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A Neutrosophic-Based Hybrid MCDM Framework Integrating OWCM and ARAS for Financial Performance Assessment and Selection under Uncertainty

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Abstract

In contemporary financial decision-making, the accurate assessment of financial performance and the selection of optimal investment opportunities are pivotal for organizational success. Multi-criteria decision-making (MCDM) methods are widely used in many different fields to address selection problems when there are numerous competing criteria and multiple alternatives. This paper introduces a novel approach that integrates the neutrosophic set, the Opinion Weight Criteria Method (OWCM) and Additive Ratio Assessment (ARAS) for a comprehensive assessment of financial performance and selection processes. The OWCM framework facilitates the aggregation of subjective opinions from diverse decision makers, allowing for the incorporation of decision makers insights and preferences into the decision-making process. By assigning weights to evaluation criteria and leveraging neutrosophic techniques, OWCM accommodates the inherent uncertainties in subjective judgments, fostering consensus-driven decision-making. Complementing OWCM, ARAS extends traditional ratio analysis methods by enabling the systematic evaluation of alternatives based on multiple criteria, enhancing the objectivity and rigor of decision-making. Through the integration of OWCM and ARAS, decision-makers gain a holistic understanding of investment opportunities, considering a wide range of qualitative and quantitative factors. Case study and comparative analysis demonstrate the practical applicability and effectiveness of the proposed approach across decision contexts. This integrated framework offers decision-makers a robust toolset for navigating complex financial landscapes and making informed investment decisions with confidence and precision.

Keywords: Financial Decision-making; MCDM; Neutrosophic Sets; Opinion Weight Criteria Method; Additive Ratio Assessment.

1 | Introduction

Over the past few years, with the continuous and rapid development of enterprise modernization and the ever-evolving nature of the global market, the capital market has undeniably put forward increasingly higher and more stringent requirements for the management level and comprehensive strength of enterprises[1]. In this theory, it is abundantly clear that the financial performance of the company plays a pivotal role, acting as a key factor in determining its overall success and manifesting itself as a vital characteristic of corporate value. The ability of the company to generate substantial profits has become an undeniable and paramount

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indicator of its potential business advantage, thereby attracting a substantial amount of attention and scrutiny from stakeholders and participants in the financial market [2, 3]

In today's complex and highly intricate financial landscape, stakeholders and market participants find themselves placing even greater emphasis on understanding and evaluating the financial status of companies, specifically honing in on the organization's profound ability to generate profits and ultimately create substantial value for its esteemed shareholders[3]. However, it is important to acknowledge the inherent challenges faced by individuals when attempting to conduct an in-depth and comprehensive analysis of a company's operating and financial status. These challenges primarily consist of the prolonged duration of time required, the formidable levels of risk involved, the inherent difficulty in acquiring vast amounts of pertinent information, and the sheer magnitude of financial data which encompasses essential elements such as historical and current profit data, operational data, cost-related data, financial reports, and financial statement data [4, 5].

Efficiently gathering and compiling such a vast array of crucial financial information and factor data akin to piece together a more all-encompassing and accurate financial analysis of a company's performance has become a particularly arduous and complex task in recent times[6]. The process involves navigating through a myriad of challenges and obstacles, often leading to an increased degree of uncertainty. Notably, one must contend with the fact that financial reporting information is often diluted and stripped of its real-time nature, thus inherently limiting its accuracy and potential to be quantified with precision[7].

Due to the intensifying competition in financial markets and the profound impact of the global financial crisis that occurred in 2008, the evaluation of the financial performance of enterprises has emerged as a highly active field of research[8]. This assessment plays a pivotal role in the decision-making processes of various stakeholders, including shareholders, investors, and potential creditors. A crucial aspect towards achieving an accurate evaluation lies in the development of an optimal method that will serve as the foundation for a sound decision model[9].

Quantitative analysis methods have consistently proven to be more objective and effective when compared to qualitative approaches. However, the real-world data is plagued by a high level of uncertainty, resulting from the continuous flow of time and the complexities that arise from the external environment[10]. Consequently, the assessment of financial performance in the midst of uncertain decision information becomes not only crucial but also demands the implementation of suitable approaches to address this challenge[11].

Different technologies have been introduced with the purpose of efficiently and effectively handling multiple attribute decision making[12]. Our present research work develops a new method, the Integrated Opinion Weight Criteria Methodology, which is justified by a deep theoretical approach and a pragmatic approach[13]. The proposed financial performance assessment method solves the problem of selecting the best financial criterion by evaluating not only the financial performance, but also the Dividend Yield and the Debt-To-Equity ratio, which are the major objectives of any investment and financial DM.

Most evaluation criteria often require opinions of different decision makers (DMs). In multiple attribute decision making, these terms lead to handling sets of weighting criteria and a large amount of data, which should be gathered objectively and within a limited timeframe[14]. This is an urgent call for proposals that should be analyzed, developed, introduced, and tested to control and balance such financial performance assessments.

The paper sequence is as follows: Section 2 introduces the concepts, operation formulas of T2NNs. Section 3 the proposed model is presented. Section4 provides a description of case study and results of proposed model. Section 5 provides Comparative analysis. Section 6 summarizes our conclusions.

2 | Preliminaries

In this section, we will illustrate neutrosophic sets, single valued neutrosophic sets, type-2 neutrosophic numbers T2NN important definitions and type 2 neutrosophic numbers operations.

2.1 | Type-1 Neutrosophic Set

Definition 1: Let Ü serve as the initial universe of discourse, with a generic element ü in Ü. The neutrosophic set is represented by the object displaying its form.

$$\ddot{G} = \{\langle ü, \sigma_{\ddot{G}}(ü), \theta_{\ddot{G}}(ü), \delta_{\ddot{G}}(ü)\rangle \mid ü \in Ü\},$$

where, the functions $\sigma, \theta, \delta: Ü \to]^{-}0, 1^{+}[$ define, respectively, the degree of Truth (or membership), the degree of indeterminacy, and the degree of Falsehood (or non-membership) of the element $ü \in Ü$ to the set $\ddot{G}$ with the constraint $0^{-} \leq \sigma_{\ddot{G}}(ü) + \theta_{\ddot{G}}(ü) + \delta_{\ddot{G}}(ü) \leq 3^{+}$. There are no limits on the $\sigma_{\ddot{G}}(ü), \theta_{\ddot{G}}(ü)$, and $\delta_{\ddot{G}}(ü)$ sum.

2.2 | Type-2 Neutrosophic Set

A T2NN set $\ddot{G}$ in $\ddot{R}$ is defined by:$\ddot{G} = \{\langle ü, \sigma_{\ddot{G}}(ü), \theta_{\ddot{G}}(ü), \delta_{\ddot{G}}(ü)\rangle \mid ü \in Ü\}$, where $\sigma_{\ddot{G}}(ü): \ddot{G} \to \sigma[0,1], \theta_{\ddot{G}}(ü): \ddot{G} \to \theta[0,1]$, and $\delta_{\breve{A}}(ü): \ddot{G} \to \delta[0,1]$. The elements of the T2NN set can be shown as $\sigma_{\ddot{G}}(ü) = \left(\sigma_{\sigma_{\ddot{G}}}(ü), \sigma_{\theta_{\ddot{G}}}(ü), \sigma_{\delta_{\ddot{G}}}(ü)\right), \theta_{\ddot{G}}(ü) = \left(\theta_{\sigma_{\ddot{G}}}(ü), \theta_{\theta_{\ddot{G}}}(ü), \theta_{\delta_{\ddot{G}}}(ü)\right)$, and $\delta_{\ddot{G}}(ü) = \left(\delta_{\sigma_{\ddot{G}}}(ü), \delta_{\theta_{\ddot{G}}}(ü), \delta_{\delta_{\ddot{G}}}(ü)\right)$.

$\sigma_{\ddot{G}}(ü) = \left(\sigma^1_{\ddot{G}}(ü), \sigma^2_{\ddot{G}}(ü), \sigma^3_{\ddot{G}}(ü)\right), \theta_{\ddot{G}}(ü) = \left(\theta^1_{\ddot{G}}(ü), \theta^2_{\ddot{G}}(ü), \theta^3_{\ddot{G}}(ü)\right)$, and $\delta_{\ddot{G}}(ü) = \left(\delta^1_{\ddot{G}}(ü), \delta^2_{\ddot{G}}(ü), \delta^3_{\ddot{G}}(ü)\right)$, where $\sigma_{\ddot{G}}(ü), \theta_{\ddot{G}}(ü)$ and $\delta_{\ddot{G}}(ü)$ are $\ddot{G} \to [0,1]$. For each $ü \in \ddot{R}: 0 \leq \sigma^1_{\ddot{G}}(ü) + \theta^1_{\ddot{G}}(ü) + \delta^1_{\ddot{G}}(ü) \leq 3$ are stated.

Definition 2:

Let $\ddot{G}_1 = \left\langle\left(\sigma_{\sigma_{\ddot{G}1}}(ü), \sigma_{¥_{\ddot{G}1}}(ü), \sigma_{\delta_{\ddot{G}1}}(ü)\right), \left(\theta_{\sigma_{\ddot{G}1}}(ü), \theta_{\theta_{\ddot{G}1}}(ü), \theta_{\delta_{\ddot{G}1}}(ü)\right), \left(£_{\sigma_{\ddot{G}1}}(ü), \delta_{\theta_{\ddot{G}1}}(ü), \delta_{\delta_{\ddot{G}1}}(ü)\right)\right\rangle$ and $\ddot{G}_2 = \left\langle\left(\sigma_{\sigma_{\ddot{G}2}}(ü), \sigma_{\theta_{\ddot{G}2}}(ü), \sigma_{\delta_{\ddot{G}2}}(ü)\right), \left(\theta_{\sigma_{\ddot{G}2}}(ü), \theta_{\theta_{\ddot{G}2}}(ü), \theta_{\delta_{\ddot{G}2}}(ü)\right), \left(\delta_{\sigma_{\ddot{G}2}}(ü), \delta_{\theta_{\ddot{G}2}}(ü), \delta_{\delta_{\ddot{G}2}}(ü)\right)\right\rangle$ be T2NNs in the set of real numbers. Some standard operations for T2NNs can be expressed as follows:

$$\begin{aligned}\ddot{G}_1 \oplus \ddot{G}_2 = \Big\langle\Big(&\sigma_{\sigma_{\ddot{G}1}}(ü) + \sigma_{\sigma_{\ddot{G}2}}(ü) - \sigma_{\sigma_{\ddot{G}1}}(ü) \cdot \sigma_{\sigma_{\ddot{G}2}}(ü), \sigma_{\theta_{\ddot{G}1}}(ü) + \sigma_{\theta_{\ddot{G}2}}(ü) - \sigma_{\theta_{\ddot{G}1}}(ü) \\ &\cdot \sigma_{\theta_{\ddot{G}2}}(ü), \sigma_{\delta_{\ddot{G}1}}(ü) + \sigma_{\delta_{\ddot{G}2}}(ü) - \sigma_{\delta_{\ddot{G}1}}(ü) \cdot \sigma_{\delta_{\ddot{G}2}}(ü)\Big), \Big(\theta_{\sigma_{\ddot{G}1}}(ü) \cdot \theta_{\sigma_{\ddot{G}2}}(ü), \theta_{\theta_{\ddot{G}1}}(ü) \\ &\cdot \theta_{\theta_{\ddot{G}2}}(ü), \theta_{\delta_{\ddot{G}1}}(ü) \cdot \theta_{\delta_{\ddot{G}2}}(ü)\Big), \Big(\delta_{\sigma_{\ddot{G}1}}(ü) \cdot \delta_{\sigma_{\ddot{G}2}}(ü), \delta_{\theta_{\ddot{G}1}}(ü) \cdot \delta_{\theta_{\ddot{G}2}}(ü), \delta_{\delta_{\ddot{G}1}}(ü) \\ &\cdot \delta_{\delta_{\ddot{G}2}}(ü)\Big)\Big\rangle\end{aligned} \tag{1}$$

$$\begin{aligned}\ddot{G}_1 \otimes \ddot{G}_2 = \Big\langle\Big(&\sigma_{\sigma_{\ddot{G}1}}(ü) \cdot \sigma_{\sigma_{\ddot{G}2}}(ü), (ü), \sigma_{\theta_{\ddot{G}1}}(ü) \cdot \sigma_{\theta_{\ddot{G}2}}(ü), \sigma_{\delta_{\ddot{G}1}}(ü) \cdot \sigma_{\delta_{\ddot{G}2}}(ü)\Big), \Big(\theta_{\delta_{\ddot{G}1}}(ü) \\ &+ \theta_{\delta_{\ddot{G}2}}(ü) - \theta_{\delta_{\ddot{G}1}}(ü) \cdot \theta_{\delta_{\ddot{G}2}}(ü)\Big), \Big(\theta_{\theta_{\ddot{G}1}}(ü) + \theta_{\theta_{\ddot{G}2}}(ü) - \theta_{\theta_{\ddot{G}1}}(ü) \cdot \theta_{\theta_{\ddot{G}2}}(ü)\Big), \Big(\theta_{\delta_{\ddot{G}1}}(ü) \\ &+ \theta_{\delta_{\ddot{G}2}}(ü) - \theta_{\delta_{\ddot{G}1}}(ü) \cdot \theta_{\delta_{\ddot{G}2}}(ü)\Big), \Big(\delta_{\sigma_{\ddot{G}1}}(ü) + \delta_{\sigma_{\ddot{G}2}}(ü) - \delta_{\sigma_{\ddot{G}1}}(ü) \cdot \delta_{\sigma_{\ddot{G}2}}(ü)\Big), \Big(\delta_{\theta_{\ddot{G}1}}(ü) \\ &+ \delta_{\theta_{\ddot{G}2}}(ü) - \delta_{\theta_{\ddot{G}1}}(ü) \cdot \delta_{\theta_{\ddot{G}2}}(ü)\Big), \Big(\delta_{\delta_{\ddot{G}1}}(ü) + \delta_{\delta_{\ddot{G}2}}(ü) - \delta_{\delta_{\ddot{G}1}}(ü) \cdot \delta_{\delta_{\ddot{G}2}}(ü)\Big)\Big\rangle\end{aligned} \tag{2}$$

$$
\text{Þ}\ddot{G} = \left\langle \left(1-\left(1-\sigma_{\sigma_{\ddot{G}}}(\ddot{u})\right)^{Þ}, 1-\left(1-\sigma_{\theta_{\ddot{G}}}(\ddot{u})\right)^{Þ}, 1-\left(1-\sigma_{£_{\ddot{G}}}(\ddot{u})\right)^{Þ}\right), \left(\left(\theta_{\sigma_{\ddot{G}}}(\ddot{u})\right)^{Þ}, \left(\theta_{\theta_{\ddot{G}}}(\ddot{u})\right)^{Þ}, \left(\theta_{\delta_{\ddot{G}}}(\ddot{u})\right)^{Þ}\right), \left(\left(\delta_{\sigma_{\ddot{G}}}(\ddot{u})\right)^{Þ}, \left(\delta_{\theta_{\ddot{G}}}(\ddot{u})\right)^{Þ}, \left(\delta_{\delta_{\ddot{G}}}(\ddot{u})\right)^{Þ}\right) \right\rangle \tag{3}
$$

where $Þ > 0$.

$$
\ddot{G}^{Þ} = \left\langle \left(\left(\sigma_{\sigma_{\ddot{G}}}(\ddot{u})\right)^{Þ}, \left(\sigma_{\theta_{\ddot{G}}}(\ddot{u})\right)^{Þ}, \left(\sigma_{\delta_{\ddot{G}}}(\ddot{u})\right)^{Þ}\right), \left(1-\left(1-\theta_{\sigma_{\ddot{G}}}(\ddot{u})\right)^{Þ}, 1-\left(1-\theta_{\theta_{\ddot{G}}}(\ddot{u})\right)^{Þ}, 1-\left(1-\theta_{\delta_{\ddot{G}}}(\ddot{u})\right)^{Þ}\right), \left(1-\left(1-\delta_{\sigma_{\ddot{G}}}(\ddot{u})\right)^{Þ}, 1-\left(1-\delta_{\theta_{\ddot{G}}}(\ddot{u})\right)^{Þ}, 1-\left(1-\delta_{\delta_{\ddot{G}}}(\ddot{u})\right)^{Þ}\right) \right\rangle \tag{4}
$$

Where, $Þ > 0$.

Definition 3: The score function of $\ddot{G}1, S(\ddot{G}1)$, is shown by:

$$
S(\ddot{G}1) = \frac{1}{12}\left\langle 8 + \left(\sigma_{\sigma_{\ddot{G}1}}(\ddot{u}) + 2\left(\sigma_{\theta_{\ddot{G}1}}(\ddot{u})\right) + \sigma_{\delta_{\ddot{G}1}}(\ddot{u})\right) - \left(\theta_{\sigma_{\ddot{G}1}}(\ddot{u}) + 2\left(\theta_{\theta_{\ddot{G}1}}(\ddot{u})\right) + \theta_{\delta_{\ddot{G}1}}(\ddot{u})\right) - \left(\delta_{\sigma_{\ddot{G}1}}(\ddot{u}) + 2\left(\delta_{\theta_{\ddot{G}1}}(\ddot{u})\right) + \delta_{\delta_{\ddot{G}1}}(\ddot{u})\right)\right\rangle \tag{5}
$$

Definition 4: The accuracy function of $\ddot{G}1$, $A(\ddot{G}1)$, is shown by:

$$
A(\ddot{G}1) = \frac{1}{4}\left\langle 8 + \left(\sigma_{\sigma_{\ddot{G}1}}(\ddot{u}) + 2\left(\sigma_{\theta_{\ddot{G}1}}(\ddot{u})\right) + \sigma_{\delta_{\ddot{G}1}}(\ddot{u})\right) - \left(\delta_{\sigma_{\ddot{G}1}}(\ddot{u}) + 2\left(\delta_{\theta_{\ddot{G}1}}(\ddot{u})\right) + \delta_{\delta_{\ddot{G}1}}(\ddot{u})\right)\right\rangle \tag{6}
$$

Definition 5: suppose $\bar{S}(\ddot{G}_i)$ and $\bar{A}(\ddot{G}_i)$ refer to the score and accuracy functions for the T2NNs $\ddot{G}_i(i = 1,2)$, respectively. The following properties are valid:

If $\bar{S}(\ddot{G}_1) > \bar{S}(\ddot{G}_2)$, then $\ddot{G}_1 > \ddot{G}_2$,

If $\bar{S}(\ddot{G}_1) = \bar{S}(\ddot{G}_2)$ and $\bar{A}(\ddot{G}_1) > \bar{A}(\ddot{G}_2)$, then $\ddot{G}_1 > \ddot{G}_2$,

If $\bar{S}(\ddot{G}_1) = \bar{S}(\ddot{G}_2)$ and $\bar{A}(\ddot{G}_1) = \bar{A}(\ddot{G}_2)$, then $\ddot{G}_1 = \ddot{G}_2$.

Definition 6:[12] Let $\ddot{G}_1 = ((\sigma_1, \sigma_2, \sigma_3), (\theta_1, \theta_2, \theta_3), (\delta_1, \delta_2, \delta_3))$ and $\ddot{G}_2 = ((\tilde{T}_1, \tilde{T}_2, \tilde{T}_3), (\tilde{I}_1, \tilde{I}_2, \tilde{I}_3), (\tilde{F}_1, \tilde{F}_2, \tilde{F}_3))$ be T2NNs. The distance measure $d(\ddot{G}_1, \ddot{G}_2)$ between $\ddot{G}_1$ and $\ddot{G}_2$ can be expressed by:

$$
d(\ddot{G}_1, \ddot{G}_2) = 1 - \frac{\sum_{i=1}^{3} \sigma_i \tilde{T}_i + \sum_{i=1}^{3} \theta_i \tilde{I}_i + \sum_{i=1}^{3} \delta_i \tilde{F}_i}{\left(\sum_{i=1}^{3} (\sigma_i)^2 + \sum_{i=1}^{3} (\theta_i)^2 + \sum_{i=1}^{3} (\delta_i)^2\right) \times \left(\sum_{i=1}^{3} (\tilde{T}_i)^2 + \sum_{i=1}^{3} (\tilde{I}_i)^2 + \sum_{i=1}^{3} (\tilde{F}_i)^2\right)} \tag{7}
$$

3 | Proposed Framework

we describe the details of Neutrosophic Multi-Criteria Decision-Making Model for Evaluating and Selecting Digital Twin Applications According to Lean Six Sigma philosophy, as shown in Figure 1. This section is divided into three subsections: (1) type 2 neutrosophic sets steps, (2) weight determination by Opinion Weight Criteria Method (OWCM) steps, (3) Evaluation steps according to Additive ratio assessment (ARAS)method.

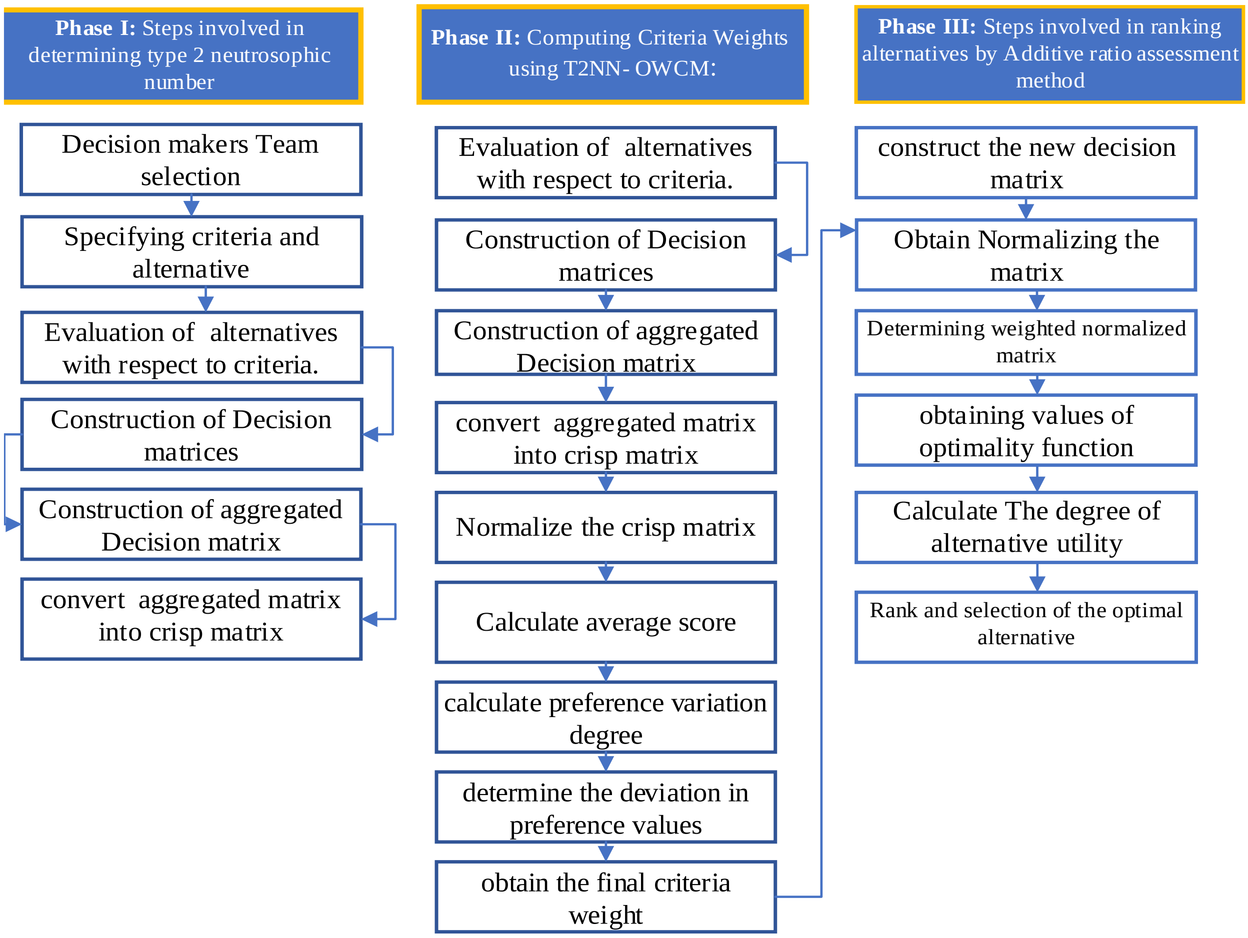

Figure 1. Proposed model.

3.1 | Phase I Steps Involved in Determining Type 2 Neutrosophic Number

Step 1: Definition of experts group who are relevant to the problem domain.

Step 2: specifying criteria and alternatives appropriate for the problem.

Step 3: Assess alternatives based on each criterion considering the judgement of experts group by utilizing Table 1.

Step4: construct the decision matrix to gather the judgement of experts group based on T2NN as outlined.

The fundamental problem is introduced as selecting one alternative from n alternatives ($\tilde{A}_i$, i = 1, 2, ⋯, y), which we assess and contrast against the remaining alternatives using m criteria ($\tilde{C}_j$,j = 1, 2, ⋯ , z)

$$\hat{X}^K = \begin{array}{c} \\ \tilde{A}_1 \\ \vdots \\ \tilde{A}_i \\ \vdots \\ \tilde{A}_y \end{array} \begin{array}{c} \begin{array}{ccc} \tilde{C}_1 & \tilde{C}_j & \tilde{C}_z \end{array} \\ \left(\begin{array}{ccccc} \hat{x}^K{}_{11} & \cdots & \hat{x}^K{}_{1j} & \cdots & \hat{x}^K{}_{1z} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}^K{}_{i1} & \cdots & \hat{x}^K{}_{ij} & \cdots & \hat{x}^K{}_{iz} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}^K{}_{y1} & \cdots & \hat{x}^K{}_{yj} & \cdots & \hat{x}^K{}_{yz} \end{array} \right) \end{array}$$

Where $\hat{x}^K{}_{ij}$ is expert k assessment of an ith alternative according to jth criterion.

Step 5: obtain crisp values decision matrices by utilizing the score function, as outlined in Eq. (5), to change the T2NN decision matrices obtained from each expert to single values decision matrices.

Step 6: aggregate all experts decision matrices to construct the aggregated decision matrix the aggregated x_{ij} is achieved by Eq. (8).

$$\hat{x}_{ij} = \frac{\sum_{K=1}^{K} k_{ij}}{K} \tag{8}$$

The aggregated decision matrix is constructed by calculating the mathematical mean for each expert's assessment as follow.

$$\hat{X} = \begin{pmatrix} \hat{x}_{11} \cdots \hat{x}_{1j} \cdots \hat{x}_{1z} \\ \vdots \quad \ddots \quad \vdots \quad \ddots \quad \vdots \\ \hat{x}_{i1} \cdots \hat{x}_{ij} \cdots \hat{x}_{iz} \\ \vdots \quad \ddots \quad \vdots \quad \ddots \quad \vdots \\ \hat{x}_{y1} \cdots \hat{x}_{nj} \cdots \hat{x}_{yz} \end{pmatrix}$$

Table 1: T2NN Sets for criteria assessment.

Linguistic terms	CODE	T2NN sets
Very Bad	VB	⟨(0.20,0.20,0.10), (0.65, 0.80, 0.85), (0.45,0.80,0.70)⟩
Bad	B	⟨(0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65)⟩
Medium Bad	MB	⟨(0.50,0.30,0.50)(0.50,0.35,0.45), (0.45,0.30,0.60)⟩
Medium	M	⟨(0.40,0.45,050). (0.40,0.45,0.50), (0.35,0.40,0.45)⟩
Medium Good	MG	⟨(0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15)⟩
Good	G	⟨(0.70,0.75,0.30), (0.15,0.20,0.25), (0.10,0.15,0.20)⟩
Very Good	VG	⟨(0.95,0.90, 0.95), (0.10,0.10,0.05), (0.05,0.05,0.05)⟩

3.2 | Phase II Computing Criteria Weights using T2NN- OWCM

Opinion Weight Criteria Method(OWCM) was proposed by Mandil et al. [13] in 2023. OWCM considered the objective and subjective weighing in the calculation of criteria weights. OWCM eliminate inconsistencies during the weight determination according to decision maker's preferences.

Step 1: construct decision matrices based on number of experts that assessing alternatives according to criteria, by utilizing T2NN scale shown in Table 2. Then apply Eq.(5) to obtain crisp decision matrices.

Table 2. T2NN scale for relative importance of each criterion.

Linguistic term	CODE	T2NNS
Weakly important	WI	⟨(0.20,0.20,0.10), (0.65, 0.80, 0.85), (0.45,0.80,0.70)⟩
Equal important	EL	⟨(0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65)⟩
Strong important	SI	⟨(0.50,0.30,0.50)(0.50,0.35,0.45), (0.45,0.30,0.60)⟩
Very strongly important	VSI	⟨(0.40,0.45,050). (0.40,0.45,0.50), (0.35,0.40,0.45)⟩
Absolutely important	AI	⟨(0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15)⟩

Step 2: aggregate the crisp decision matrices obtained from all experts to construct aggregated crisp decision matrix using Eq. (8).

Step 3: Normalize the aggregated crisp decision matrix by utilizing Eq. (9):

$$\bar{R}_{ij} = \frac{\hat{x}_{ij}}{\hat{x}_j^{max}} \tag{9}$$

Step 4: Calculate the average score of the normalized aggregated decision matrix. as Eq. (10):

$$N_j = \frac{\sum_{i=1}^{y} \bar{R}_{ij}}{y} \tag{10}$$

Step 5: calculate preference variation degree as Eq. (11)

$$P_j = \sum_{i=1}^{y} (\bar{R}_{ij} - N_j)^2 \tag{11}$$

Where P_j denote each criteria's preference variation.

Step 6: determine calculate the deviation in preference values as Eq.

$$D_j = 1 - P_j$$

Step 7: obtain the final criteria weight by using the following Eq.(12)

$$W_j = \frac{D_j}{\sum_{i=1}^{z} D_j} \tag{12}$$

3.3 | Phase III Steps Involved in Ranking Alternatives by Additive Ratio Assessment Method

Zavadskas and Turskis introduced ARAS firstly in 2010, In ARAS The relative efficiency of a feasible alternative can be determined by the utility function value, which is directly influenced by the relative impact of values and weights of the main criteria evaluated [15].

Step 1: Begin with the aggregated decision matrix constructed in Phase I.

Step 2: Calculate the optimal value for each criterion as Eqs. (13) and (14)

$$\hat{x}_{0j} = \max_i \hat{x}_{ij}; \mathit{if\ criterion\ is\ benefit} \tag{13}$$

$$\hat{x}_{0j} = \min_i \hat{x}_{ij}; \mathit{if\ criterion\ is\ cost} \tag{14}$$

Then, we construct the decision matrix as follow

$$\hat{X} = \begin{pmatrix} \hat{x}_{01} \cdots \hat{x}_{0j} \cdots \hat{x}_{0z} \\ \vdots \quad \ddots \quad \vdots \quad \ddots \quad \vdots \\ \hat{x}_{11} \cdots \hat{x}_{1j} \cdots \hat{x}_{1z} \\ \vdots \quad \ddots \quad \vdots \quad \ddots \quad \vdots \\ \hat{x}_{i1} \cdots \hat{x}_{ij} \cdots \hat{x}_{iz} \\ \vdots \quad \ddots \quad \vdots \quad \ddots \quad \vdots \\ \hat{x}_{y1} \cdots \hat{x}_{nj} \cdots \hat{x}_{yz} \end{pmatrix}$$

Where $\hat{x}_{01}$ is the optimal value for first criterion

Step2: Obtain normalized decision matrix values as the following Eqs. (15) and (16)

The criteria, whose type is beneficial, are normalized as follows:

$$r_{ij} = \frac{\hat{x}_{ij}}{\sum_{i=1}^{y} \hat{x}_{ij}} \tag{15}$$

The criteria, whose type is nonbeneficial, A two-stage procedure is used to normalize them as follows:

$$\dot{x}_{ij} = \frac{1}{\hat{x}_{ij}}; r_{ij} = \frac{\dot{x}_{ij}}{\sum_{i=0}^{y} \dot{x}_{ij}} \tag{16}$$

Step3: Build weighted normalized decision matrix as Eq. (17)

$$n_{ij} = r_{ij} \cdot w_j \tag{17}$$

Where n_{ij} denote the weighted normalized value at ith alternative and jth criterion.

Step4: Obtaining values of optimality function through Eq. (18)

$$\tilde{S}_i = \sum_{j=1}^{z} n_{ij}\ ;\ i = 0, \cdots, y \tag{18}$$

where $\tilde{S}_i$ is the value of optimality function of i alternative

Step5: Calculate The degree of alternative utility ($\ddot{U}$) by Comparing the analyzed variant with the ideally best one $\tilde{S}_0$ using Eq. (19), which determines its rank.

$$\ddot{U}_j = \left[\frac{S_i}{S_0}\right] \tag{19}$$

It is clear that the degree of alternative utility values is in $[0,1]$ interval. The alternative with the highest final value of $\ddot{U}$ is the best one.

4 | Case Study

REENERGY Company, a multinational corporation operating in the renewable energy sector, is planning to expand its portfolio by acquiring a solar energy company. With a strategic focus on sustainability and clean energy initiatives, the Company aims to identify the best company that aligns with its long-term growth objectives and enhances its market position in the renewable energy industry. The management team has identified 7 potential companies and needs to conduct a thorough financial performance evaluation to select the most suitable candidate.

4.1 | Case Study Results

In this subsection we will present our proposed model results.

4.1.1 | Phase I: T2NN

We selected five decision-makers to assess criteria and alternatives. The criteria are collected from previous studies. We used ten criteria and seven alternatives. Table 3 shows the criteria for this study. Figure 2 shows the hierarchy tree of criteria and alternatives. The Decision makers assess criteria according to Table 1. Then, we construct decision matrices that contain all decision makers' judgement. We apply score function as Eq.(7) to obtain crisp values decision matrices which are aggregated by Eq.(8) to obtain the aggregated decision matrix .

Table **4** shows the values of aggregated decision matrix.

Table 3. selected criteria for the evaluation process.

criteria	description	Type
Revenue Growth (RG)	Measure the percentage increase in revenue over a specific period. Higher growth indicates business expansion and market demand.	Max
Market Share (MS)	Determine the percentage of total sales within an industry that a company captures over time, indicating competitiveness and growth potential.	Max
Profit Margin (PM)	Evaluate the percentage of profit a company earns from its total revenue. Higher margins signify efficient cost management and pricing strategies	Max
Return on Investment (ROI)	Determine the profitability of an investment relative to its cost. Higher ROI indicates better utilization of resources.	Max
Earnings Per Share (EPS)	Calculate the portion of a company's profit allocated to each outstanding share of common stock. Higher EPS reflects increased profitability per share.	Max
Return on Assets (ROA)	Measure how efficiently a company uses its assets to generate earnings, providing insights into operational efficiency and asset utilization.	Max
Cash Flow Adequacy (CFA)	Analyze the ability of a company to generate cash to meet its obligations and fund operations efficiently. Positive cash flow indicates financial health and stability.	Max
Debt-to-Equity Ratio (DER)	Assess the proportion of debt and equity used to finance a company's assets. Lower ratios suggest lower financial risk and better solvency.	Min
Dividend Yield (DY)	Assess the annual dividend income as a percentage of the current share price, indicating returns for shareholders through dividends.	Min
Stock Price Performance (SPP)	Evaluate the movement in stock prices over time relative to benchmarks or competitors, reflecting investor confidence and market perception.	Max

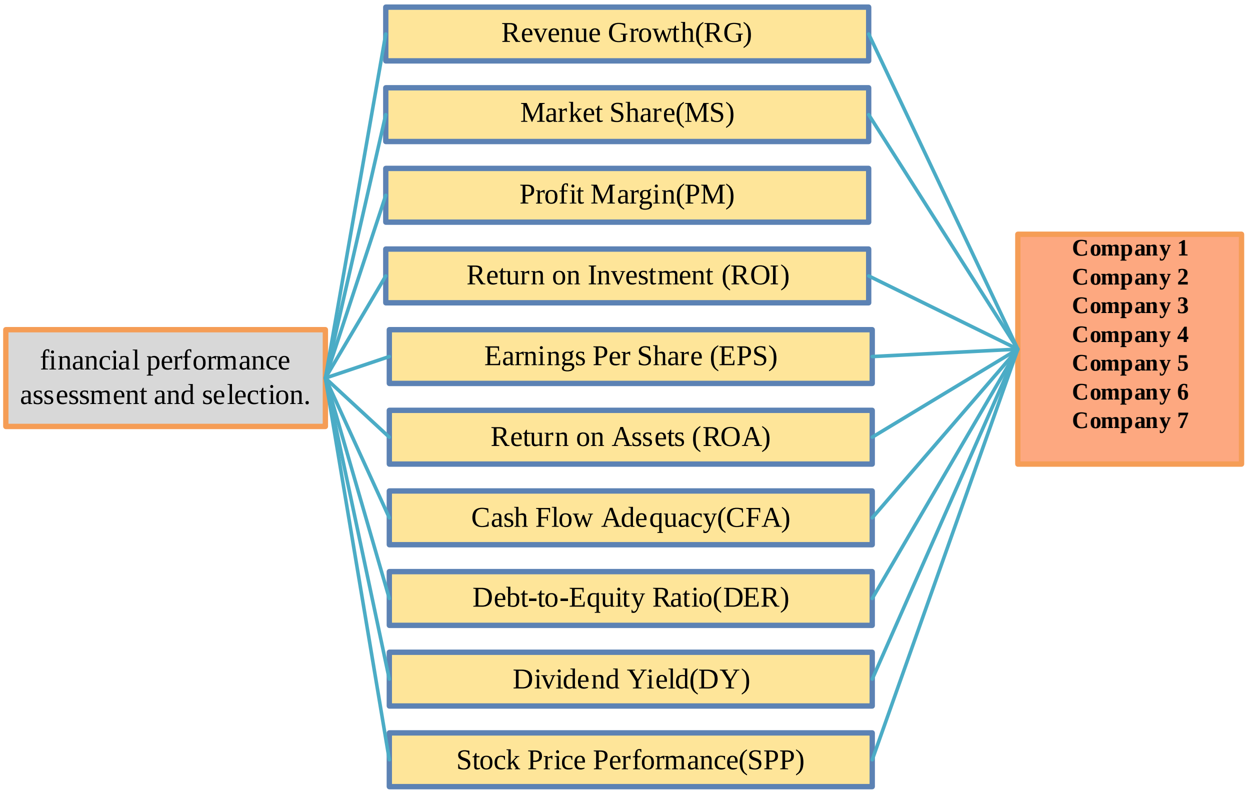

Figure 2. Study hierarchy tree.

Table 4. Aggregated decision matrix.

Criteria Companies	RG	MS	PM	ROI	EPS	ROA	CFA	DER	DY	SPP
CO1	0.609	0.413	0.450	0.598	0.483	0.485	0.518	0.504	0.561	0.506
CO2	0.530	0.645	0.412	0.738	0.460	0.428	0.468	0.461	0.522	0.578
CO3	0.609	0.370	0.519	0.323	0.483	0.509	0.370	0.485	0.588	0.447
CO4	0.703	0.612	0.622	0.654	0.647	0.599	0.309	0.448	0.612	0.563
CO5	0.540	0.418	0.429	0.436	0.561	0.505	0.266	0.553	0.518	0.561
CO6	0.609	0.563	0.667	0.564	0.579	0.553	0.367	0.544	0.624	0.368
CO7	0.608	0.477	0.370	0.440	0.541	0.429	0.428	0.482	0.563	0.469

4.1.2 | Phase II: Criteria Weights using Entropy Weight Method (EWM)

The Decision makers assess criteria according to Table 2. Then, we construct decision matrices that contain all decision makers' judgement. We apply score function as Eq.(7) to obtain crisp values decision matrices which are aggregated by Eq.(8) to obtain the aggregated decision matrix .Table 5 shows the values of aggregated decision matrix to be used in criteria weight determination. The aggregated matrix is normalized by utilizing Eqs. (9) and (10) for constructing normalized matrix as

Table 6. Eq. (10) is utilized to Calculate the average score of the normalized decision matrix as

Table 7. By using Eq. (11), values of normalized matrix and average score, we calculate preference variation degree score as Table 8. By utilizing Eq. (11) preference variation degree is calculated as

Table 9. Then, Eq. (12) was utilized for obtaining the final criteria's weights as shown in Figure 3. According to this Figure, we noticed that Market Share (MS) has the greatest weight while Debt-to-Equity Ratio (DER) has the smallest weight.

Table 5. Aggregated decision matrix for criteria weight determination.

Criteria Companies	RG	MS	PM	ROI	EPS	ROA	CFA	DER	DY	SPP
CO 1	0.603	0.484	0.522	0.504	0.637	0.557	0.485	0.562	0.518	0.565
CO 2	0.602	0.592	0.395	0.513	0.473	0.367	0.468	0.280	0.522	0.522
CO 3	0.600	0.448	0.477	0.367	0.440	0.356	0.433	0.426	0.557	0.504
CO 4	0.673	0.579	0.637	0.426	0.563	0.543	0.339	0.498	0.338	0.522
CO 5	0.499	0.534	0.512	0.346	0.418	0.485	0.412	0.383	0.522	0.367
CO 6	0.397	0.555	0.463	0.448	0.485	0.512	0.426	0.600	0.541	0.557
CO 7	0.543	0.555	0.478	0.367	0.635	0.443	0.418	0.438	0.397	0.485

Table 6. Normalized decision matrix for criteria weight determination.

Criteria Companies	RG	MS	PM	ROI	EPS	ROA	CFA	DER	DY	SPP
CO 1	0.896	0.818	0.819	0.982	1.000	1.000	1.000	0.936	0.931	1.000
CO 2	0.894	1.000	0.620	1.000	0.742	0.659	0.964	0.467	0.937	0.923
CO 3	0.891	0.758	0.749	0.714	0.691	0.639	0.893	0.710	1.000	0.892
CO 4	1.000	0.979	1.000	0.830	0.885	0.975	0.699	0.829	0.606	0.923
CO 5	0.741	0.903	0.804	0.674	0.656	0.871	0.849	0.638	0.937	0.649
CO 6	0.589	0.938	0.726	0.873	0.762	0.919	0.878	1.000	0.972	0.985
CO 7	0.806	0.938	0.751	0.714	0.997	0.796	0.861	0.731	0.713	0.858

Table 7. Average score.

Criteria	RG	MS	PM	ROI	EPS	ROA	CFA	DER	DY	SPP
$\boldsymbol{N_j}$	0.831	0.905	0.781	0.827	0.819	0.837	0.878	0.759	0.871	0.890

Table 8. Preference variation degree.

Criteria	RG	MS	PM	ROI	EPS	ROA	CFA	DER	DY	SPP
P_j	0.108	0.046	0.081	0.105	0.121	0.126	0.056	0.198	0.134	0.082

Table 9. preference variation degree.

Criteria	RG	MS	PM	ROI	EPS	ROA	CFA	DER	DY	SPP
D_j	0.892	0.954	0.919	0.895	0.879	0.874	0.944	0.802	0.866	0.918

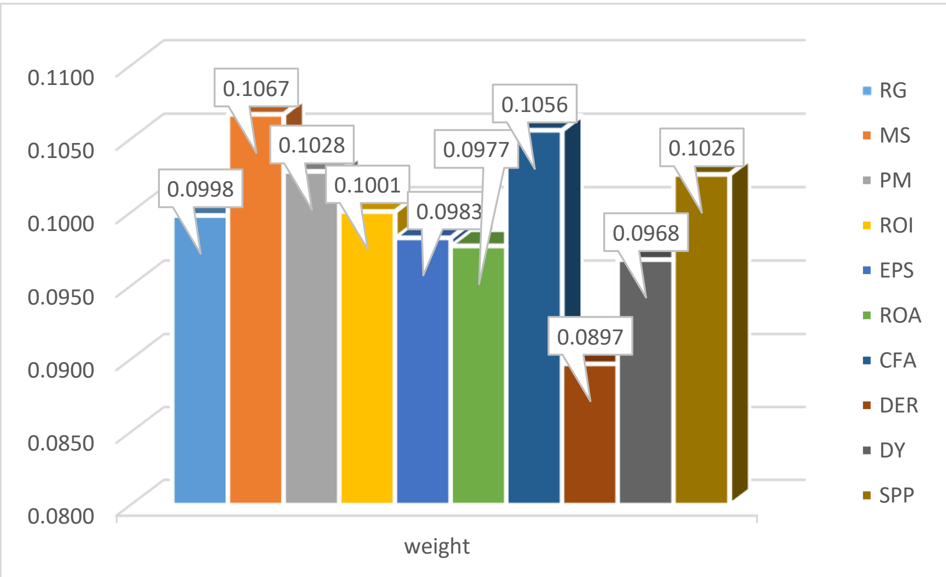

Figure 3. Final criteria weights.

4.1.3 | Phase III: Alternatives Ranking by Additive Ratio Assessment Method

We start with aggregated decision matrix shown in

Table 4. We utilize Eqs. (12) and (13) to calculate the optimal value (δ) for each criterion. Then, we construct the new decision matrix as Table 10. By applying Eqs. (14) and (15) we obtain normalized new decision matrix values as Table 11. The weighted normalized new decision matrix values are calculated through Eq. (17) and presented in Table 12. Eqs. (18) and (19) are utilized respectively to obtain optimality function and degree of alternative utility values as Table 13. Finally, according to the values of alternative utility the final ranks of alternatives are determined as Figure 3. This Figure, indicate that CO4 is optimal otherwise, CO3 is the worst company.

Table 10. New decision matrix.

	RG	MS	PM	ROI	EPS	ROA	CFA	DER	DY	SPP
δ	0.703	0.645	0.667	0.738	0.647	0.599	0.518	0.553	0.624	0.578
CO 1	0.609	0.413	0.450	0.598	0.483	0.485	0.518	0.504	0.561	0.506
CO 2	0.530	0.645	0.412	0.738	0.460	0.428	0.468	0.461	0.522	0.578
CO 3	0.609	0.370	0.519	0.323	0.483	0.509	0.370	0.485	0.588	0.447
CO 4	0.703	0.612	0.622	0.654	0.647	0.599	0.309	0.448	0.612	0.563
CO 5	0.540	0.418	0.429	0.436	0.561	0.505	0.266	0.553	0.518	0.561
CO 6	0.609	0.563	0.667	0.564	0.579	0.553	0.367	0.544	0.624	0.368
CO 7	0.608	0.477	0.370	0.440	0.541	0.429	0.428	0.482	0.563	0.469

Table 11. Normalized new decision matrix.

	RG	MS	PM	ROI	EPS	ROA	CFA	DER	DY	SPP
δ	0.143	0.156	0.161	0.164	0.147	0.146	0.160	0.113	0.115	0.142
CO 1	0.124	0.100	0.109	0.133	0.110	0.118	0.160	0.124	0.128	0.124
CO 2	0.108	0.156	0.100	0.164	0.105	0.104	0.144	0.136	0.137	0.142
CO 3	0.124	0.089	0.126	0.072	0.110	0.124	0.114	0.129	0.122	0.110
CO 4	0.143	0.148	0.150	0.146	0.147	0.146	0.095	0.140	0.117	0.138
CO 5	0.110	0.101	0.104	0.097	0.127	0.123	0.082	0.113	0.139	0.138
CO 6	0.124	0.136	0.161	0.126	0.132	0.135	0.113	0.115	0.115	0.090
CO 7	0.124	0.115	0.089	0.098	0.123	0.105	0.132	0.130	0.127	0.115

Table 12. Weighed normalized new decision matrix.

	RG	MS	PM	ROI	EPS	ROA	CFA	DER	DY	SPP
δ	0.014	0.017	0.017	0.016	0.014	0.014	0.017	0.010	0.011	0.015
CO 1	0.012	0.011	0.011	0.013	0.011	0.012	0.017	0.011	0.012	0.013
CO 2	0.011	0.017	0.010	0.016	0.010	0.010	0.015	0.012	0.013	0.015
CO 3	0.012	0.010	0.013	0.007	0.011	0.012	0.012	0.012	0.012	0.011
CO 4	0.014	0.016	0.015	0.015	0.014	0.014	0.010	0.013	0.011	0.014
CO 5	0.011	0.011	0.011	0.010	0.013	0.012	0.009	0.010	0.013	0.014
CO 6	0.012	0.014	0.017	0.013	0.013	0.013	0.012	0.010	0.011	0.009
CO 7	0.012	0.012	0.009	0.010	0.012	0.010	0.014	0.012	0.012	0.012

Table 13. optimality function and degree of alternative utility.

Alternatives	optimality function	alternative utility
CO 1	0.145	1.000
CO 2	0.123	0.846
CO 3	0.130	0.893
CO 4	0.112	0.768
CO 5	0.137	0.942
CO 6	0.113	0.778
CO 7	0.125	0.858
CO 1	0.116	0.796

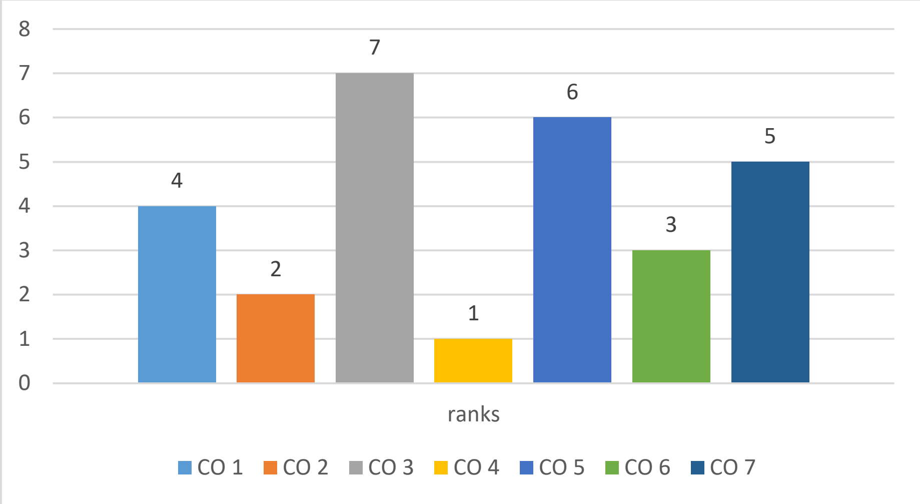

Figure 4. Final criteria rank.

4.2 | Comparative Analysis

We conduct a rigorous and comprehensive comparison analysis to assess the effectiveness and feasibility of our model by comparing it with three other T2NN methods. Firstly, a comparison with Weighted Sum Method (WSM)[16] is conducted, then we can get the following results of preference score for each alternative as CO1= 0.822, CO2= 0.866, CO3= 0.751, CO 4= 0.916, CO 5= 0.762, CO6= 0.831, CO7= 0.777.Thus, the order of ranking is CO4 ≻ CO2 ≻ CO6 ≻ CO1 ≻ CO7 ≻ CO5 ≻ CO3. Next, we compare our model to the multi-attributive real–ideal comparative analysis (MARICA) method[17], We can obtain the following final values for alternatives as CO1= 0.075, CO2= 0.060, CO3= 0.096, CO 4= 0.033, CO 5= 0.091, CO6= 0.077, CO7= 0.087. Then, the ranking order is CO4 ≻ CO2 ≻ CO1 ≻ CO6 ≻ CO7 ≻ CO5 ≻ CO3. Finally, we compare our model to COmplex PRoportional ASsessment (COPRAS) [18], [19] is performed. Then, quantitative utility of alternatives is CO1= 91.07, CO2= 92.21, CO3= 84.05, CO 4= 100.00, CO 5= 84.81, CO6= 95.89, CO7= 85.64. Thus, the order of ranking is CO4 ≻ CO6 ≻ CO2 ≻ CO1 ≻ CO7 ≻ CO5 ≻ CO3.

The results of comprehensive analysis provided above, all four models indicate that the optimal choice is company 4 and the worst choice is company 3, as illustrated in Figure 5. This confirmation validates the model's reliability, validity, and efficiency.

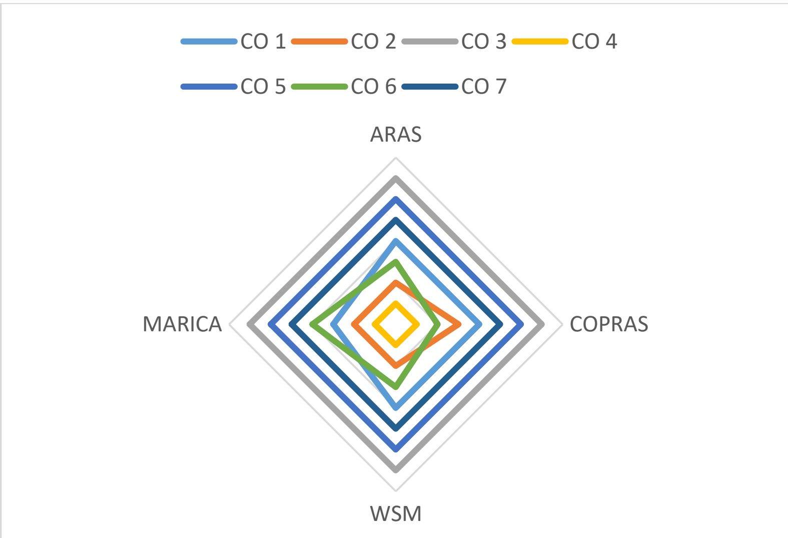

Figure 5. Comparative analysis.

5 | Conclusions

This study introduced an innovative approach, the Integrated Opinion Weight Criteria Method and Neutrosophic Additive Ratio Assessment, for assessing financial performance and selecting optimal alternatives. By combining these two methodologies, a comprehensive and robust framework was established to address the complexities and uncertainties inherent in financial decision-making processes.

Through the application of the Integrated Opinion Weight Criteria Method, stakeholders can effectively incorporate diverse opinions and preferences into the evaluation process, ensuring a more inclusive and balanced assessment of financial performance. This method allows for the integration of subjective judgments with objective criteria, leading to more informed and reliable decision-making outcomes.

Furthermore, the utilization of Neutrosophic Additive Ratio Assessment offers a flexible and adaptive approach to handling uncertain and imprecise information in financial evaluations. By accommodating indeterminacy, inconsistency, and incompleteness in data, this methodology enhances the accuracy and reliability of performance assessments while providing a systematic means of comparing alternative options.

The combination of these two approaches not only enhances the efficiency and effectiveness of financial performance evaluations but also contributes to improved decision-making processes within organizations. By leveraging the strengths of both methodologies, stakeholders can gain deeper insights into complex financial scenarios, identify key performance indicators more accurately, and make well-informed choices that align with strategic objectives.

Overall, this study underscores the importance of adopting innovative methodologies that can address the multifaceted challenges associated with financial performance assessment and selection. The Integrated Opinion Weight Criteria Method and Neutrosophic Additive Ratio Assessment offer a promising avenue for enhancing decision-making processes in finance by providing a structured framework that integrates diverse perspectives, handles uncertainty effectively, and facilitates informed choices based on comprehensive evaluations.

As organizations navigate an increasingly dynamic and competitive business environment, embracing such advanced methodologies will be crucial for achieving sustainable growth, mitigating risks, and maximizing returns on investment. Moving forward, further research and practical applications of these methodologies are warranted to explore their full potential in enhancing financial performance assessment practices across various industries.

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Conflicts of Interest

The authors declare that there is no conflict of interest in the research.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors

Data Availability

There is no data used in this study.

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