight of the first-level indicator and the weight of the corresponding second-level indicator, we will build the relevant indicator weight of the green quality management system:

Table 4 Weights of indicators related to the green quality management system

First-level indicator	Second-level indicator	Weight
Planning	Product rejection rate	0.03
	Product out of tolerance rate	0.07
	Green design and development	0.16
Producing	Development utilization rate of abandoned sites	0.09
	Green building industry ratio	0.07
	Site energy-saving design standards	0.12
	Green equipment adoption rate	0.03
	Environmental protection material utilization rate	0.02
	Energy-saving equipment penetration rate	0.03
Management	Centralized waste treatment rate	0.08
	Training rate of green production personnel	0.07
	Low-carbon operation coverage rate	0.07
Sales	Green marketing cost	0.03
	Green product value	0.05
	Green product storage and sales rate	0.01
Feedback	Green product return rate	0.01
	Quality target achievement rate	0.03
	Customer information feedback	0.03

4.3 Construction of fuzzy evaluation matrix

The study takes company A as an example and uses the fuzzy evaluation matrix to study its green quality management system construction status. In response to the company's relevant situation, this study invited 10 experts to evaluate the indicators we set according to the evaluation set V=（Excellent, Good, Moderate, Poor）. The evaluation is mainly based on the four dimensions of indicator requirements: completion, innovation, whether it meets production requirements and whether it meets the environmental protection and green goals. Specific rules are described in the following table.

Table 5 Evaluation criteria

Evaluation	Evaluation criteria
Excellent（90-100）* Calculated by 90	For the data required by the indicators, companies have a high degree of completion and at the same time have a certain degree of innovation, which can not only meet production requirements but also achieve en-vironmental protection and green goals.
Good（80-90）* Calculated by 80	For the data required by the indicators, companies have a high degree of completion and innovation, and can meet production requirements and achieve environmental protection and green goals.
Moderate（70-80）* Calculated by70	For the data required by the indicators, companies can basically complete, and the innovation is general. Companies can meet the production requirements and can basically achieve environmental protection and green goals.
Poor（60-70）* Calculated by 60	For the data required by the indicators, companies have poor completion and poor innovation, and it is difficult to complete production require-ments and achieve environmental protection and green goals.

During the evaluation, fill in 1 when selecting an option, and the remaining options are indicated by 0. The form is shown in (table):

Table 6 Examples of scoring

Indicator	Excellent	Good	Moderate	Poor
A	1	0	0	0
B	0	0	0	1
C	…	…	…	…
D	…	…	…	…
E	…	…	…	…

After the evaluation is completed, we can obtain the membership degrees evaluation matrix R, and then use $S = W \bullet R$ to calculate the comprehensive evaluation result of the membership degrees. Taking production in the first-level Indicator as an example, the results of expert evaluation scores are summarized as:

Table 7 Summary table of expert scorings

Indicator	Excellent	Good	Moderate	Poor
Development utilization rate of abandoned sites	6	3	0	0
Green building industry ratio	4	6	0	0
Site energy-saving design standards	3	4	1	2
Green equipment adoption rate	4	3	2	1
Environmental protection material utilization rate	5	3	2	0
Energy-saving equipment penetration rate	6	4	0	0
Centralized waste treatment rate	5	4	1	0

After normalization, the first-level indicator production membership degrees matrix R is:

$$R = \begin{pmatrix} 0.6 & 0.3 & 0 & 0 \\ 0.4 & 0.6 & 0 & 0 \\ 0.3 & 0.4 & 0.1 & 0.2 \\ 0.4 & 0.3 & 0.2 & 0.1 \\ 0.5 & 0.3 & 0.2 & 0 \\ 0.6 & 0.4 & 0 & 0 \\ 0.5 & 0.4 & 0.1 & 0 \end{pmatrix}$$

Combined with the first-level indicator weights obtained by the analytic hierarchy process in the study, the comprehensive evaluation results of the membership degree can be obtained as:

$$S = WR = (0.21\ 0.17\ 0.26\ 0.08\ 0.04\ 0.06\ 0.18) \times \begin{pmatrix} 0.6 & 0.3 & 0 & 0 \\ 0.4 & 0.6 & 0 & 0 \\ 0.3 & 0.4 & 0.1 & 0.2 \\ 0.4 & 0.3 & 0.2 & 0.1 \\ 0.5 & 0.3 & 0.2 & 0 \\ 0.6 & 0.4 & 0 & 0 \\ 0.5 & 0.4 & 0.1 & 0 \end{pmatrix} = (0.45\ 0.40\ 0.07\ 0.06)$$

Based on this, we continue to carry out fuzzy comprehensive evaluation of relevant indicators.

Table 8 Fuzzy comprehensive evaluation results

First-level indicator	Weight	Second-level indicator	Weight	Membership degrees matrix	Fuzzy comprehensive evaluation result S
Planning	0.25	Product rejection rate	0.10	$\begin{pmatrix} 0.5 & 0.3 & 0.2 & 0 \\ 0.4 & 0.2 & 0.3 & 0.1 \\ 0.6 & 0.1 & 0.3 & 0 \end{pmatrix}$	$\begin{pmatrix} 0.54 & 0.15 & 0.29 & 0.03 \end{pmatrix}$
		Product out of tolerance rate	0.26		
		Green design and development	0.64		
Producing	0.44	Development utilization rate of abandoned sites	0.22	$\begin{pmatrix} 0.6 & 0.3 & 0 & 0 \\ 0.4 & 0.6 & 0 & 0 \\ 0.3 & 0.4 & 0.1 & 0.2 \\ 0.4 & 0.3 & 0.2 & 0.1 \\ 0.5 & 0.3 & 0.2 & 0 \\ 0.6 & 0.4 & 0 & 0 \\ 0.5 & 0.4 & 0.1 & 0 \end{pmatrix}$	（0.45 0.40 0.07 0.06）
		Green building industry ratio	0.17		
		Site energy-saving design standards	0.26		
		Green equipment adoption rate	0.08		
		Environmental protection material utilization rate	0.04		
		Energy-saving equipment penetration rate	0.06		
		Centralized waste treatment rate	0.18		
Management	0.14	Training rate of green production personnel	0.50	$\begin{pmatrix} 0.5 & 0.3 & 0.1 & 0.1 \\ 0.4 & 0.6 & 0 & 0 \end{pmatrix}$	$\begin{pmatrix} 0.45 & 0.45 & 0.05 & 0.05 \end{pmatrix}$
		Low-carbon operation coverage rate	0.50		
Sales	0.09	Green marketing cost	0.29	$\begin{pmatrix} 0.6 & 0.2 & 0.2 & 0 \\ 0.4 & 0.4 & 0.2 & 0.1 \\ 0.5 & 0.3 & 0.2 & 0 \\ 0.4 & 0.1 & 0.3 & 0.2 \end{pmatrix}$	$\begin{pmatrix} 0.46 & 0.30 & 0.21 & 0.08 \end{pmatrix}$
		Green product value	0.53		
		Green product storage and sales rate	0.07		
		Green product return rate	0.11		
Feedback	0.07	Quality target achievement rate	0.50	$\begin{pmatrix} 0.6 & 0.4 & 0 & 0 \\ 0.5 & 0.1 & 0.3 & 0.1 \end{pmatrix}$	$\begin{pmatrix} 0.55 & 0.25 & 0.15 & 0.05 \end{pmatrix}$
		Customer information feedback	0.50		

On this basis, the fuzzy comprehensive evaluation of Company A can be calculated.

$$S = WR = \begin{pmatrix} 0.25 & 0.44 & 0.14 & 0.09 & 0.07 \end{pmatrix} \times \begin{pmatrix} 0.54 & 0.15 & 0.29 & 0.03 \\ 0.45 & 0.40 & 0.07 & 0.06 \\ 0.45 & 0.45 & 0.05 & 0.05 \\ 0.46 & 0.30 & 0.21 & 0.08 \\ 0.55 & 0.25 & 0.15 & 0.05 \end{pmatrix} = \begin{pmatrix} 0.48 & 0.32 & 0.14 & 0.05 \end{pmatrix}$$

Calculated according to the score, the score of A's green quality management system is 81.37 points, and the evaluation of the green quality management system is good. The indicator requires data that the company has a high degree of completion and good innovation, and can meet the production requirements and achieve environmental protection and green goals. In order to study the evaluation of its first-level indicators, the study separately calculates its scores on the first-level indicators.

Table 9 Fuzzy comprehensive evaluation scores of first-level indicators

First-level indicator	Score
Planning	82.7
Producing	81.0
Management	83.0
Sales	84.9
Feedback	83.0

In terms of first-level indicators, Company A's production score was the lowest at 81 points, and the highest score was sales at 84.9. It can be found that Company A's main problem lies in production, and sales have been completed well. For the secondary indicators of company A's production, three indicators can be seen from the site energy-saving design standards (0.26), Development utilization rate of abandoned sites (0.22), and Green building industry ratio (0.17): In order to improve the green quality management level of production, Company A needs to use more corresponding energy-saving equipment, and the use of abandoned sites also needs to be improved. For the abandoned sites generated in production, the enterprise should try to reuse the sites as much as possible to save space. For several other indicators, the sales performance is better, to a certain extent, the company's products have left consumers with green products. This aspect should continue to carry out certain green marketing and promotion to improve the score in this area. In addition, enterprises should focus on improving the planning and management of green quality management to steadily improve the overall quality management level.

5. Conclusion

In the research process, the research used the analytic hierarchy process to study the construction of green quality management system from five aspects of planning, production, management, sales and feedback. After the system construction is completed, the research-built system mainly focuses on the production process, and its weight is as high as 0.44. It can be seen from the research starting point of this study that the bottleneck of green quality management in many enterprises is still the production stage. The development process of quality management has always been based on the management of production from the initial quality inspection stage to statistical quality control stage to statistical quality management to total quality management stage. In the further development of quality management, such as lean production proposed by Japan Toyota, the starting point is from production. The green quality management evaluation system constructed in this study is also centered on production, and then supplemented by traditional quality management. Green quality management will focus on planning (0.25) and management (0.14) on the basis of production. In the future development of the quality management system, enterprises will pay more attention to the comprehensive construction of green quality management system. This research hopes to make some supplements to traditional quality management.

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