Research on the Performance Appraisal System of Workshop Quality Inspectors after Green Manufacturing Transformation in Company A – An Attempt Based on Fuzzy Comprehensive Evaluation (Entropy Weight Method)

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Abstract. In the rapidly developing modern society, where market demands fluctuate rapidly, the relevant evaluation criteria for green manufacturing quality inspectors remain somewhat ambiguous. This paper presents an evaluation method for assessing the performance of workshop quality inspectors after a green manufacturing transformation, and verifies the feasibility of this method through an enterprise experimentation.

Keywords: Industry 4.0, SMEs, digitalisation, green production, fuzzy comprehensive evaluation (entropy weight method).

1 INTRODUCTION

Businesses today face significant environmental challenges in society, requiring a focus on improving eco-efficiency as a core aspect of sustainable growth. The transition to environmental management systems, including setting conservation targets, promoting green operations and balancing economic, environmental and social benefits, is imperative for companies[1].

1.1 Company Background

Company A, founded in 1999, is committed to 'continuous improvement' and excellence in its offering. In 2023, in response to the post-pandemic landscape, the company has embarked on a dual strategy of digitalisation and environmental improvement, focusing on the modernisation of its production facilities. These efforts aim to increase productivity, improve product quality, reduce costs and strengthen market position, thereby ensuring the company's adaptability, resilience and future prosperity.

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1.2 Study Synopsis

This study empirically investigates and evaluates the effectiveness of quality control inspectors at Company A following its digital and green transformation[2].By examining the work environment, using green performance metrics and delving into human capital datasets, a bespoke inspector performance evaluation framework is formulated that is aligned with the company's phased development trajectory, employee strengths and HR structures.

2 DATA EXTRACTION & ANALYSIS TECHNIQUES

The study uses fuzzy comprehensive evaluation[3], an approach developed by L.A. Zadeh to deal with ambiguous problems. It breaks down problems, assigns scores and mathematically combines them into a comprehensive score. It converts qualitative judgements into numerical values. It is suitable for scenarios with interrelated factors. Inspectors' assessments benefit from this[4]. The study includes Company A's financial statements, customer feedback, staff appraisals and operational data. The data has been cleaned and verified. A panel of experts provided guidance. Ten evaluation criteria were identified[5].

Table 1. Key performance indicator rating scale for quality inspectors

Category	Performance Indicator	Calculation Formula or Explanation
Quality control & efficiency improvement	1. First time pass rate	(Number of products passing the first inspection/total number of products inspected)×100%(Number of products passing the first inspection/total number of products inspected)×100%.
	2. Timeliness of Defect Detection	(number of defects detected in time / total number of defects)×100%(number of defects detected in time / total number of defects)×100%.
	3. Quality problem resolution cycle time	Average time to resolve each quality issue from detection to resolution
Environmental compliance	4. Compliance with green inspection procedures	(number of inspections carried out in accordance with green inspection procedures/total number of inspections)×100%(number of inspections carried out in accordance with green inspection procedures/total number of inspections)×100%.
	5. Compliance rate with product environmental standards	(Number of products complying with environmental regulations/total number of products checked)×100%(Number of products complying with environmental regulations/total number of products checked)×100%.
Customer Satisfaction	6. Customer Feedback Handling Satisfaction	Customer Feedback Handling Satisfaction
Continuous Improvement & Innovation	7. Suggestion submission & acceptance rate	(Number of improvement suggestions/total number of improvement suggestions submitted)×100%(Number of improvement suggestions/total number of improvement suggestions submitted)×100%.
	8. Participation & performance in quality training	Participation rate = (number of attendees/number of expected attendees)×100% (number of attendees/number of expected

		attendees)×100% Score = average exam or assessment score
Team Collaboration & Leadership	9. Success rate of team collaboration projects	(Number of successfully completed collaborative projects/total number of collaborative projects)×100%(Number of successfully completed collaborative projects/total number of collaborative projects)×100%.
	10. Cross-functional training completion rate	Percentage of employees having completed all designated cross-functional training programmes

2.1 Comprehensive Evaluation Using Entropy Informed Fuzzy Logic

Before we started, we gave questionnaires to five experts, asking them to rate the weighting indicators in these ten categories from their individual perspectives. The numerical annotations used are explained in the following Table 2: Score and Meaning[6].

Table 2. Score and Meaning

Score	Meaning
1	Equally important, there is no clear preference between the two.
3	Slightly more important; the first element has a slight advantage over the second.
5	Clearly more important; a clear distinction in favour of the first element.
7	Strongly more important; the first element significantly outweighs the second.
9	Extremely important; the first element is almost absolutely dominant over the second.
2, 4, 6, 8	Intermediate scores representing gradations of preference intensity between final judgments. For example, a score of 4 might be assigned when a factor is considered to be slightly more important than "slightly" but not "noticeably" more important.
Reciprocal	The reciprocal of the above scores, used for inverse comparisons when the direction of comparison is reversed.

Formation of a Framework of Evaluation Criteria. In Table 1, the performance of the quality inspectors in Company A's workshops after the green transformation is outlined at a target level, which is subdivided into four evaluation categories at the criteria level, labelled $U_{A1}=(U_{A11},U_{A12},U_{A13})$. Each of these criteria is further subdivided into specific indicators; for example, U_{A1} includes three indicators, labelled $U_{A1}=(U_{A11},U_{A12},U_{A13})$.

Development of the Assessment Outcome Set. An outcome set, V, is formulated to rank the performance level of each indicator within the indicator set. It is formulated as $V=\{V_1, V_2, V_3, ..., V_n\}$, where n indicates the number of levels. To reflect the context of the quality inspectors' assessment after the green conversion, this study stratifies the rating scale into five levels: "outstanding", "above average", "satisfactory", "below par" and "inadequate".

Derivation of Weight Set W. In status assessment research, weighting is a critical factor, the rationality of which is directly related to the accuracy of the assessment results. Conventional approaches, such as the Delphi method, frequency statistics, principal component analysis and the Analytic Hierarchy Process (AHP), often carry a significant degree of subjectivity that can undermine the objectivity of the assessment. In order to ensure fairness in the evaluation of the performance of quality inspectors in the workshops of A company following its transition to green manufacturing, this study adopts a combined strategy of entropy weighting and AHP. This integrated approach aims to minimise subjective biases and correct discrepancies that may arise from over-reliance on data alone, thereby enhancing the authenticity and reliability of the assessment in reflecting real production contexts[7].

2.1.1 Entropy Based Objective Weight Calculation.

Rooted in information theory, entropy weighting is inversely related to the information content of an indicator. The procedure for the entropy weighting methodology includes

(1) Construction of the evaluation matrix: Given M evaluation dimensions and N metrics,

(2) Formulate the raw data assessment matrix $Y=(y_{ij})m\times n$: This encapsulates the baseline assessment scores for each metric across all dimensions, where yij symbolises the score of the j-th metric under the i-th assessment category.

Construct the original data scoring matrix $Y=（y_{ij}）m\times n$. As shown in the matrix (1).

$$Y=\begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \end{bmatrix} \tag{1}$$

2.1.2 Normalization of the Evaluation Matrix.

Use a linear transformation to normalise the scoring matrix $Y=(y_{ij})m\times n$ into a normalised matrix $Q=(q_{ij})m\times n$. Depending on the relationship between indicators and evaluation results, indicators are classified as positive (where higher values are better) and negative (where lower values are better). The calculation methods are as follows Formula 2:

$$y'_{ij}=\frac{y_{ij}-\min y_{1j,\cdots,}y_{nj}}{\max\{y_{1j,\cdots,}\ y_{nj}\}-\min y_{1j,\cdots,}\ y_{nj}} \tag{2}$$

For positive indicators: Calculate the proportion q_{ij} of the i-th evaluation value under the j-th indicator in the total of this indicator. As shown in formula (3).

$$q_{ij}=\frac{y'_{ij}}{\sum_{i=1}^{m}y'_{ij}} \tag{3}$$

Where m is the number of evaluation values.

2.1.3 Calculation of the indicator information entropy Mj.

Entropy quantifies the amount of uncertainty or disorder in the distribution of normalised values across indicators.

$$M_j = -\frac{1}{\ln m}\sum_{i=1}^{m} q_{ij} \ln q_{ij} \tag{4}$$

2.1.4 Calculation of Indicator Weights Nj.

Here, j ranges from 1 to n (the total number of indicators), and N_j values indicate the contribution of each indicator Ni to distinguishing sample categories. A larger N_j implies a larger contribution. Thus, the vector $[N_1, N_2, ..., N_M]$ serves as the weight vector or entropy weights, reflecting the objective importance of each indicator based on the information contained in the data. As shown in formula (5).

$$N_J = \frac{(1-M)}{\sum_{j=1}^{n}(1-M_j)} \tag{5}$$

2.2 Composite weight calculation

In order to avoid the over-reliance of the entropy weighting method on indicator data, which may lead to unreasonable evaluation results, this study combines two methods to derive composite weights, thus ensuring both objectivity and rationality in weighting. The set of weights Vj ={V1,V2, ..., V3} is obtained using the Analytic Hierarchy Process (AHP), while the set of weights Nj ={N1, N2, ..., Nm} is derived from the entropy weighting method. The composite weights Wj =[W1, W2, ..., Wj] are calculated according to formula (6):

$$w_j = \alpha v_j + (1-\alpha) n_j \tag{6}$$

Where Vj is the weight of indicator j obtained via AHP, nj is the weight of indicator j derived from the entropy method, and $\propto$ is a weighting factor between 0 and 1 to balance the contributions of both methods.

Creation of a fuzzy evaluation matrix. A fuzzy evaluation matrix A is constructed using membership functions. As shown in matrix (7).

$$Y = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}_{m\times n} \tag{7}$$

Based on the company's previous performance experience, a membership degree evaluation matrix for the performance evaluation of workshop quality inspectors after the green manufacturing transformation in Company A is established.

R_{ij} （i=1，2，…，m；j=1，2，…，n）represents the membership degree of the i-th evaluation indicator to the j-th evaluation level, reflecting the fuzzy relationship between the evaluation indicators and the evaluation grades.

2.2.1 Calculation of Evaluation Results.

The obtained composite weights and the membership degree matrix are combined. The result of the fuzzy comprehensive evaluation, which determines the status level B of the performance evaluation for workshop quality inspectors after the green manufacturing transformation in Company A, is derived based on the maximum membership degree principle. As shown in formula (8)

$$B = WR \tag{8}$$

3 CASE ANALYSIS

Following the methodology outlined above, we drew inspiration from below[9-11], with the detailed programme outlined in Appendix I.

Prior to the start of the project, we weighted the ratings of the 100 experts as follows: two PhD experts were given a weight of 0.8 each, two Masters experts were given a weight of 0.3 each, and a Junior College expert was given a weight of 0.1. After applying these weights to the data, we first performed a CI (Consistency Index) and CR (Consistency Ratio) test. Using spss, the resulting CI value was 0.03904699920890812 and the CR value was 0.04387303281899788. With both CI and CR values below 0.1, we can conclude that our data has a high degree of consistency and reliability. The programme was then run, resulting in the following data, which is presented in Table 3 Performance evaluation weightings.

Table 3. Performance evaluation weightings

Category	Performance Indicator
Quality control & efficiency improvement (20.458%)	1. First time pass rate (24.59%)
	2. Timeliness of Defect Detection (28.04%)
	3. Quality problem resolution cycle time (47.38%)
Environmental compliance (23.69%)	4. Compliance with green inspection procedures (40.40%)
Customer Satisfaction (10.64%)	5. Compliance rate with product environmental standards (48.96%)
	6. Customer Feedback Handling Satisfaction（10.64%）
Continuous Improvement & Innovation (24.164%)	7. Suggestion submission & acceptance rate (10.65%)
	8. Participation & performance in quality training (90.35%)
Team Collaboration & Leadership (21.044%)	9. Success rate of team collaboration projects (48.16%)
	10. Cross-functional training completion rate (51.84%)

4 CONCLUSION

This study investigated the performance evaluation system for workshop quality inspectors following the green manufacturing transformation in Company A. Through close collaboration with company experts, we established evaluation criteria in five dimensions: quality control and efficiency improvement, environmental compliance, customer satisfaction, continuous improvement and innovation, and team collaboration and leadership. Using a fuzzy comprehensive evaluation method centred on entropy weighting, we successfully calculated the required performance indicators for both major and minor categories using Matlab software. Post-implementation practice confirmed that this evaluation method demonstrated objectivity and practicality, and accurately reflected the performance evaluation of workshop quality inspectors after the green transformation in Company A.

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Appendix I: Program Outline

The program will be published in https://github.com/yanyuyoulan/Fuzzy-comprehensive-evaluation-entropy-weight-method-