ORIGINAL

Construction of a Model for Evaluating the Operating Efficiency and Performance of State-Owned Enterprises Using Fuzzy Comprehensive Evaluation

Construcción de un modelo para evaluar la eficiencia operativa y el desempeño de las empresas estatales mediante la evaluación comprensiva difusa

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ABSTRACT

State-owned energy, transportation, and telecommunications enterprises power many countries' economies and societies. Considering commercial and social objectives, SOE performance evaluation is complex. Rather than innovation, sustainability, and stakeholder satisfaction, financial factors have determined SOE's success. The present study simulates an SOE Fuzzy Comprehensive Evaluation approach to overcome the constraint. The model encompasses quantitative and qualitative performance. The proposed model prioritizes the whole evaluation aim and follows it with performance criteria and sub-criteria. This paper used the analytical hierarchy process with expert survey input to fine-tune the standard weights. Fuzzy logic addresses the uncertainty in qualitative analysis. This method performs traditional financial ratio analysis, balanced scorecard, and data envelope analysis.

Keywords: State-Owned Enterprises; Fuzzy Comprehensive Evaluation; Analytic Hierarchy Process; Machine Learning; Balanced Scorecard; Data Envelopment Analysis.

RESUMEN

Las empresas estatales de energía, transporte y telecomunicaciones impulsan las economías y sociedades de muchos países. Si se tienen en cuenta los objetivos comerciales y sociales, la evaluación del desempeño de las empresas estatales es compleja. En lugar de la innovación, la sostenibilidad y la satisfacción de las partes interesadas, los factores financieros han determinado el éxito de las empresas estatales. El presente estudio simula un enfoque de evaluación integral difusa de las empresas estatales para superar la limitación. El modelo abarca el desempeño cuantitativo y cualitativo. El modelo propuesto prioriza todo el objetivo de la evaluación y lo sigue con criterios y subcriterios de desempeño. Este documento utilizó el proceso de jerarquía analítica con aportes de encuestas a expertos para ajustar los pesos estándar. La lógica difusa aborda la incertidumbre en el análisis cualitativo. Este método realiza análisis de ratios financieros tradicionales, cuadro de mando integral y análisis de datos.

Palabras clave: Empresas Públicas; Evaluación Integral Difusa; Proceso de Jerarquía Analítica; Aprendizaje Automático; Cuadro de Mando Integral; Análisis Envolvente de Datos.

INTRODUCTION

State-owned enterprises play a significant role in the economic and social landscape of many countries, particularly in emerging and transitional economies.[1,2] The SOE are more related to the fields of industry like energy, transportation, and telecommunications, as such sectors are more public related and contribute to nation development.[3] Evaluating such enterprises contributes to particular challenges as those enterprises are built to achieve commercial and social goals.[4] To evaluate the performance of such establishments, the traditional models such as financial ratio analysis or basic efficiency measures struggle to identify and include the complex nature of SOE performance as it includes financial viability, operational efficiency, innovation, sustainability, and stakeholder satisfaction.[5,6] A comprehensive model considers the quantitative and qualitative aspects of the SOE's performance to evaluate such enterprises.[7,8] because the available models that are in practice to evaluate such enterprises only focus on financial indicators or operational metrics and fail to consider factors such as innovation capacity, sustainability practices, and stakeholder satisfaction.[9,10] This narrowed approach leads to incomplete assessments that could lead to suboptimal decision-making by policymakers and managers. This research aims to address the limitations of current SOE performance evaluation models by developing a comprehensive framework that integrates multiple performance dimensions.

The primary objectives of this study are

- The project aims to create a model that integrates quantitative and qualitative factors in evaluating SOEs, assesses the significance of performance criteria through AHP and expert surveys, and validates the model through empirical analysis.

This research proposes a Fuzzy Comprehensive Evaluation (FCE) model to evaluate SOE to achieve the above objectives. The FCE model is designed to combine multiple criteria into a single performance score that shows the overall performance of an enterprise. The model uses Fuzzy Logic (FL) to handle the inherent uncertainties in evaluating qualitative aspects of performance. The model includes performance indicators such as financial performance, operational efficiency, innovation capacity, sustainability practices, and stakeholder satisfaction. Each metric is weighted based on relative importance and measured using AHP and the Delphi method. The FCE model is designed hierarchically to evaluate SOE performance at the top, followed by key performance criteria and sub-criteria. The model aggregates the evaluations of these sub-criteria through fuzzy aggregation methods and results in a final crisp score that represents the SOE's overall performance.

Fuzzy Set Theory

A fuzzy set is denoted as $A \subseteq X$, where X is the universe of discourse, and A is a set of ordered pairs. Each pair $(x, \mu_A(x))$ consists of an element $x \in X$ and its degree of membership $\mu_A(x)$, where $\mu_A : X \in [0,1]$. The function $\mu_A(x)$ is called the membership function of x in A, and it quantitatively represents the grade of membership of x ranging from complete non-membership (0) to full membership (1). The following are set of operations that are defined on fuzzy sets:

Union: the union of two fuzzy sets A and B in X is a fuzzy set C where the membership function is defined as:

$$\mu_C(x) = \max(\mu_A(x), \mu_B(x)) \text{ for all } x \in X. \qquad (1)$$

Intersection: the intersection of fuzzy sets A and B is defined by:

$$\mu_C(x) = \min(\mu_A(x), \mu_B(x)) \text{ for each } x \in X. \qquad (2)$$

Complement: the complement of a fuzzy set A is a set A^c where:

$$\mu_{A^c}(x) = 1 - \mu_A(x) \text{ for all } x \in X. \qquad (3)$$

METHOD

Model Design

The FCE model is structured hierarchically with the topmost Goal Layer, denoted as G, which measures the overall objective of the evaluation process. Next to the Goal Layer follows the Criteria Layer, represented as:

$$C = \{C_1, C_2, \ldots, C_m\} \qquad (4)$$

Where each criterion C_i corresponds to SOE performances in financial performance, operational efficiency, innovation capacity, sustainability, and stakeholder satisfaction. Each criterion C_i is independently evaluated to measure the overall performance assessment.

Further down the hierarchy is the Sub-Criteria Layer, where each criterion C_i is broken down into a set of sub-criteria.

$$S_i = \{S_{i1}, S_{i2}, \ldots, S_{in_i}\}, \qquad (5)$$

Where S_{ij} represents the j-th sub-criterion under the i-th criterion. The evaluation of each sub-criterion S_{ij} is expressed through a fuzzy evaluation set:

$$E = \{E_1, E_2, \ldots, E_k\}, \qquad (6)$$

Where E_k corresponds to a linguistic term like Poor, Fair, Good, or Excellent. These terms are associated with fuzzy membership functions, which evaluate the degree to which an input value x belongs to the fuzzy set representing each sub-criterion. The membership function $\mu_{ij}(x)$ operates over the interval [0,1], quantifying the degree of membership for the input value x in the fuzzy set of the sub-criterion S_{ij}. The fuzzy rule base comprises a series of if-then rules that establish relationships between input variables (sub-criteria evaluations) and output variables (overall performance scores). Each rule R_k takes the form: "If S_{i1} is E_1 and S_{i2} is E_2, then C_i is E_k." These rules are applied during the fuzzy inference process to derive conclusions based on the input data. The overall fuzzy evaluation for each criterion C_i is obtained by aggregating the weighted evaluations of its sub-criteria:

$$\mu_{C_i}(x) = \sum_{j=1}^{n_i} w_{ij} \cdot \mu_{S_{ij}}(x) \qquad (7)$$

Where w_{ij} is the weight assigned to the sub-criterion S_{ij}, and $\mu_{(Sij)}(x)$ is the membership value for the subcriterion. The overall evaluation G is then aggregated from the criteria evaluations using:

$$\mu_G(x) = \sum_{i=1}^{m} w_i \cdot \mu_{C_i}(x) \qquad (8)$$

Where w_i is the weight assigned to the criterion C_i, and $\mu_{(Ci)}(x)$ is the aggregated fuzzy score for the criterion. The final step in the FCE model is defuzzification, which transforms the fuzzy output $\mu_G(x)$ into a crisp score G_{crisp}.

$$G_{crisp} = \frac{\int x \cdot \mu_G(x)\,dx}{\int \mu_G(x)\,dx} \qquad (9)$$

Key Performance Indicators (KPI) for SOE

The KPIs are chosen to capture the multi-layered nature of SOE performance, including financial and non-financial aspects. The following table 1 presents the KPIs considered in this work:

Category	KPI	Description	Formula
Profitability	KPI_1: Return on Assets (ROA)	Measures the ability of the SOE to generate income relative to total assets.	ROA = Net Income / Total Assets
	KPI_1: Return on Equity (ROE)	Measures the ability of the SOE to generate income relative to shareholders' equity.	ROE = Net Income / Shareholder's Equity
	KPI_1: Net Profit Margin (NPM)	Measures the percentage of revenue that is converted into profit.	NPM = Net Profit / Revenue
Liquidity	KPI_2: Current Ratio (CR)	Evaluates the ability of the SOE to meet short-term obligations with current assets.	CR = Current Assets / Current Liabilities
	KPI_2: Quick Ratio (QR)	Measures the ability to meet short-term obligations excluding inventory.	QR = (Current Assets - Inventory) / Current Liabilities
Leverage	KPI_3: Debt-to-Equity Ratio (DER)	Assesses the degree to which the SOE is utilizing borrowed funds.	DER= Total Liabilities / Shareholder's Equity
	KPI_3: Debt-to-Assets Ratio (DAR)	Measures the percentage of the SOE's assets financed by debt.	DAR= Total Liabilities / Total Assets
Operational Efficiency	KPI_4: Asset Turnover Ratio (ATR)	Reflects how efficiently the SOE is using its assets to generate revenue.	ATR= Revenue / Total Assets
	KPI_4: Inventory Turnover Ratio (ITR)	Measures how effectively inventory is managed by comparing the cost of goods sold to average inventory.	ITR = Cost of Goods Sold / Average Inventory
	KPI_5: Operating Expense Ratio (OER)	Measures the SOE's ability to manage its operational costs.	OER = Operating Expenses / Revenue
	KPI_5: Cost-to-Income Ratio (CIR)	Assesses the operational cost management relative to income generated.	CIR= Total Operating Cost / Total Income
Productivity	KPI_6: Labor Productivity (LP)	Examines the output relative to the labor input.	LP= Output / Labor Input
	KPI_6: Capital Productivity (CP)	Evaluates the efficiency of capital usage relative to the output produced.	CP = Output / Capital Input
Innovation Capacity	KPI_7: R&D Intensity	Evaluates the level of investment in research and development activities.	R&D Intensity = R&D Expenditure / Total Revenue
	KPI_8: Patent Intensity (PI)	Measures innovation output through the number of patents filed or granted relative to R&D expenditure.	PI = Number of Patents / R&D Expenditure
Sustainability Practices	KPI_9: Carbon Footprint (CF)	Assesses the environmental footprint of the SOE's operations.	CF= Total CO_2 Emissions
	KPI_9: Energy Efficiency (EE)	Measures how effectively energy is utilized in operations.	EE = Output / Energy Input
	KPI_10: Water Usage Efficiency (WUE)	Evaluates the efficiency of water usage relative to the output produced.	WUE = Output / Water Input
	KPI_10: Recycling Rate (RR)	Measures the proportion of materials that are recycled relative to total waste generated.	RR= Recycled Materials / Total Waste
Stakeholder Satisfaction	KPI_11: Customer Satisfaction (CS)	Measures the level of satisfaction among the SOE's customers.	CS Score = Survey-Based Score
	KPI_12: Employee Engagement	Evaluates the engagement and satisfaction of employees.	Retention Rate = Number of Retained Employees / Total Number of Employees
	KPI_13: Community Contribution Index (CCI)	Assesses the SOE's contributions to the community relative to its total revenue.	CCIx = Community Contributions / Total Revenue

Table 1. Key Performance Indicators (KPIs) for the State-Owned Enterprise (SOE)

Methodology for Assigning Weights to Different Criteria

The AHP method determines the weights of criteria in multi-criteria decision-making models. This process organizes the evaluation criteria into a hierarchical structure of goals based on priority. Then, pairwise comparisons are made between each criterion based on a scale (1 to 9). For example, if Criterion C_1 is judged to be more important than the Criterion C_2, the pairwise comparison matrix A for two criteria is depicted as:

$$A = \begin{pmatrix} 1 & 3 \\ \frac{1}{3} & 1 \end{pmatrix} \qquad (10)$$

Where $A_{12}=3$ indicates that C_1 is three times more important than C_2, and $A_{21}=1/3$ indicates that C_2 is one-third as important as C_1. The pairwise comparison matrix is then used to calculate the relative weights of the criteria by finding the principal eigenvector w of the matrix A:

$$A \cdot w = \lambda_{\max} \cdot w \qquad (11)$$

Where $\lambda_{\max}$ is the largest eigenvalue of the matrix A. A Consistency Ratio (CR) is calculated to ensure the pairwise comparisons' consistency. The Consistency Index (CI) is determined as follows:

$$CI = \frac{\lambda_{\max} - n}{n-1} \qquad (12)$$

Where n is the number of criteria. The CR is then computed by dividing the Cl by the Random Index (RI):

$$CR = \frac{CI}{RI} \qquad (13)$$

A CR value of 0.1 or less is considered acceptable. In addition to AHP, expert surveys and the Delphi method are employed to fine-tune the weight assignments. The Delphi method is an iterative process that involves a panel of experts who provide their input through multiple rounds of surveys.
1. Round 1: experts assign initial weights to the criteria based on their experience and understanding of the evaluation context. These weights are aggregated to form an initial weight vector.
2. Round 2: the experts will reassess their weight assignments using feedback from the first round. This process is repeated until the weights converge to stable values.
3. Final Weight Vector: The final weight vector $W=\{w_1, w_2, ..., w_m\}$ is derived by averaging the weights from the final round of the Delphi process. These weights are then normalized to ensure that their sum equals 1:

$$\sum_{i=1}^{m} w_i = 1 \qquad (14)$$

The weights obtained from AHP and expert surveys are integrated into the FCE model by multiplying them with the membership values for each criterion and sub-criterion. The weighted scores are then aggregated to generate the overall evaluation score.

Fuzzy Evaluation Method: Steps to Aggregate and Defuzzify the Input Data
The FCE method involves the following steps: constructing the fuzzy evaluation matrix, aggregating the fuzzy evaluations, and finally, demulsifying the aggregated results to obtain a crisp score.
Step 1: for each criterion C_i and sub-criteria S_{ij}, a fuzzy evaluation matrix R_i is constructed. The fuzzy evaluation matrix R_i is expressed as:

$$R_i = \begin{pmatrix} \mu_{S_{i1}}(E_1) & \mu_{S_{i1}}(E_2) & \cdots & \mu_{S_{i1}}(E_k) \\ \mu_{S_{i2}}(E_1) & \mu_{S_{i2}}(E_2) & \cdots & \mu_{S_{i2}}(E_k) \\ \vdots & \vdots & \ddots & \vdots \\ \mu_{S_{in_i}}(E_1) & \mu_{S_{in_i}}(E_2) & \cdots & \mu_{S_{iin_i}}(E_k) \end{pmatrix} \qquad (15)$$

Where $\mu_{(S_{ij})}(E_k)$ represents the membership degree of the sub-criterion S_{ij} to the linguistic term E_k.

Step 2: the fuzzy evaluations of the sub-criteria are aggregated to obtain a fuzzy evaluation vector B_i for each criterion C_i. The fuzzy evaluation vector B_i is calculated as follows:

$$B_i = W_i \cdot R_i = (w_{i1} \quad w_{i2} \quad \cdots \quad w_{in_i}) \cdot \begin{pmatrix} \mu_{S_{i1}}(E_1) & \mu_{S_{i1}}(E_2) & \cdots & \mu_{S_{i1}}(E_k) \\ \mu_{S_{i2}}(E_1) & \mu_{S_{i2}}(E_2) & \cdots & \mu_{S_{i2}}(E_k) \\ \vdots & \vdots & \ddots & \vdots \\ \mu_{S_{in_i}}(E_1) & \mu_{S_{in_i}}(E_2) & \cdots & \mu_{S_{in_i}}(E_k) \end{pmatrix} \qquad (16)$$

$$B_i = \{\mu_{C_i}(E_1), \mu_{C_i}(E_2), ..., \mu_{C_i}(E_k)\} \qquad (17)$$

Where each element $\mu_{C_i} E_k$ represents the aggregated membership degree of criterion C_i to the linguistic term E_k.
Step 3: the overall fuzzy evaluation of the SOE is obtained by aggregating the fuzzy evaluation vectors B_i of

all criteria C_i. This aggregation uses the weight vector $W=\{w_1,w_2,...,w_m\}$ assigned to the criteria. The overall fuzzy evaluation vector B_G is calculated as:

$$B_G = W \cdot \begin{pmatrix} B_1 \\ B_2 \\ \vdots \\ B_m \end{pmatrix} \tag{18}$$

$$B_G = \{\mu_G(E_1), \mu_G(E_2), ..., \mu_G(E_k)\} \tag{19}$$

Here each element $\mu_G E_k$ represents the overall membership degree of the SOE to the linguistic term E_k

Step 4: the most commonly used defuzzification method is the centroid (center of gravity) method, which calculates the crisp score G_{crisp} as follows:

$$G_{crisp} = \frac{\sum_{k=1}^{k} \mu_G(E_k) \cdot E_k}{\sum_{k=1}^{k} \mu_G(E_k)} \tag{20}$$

Where, E_k represents the numerical value corresponding to the linguistic term E_k (e.g., Poor =1, Fair =2, Good =3, Excellent =4), and $\mu_G E_k$ is the membership degree of the SOE to the term E_k.

RESULTS

Data Collection

Table 2. data type and the source of data			
Data Category	**Data Type**	**Details/Variables**	**Source of Data**
Financial Performance	Quantitative	Profitability (ROA, ROE, NPM), Liquidity (Current Ratio, Quick Ratio), Leverage (Debt-to-Equity Ratio, Debt-to-Assets Ratio)	Annual Reports, Financial Statements, Stock Exchanges (e.g., SSE, HKEX)
Operational Efficiency	Quantitative	Asset Utilization (Asset Turnover Ratio, Inventory Turnover Ratio), Cost Efficiency (Operating Expense Ratio, Cost-to-Income Ratio)	Annual Reports, Corporate Filings, Investor Relations Portals
Innovation Capacity	Quantitative	R&D Intensity (R&D Expenditure/Total Revenue), Patent Activity (Number of Patents, Patent Intensity)	Patent Databases (e.g., CNIPA), R&D Reports, Industry Reports
Sustainability Practices	Quantitative/ Qualitative	Environmental Impact (CF, EE), Sustainable Resource Use (WUE, RR)	Sustainability Reports, CSR Reports, Government and Regulatory Databases
Stakeholder Satisfaction	Qualitative	Customer Satisfaction (Survey Scores, NPS), Employee Engagement (Engagement Index, Retention Rate)	Survey Data, Expert Interviews, Employee and Customer Surveys
Strategic Importance	Qualitative	Strategic initiatives related to national interests, involvement in critical infrastructure projects	Government and Regulatory Databases (e.g., SASAC), Industry Reports
Corporate Governance	Qualitative/ Quantitative	Ownership Structure, Governance Practices, Board Composition	Corporate Filings, Stock Exchange Disclosures, Government Databases
Regulatory Compliance	Qualitative	Compliance Records, Fines and Penalties, Regulatory Ratings	Regulatory Databases (e.g., CSRC), Government Reports
Corporate Social Responsibility (CSR)	Qualitative	Community Impact (CCI), CSR Initiatives, Charitable Contributions	CSR Reports, Sustainability Reports, News Media
Market Position	Quantitative/ Qualitative	Market Share, Competitive Positioning, Industry Benchmarking	Industry Reports, Market Research Firms (e.g., CEIS, CASS)
Macroeconomic Indicators	Quantitative	GDP Contribution, Sector Growth Rate, Economic Indicators related to SOE sectors	National Bureau of Statistics of China (NBSC), Government Reports
Recent Developments	Qualitative	Strategic Decisions, Mergers & Acquisitions, Policy Changes	News Media (e.g., Xinhua, China Daily, Reuters), Press Releases

The proposed model was evaluated and analysed using the following metrics from the collected data. Also, in this study, data related to the performance of SOE operating in China were gathered from multiple government sources. The primary data sources include financial reports, annual statements, Corporate Filings, Regulatory Disclosures, Survey data, and Industry reports. The following table 2 presents the types of data collected and its source.

Consistency Ratio (CR)

The CR evaluates the reliability of the weight assignments derived through the AHP. A CR value of 0,1 or less is generally considered acceptable, indicating that the weight assignment process is consistent. Table 3 and figure 1 displays the consistency ratio of the proposed model.

Criterion	Number of Sub-Criteria	Largest Eigenvalue (λ max)	CI	RI	CR	Acceptable (Yes/No)
Financial Performance	4	4,12	0,040	0,90	0,044	Yes
Operational Efficiency	3	3,05	0,025	0,58	0,043	Yes
Innovation Capacity	4	4,08	0,027	0,90	0,030	Yes
Sustainability Practices	3	3,07	0,035	0,58	0,060	Yes
Stakeholder Satisfaction	4	4,15	0,050	0,90	0,056	Yes

<div align="center">Table 3. CR of different criteria</div>

Figure 1. CR analysis
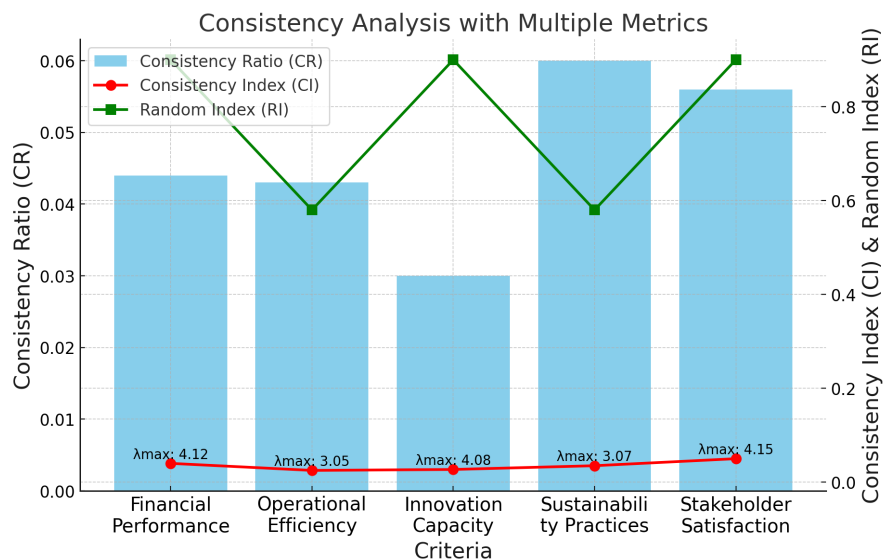
For the criterion of Financial Performance with four sub-criteria, the largest eigenvalue (λ max) was 4,12, resulting in a CI of 0,040. With a RI of 0,90, the CR is measured at 0,044. Similarly, the largest eigenvalue for Operational Efficiency with three sub-criteria was 3,05, generating a CI of 0,025. With an RI of 0,58, the CR was 0,043, confirming that the weight assignments in this criterion are consistent. Innovation Capacity, another criterion with four sub-criteria, had the largest eigenvalue of 4,08, leading to a CI of 0,027. Given the same RI of 0,90, the CR was determined to be 0,030, also falling within the acceptable range. Sustainability Practices, evaluated through three sub-criteria, exhibited a largest eigenvalue of 3,07 and a CI of 0,035. With an RI of 0,58, the resulting CR was 0,060, within acceptable limits, demonstrating consistency in the pairwise comparisons. Lastly, the Stakeholder Satisfaction criterion, which includes four sub-criteria, had the largest eigenvalue of 4,15, resulting in a CI of 0,050. With the RI set at 0,90, the CR was calculated as 0,056, confirming that the comparisons were consistent.

Sensitivity Analysis (SA)

SA measures how changes in input parameters, such as weight assignments or membership functions, impact the model's final output. Table 4 and figure 2 present the results for sensitivity. The sensitivity analysis shows that Financial Performance and Operational Efficiency are the most influential criteria, with sensitivity coefficients of 0,43 and 0,28, respectively. Innovation Capacity shows moderate sensitivity (0,20), while Sustainability Practices (0,13) and Stakeholder Satisfaction (0,10) have minimal influence, with weight variations resulting in only minor changes to the final score.

| Criterion	Original Weight	Weight Variation (%)	Performance Score Before Variation (G_{crisp})	Performance Score After Variation (G_{crisp})	Change in Performance Score	Sensitivity Coefficient
Financial Performance	0,30	+10	7,85	7,98	+0,13	0,43
Financial Performance	0,30	-10	7,85	7,72	-0,13	0,43
Operational Efficiency	0,25	+10	7,85	7,92	+0,07	0,28
Operational Efficiency	0,25	-10	7,85	7,78	-0,07	0,28
Innovation Capacity	0,20	+10	7,85	7,89	+0,04	0,20
Innovation Capacity	0,20	-10	7,85	7,81	-0,04	0,20
Sustainability Practices	0,15	+10	7,85	7,87	+0,02	0,13
Sustainability Practices	0,15	-10	7,85	7,83	-0,02	0,13
Stakeholder Satisfaction	0,10	+10	7,85	7,86	+0,01	0,10
Stakeholder Satisfaction	0,10	-10	7,85	7,84	-0,01	0,10

Table 4. Sensitivity Analysis Results
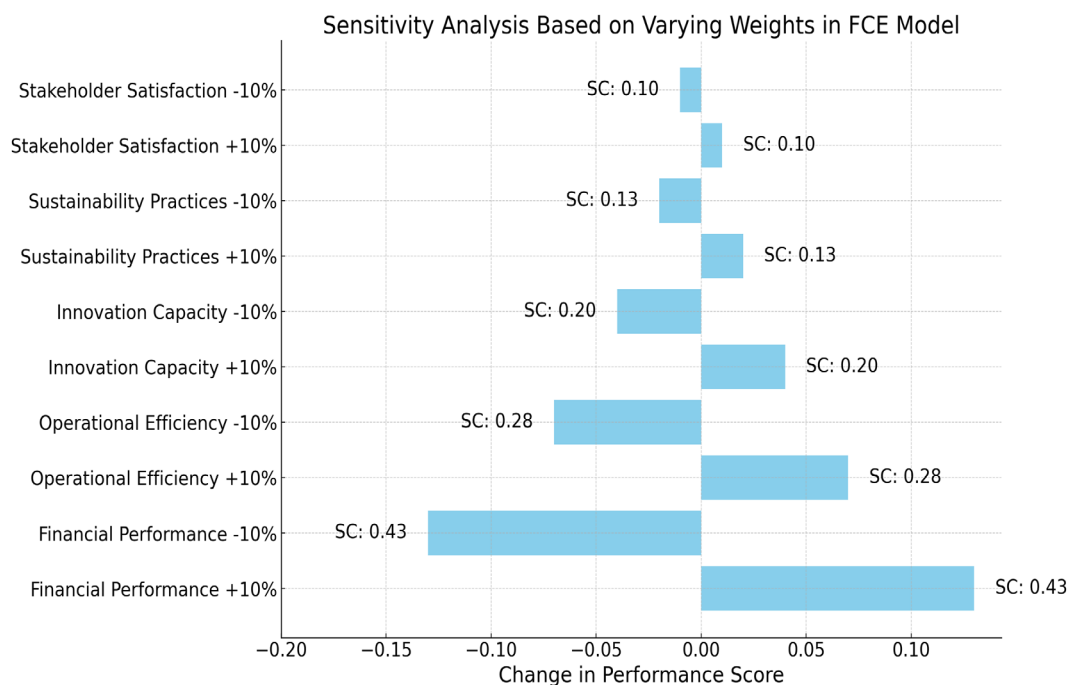
Figure 2. Sensitivity analysis

Comparative Accuracy and Predictive Validity
Comparative accuracy is measured using Mean Absolute Error (MAE)

$$MAE = \frac{1}{n}\sum_{i=1}^{n} \left| \text{ Predicted Value }_i - \text{ Actual Value }_i \right| \qquad (21)$$

A high correlation or low MAE indicates that the model accurately reflects the performance of the SOEs.

The Predictive validity is measured using Root Mean Square Error (RMSE)

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} \left(\text{ Predicted Value }_i - \text{ Actual Value }_i \right)^2} \qquad (22)$$

A low RMSE and a high R^2 value indicates strong predictive validity. The results are presented in table 5 and figure 3.

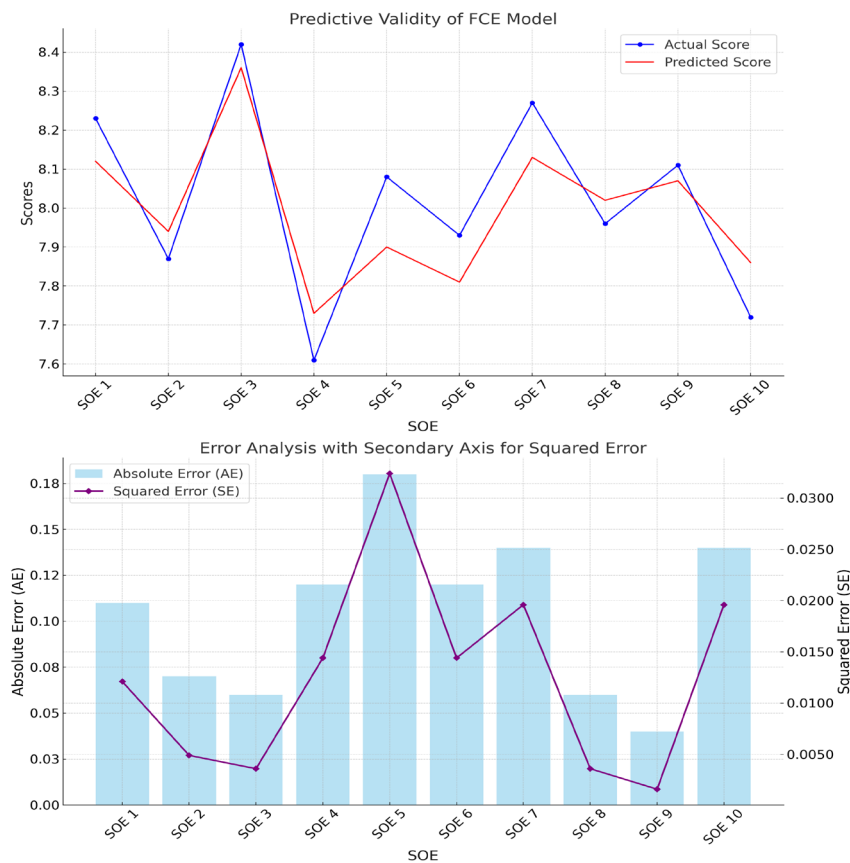| Table 5. Predictive Validity				
SOE	Actual Future Performance Score	FCE Model Predicted Score	Absolute Error (AE)	Squared Error (SE)
SOE 1	8,23	8,12	0,11	0,0121
SOE 2	7,87	7,94	0,07	0,0049
SOE 3	8,42	8,36	0,06	0,0036
SOE 4	7,61	7,73	0,12	0,0144
SOE 5	8,08	7,90	0,18	0,0324
SOE 6	7,93	7,81	0,12	0,0144
SOE 7	8,27	8,13	0,14	0,0196
SOE 8	7,96	8,02	0,06	0,0036
SOE 9	8,11	8,07	0,04	0,0016
SOE 10	7,72	7,86	0,14	0,0196

Figure 3. Predictive validity: a) Actual vs predicted, b) Absolute Error vs Squared Error

The predictive validity analysis shows that the absolute errors range between 0,04 and 0,18. SOE 5 and 10 show the highest absolute errors of 0,18 and 0,14, respectively. On the other hand, the most minor absolute error is observed for SOE 9, with a value of 0,04, which displays a close alignment between the predicted and actual scores. The squared errors also display the model's better predictive performance. The SOEs 5 and 10 have the highest squared errors (0,0324 and 0,0196), which indicate the need for refinement. The model also shows lower squared errors for SOE 3, 8, and 9 (ranging from 0,0016 to 0,0036) that reflect accurate predictions.

CONCLUSIONS

The state-owned enterprise is considered an essential driving factor in the country, as is social responsibility in many countries. Assessing the performance of such an enterprise was never easy as it involves multiple factors that must be considered, particularly all aspects of finance and society. The traditional models employed to

perform such tasks did not consider both aspects, resulting in poor assessment. The work proposed a Fuzzy Comprehensive Evaluation (FCE) model that combined quantitative and qualitative performance dimensions to handle these challenges. The fuzzy model handles the uncertainties and subjectivities inherent in evaluating these diverse criteria, and it capitalized the measures from the Analytic Hierarchy Process (AHP) and expert surveys to determine the relative importance of each criterion. The model's performance was examined in terms of multiple metrics, and the results showed that the proposed model had better evaluation capability for state-owned enterprises.

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CONFLICT OF INTEREST
The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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