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ORIGINAL ARTICLE

# An integrated plithogenic MCDM approach for financial performance evaluation of manufacturing industries

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## Abstract

Financial performance evaluation is very significant for manufacturing industries in a competitive environment to achieve investment goals, especially increasing revenue. Financial performance measures must be identified accurately, because the evaluation process reflects the effectiveness of a company. The purpose of this article is to present a plithogenic multi-criteria decision-making (MCDM) model based on neutrosophic analytic hierarchy process (AHP), Vlse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR) method, and Technique in Order of Preference by Similarity to Ideal Solution (TOPSIS) method. The financial performance in this study is measured by a set of financial ratios. To examine the proposed model, the top 10 steel companies in Egypt are evaluated based on specified financial ratios. According to steel manufacturing experts, the weight of the criteria is determined using AHP method. The company ranking is determined using VIKOR and TOPSIS comparatively. The results show that the obtained ranks of the companies by these methods are almost the same.

**Keywords** Neutrosophic analytic hierarchy process · Performance evaluation · Financial ratio · Plithogenic · Multi-criteria decision making

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## Introduction

Nowadays, the process of measuring financial performance has a great importance for all companies in the same sector, and not only for the company administrators or investors. The financial performance has various meanings, such as profitability, productivity, and economic development, so the financial ratio is a proper metric to measure the financial performance for both firms and related sectors. Generally, companies care to know their rank among their competitors in the same sector to implement convenient strategies. That is why companies' ranking is significant in the business world.

There are many studies in the literature that have shown the importance of financial ratios in financial performance measuring. Yalcin summarize the financial ratios into eight main criteria to measure the financial performance of Turkish manufacturing industries. They used traditional accounting-based financial performance measure (AFP) and value-based financial performance measures (VFP) to express the company value (Yalcin et al. 2012). On the other side, Rezaie measured the performance of Iranian cement firms for two years (2008 and 2009) using AHP and VIKOR method based on four main financial ratios (Rezaie et al. 2014). In addition, financial ratios were used to cluster companies according to their financial structures in different industries (Linares-Mustaros et al. 2018). The financial ratio improves the process of measuring profitability, operating capability, and solvency to examine 46 Indian bank based on 31 financial ratio (Bawa et al. 2019).

Evaluating a company's financial performance is a multi-criteria decision-making problem based on set of defined criteria. There are several MCDM techniques that achieved great results in different industries sectors. The financial performance of airlines was evaluated using VIKOR method (Pineda et al. 2018). A combined of fuzzy and AHP were proposed to evaluate seven petrochemical companies in Iran (Shaverdi et al. 2014).

One of the most popular MCDM method to determine the weight of the criteria (financial ratios) is analytic hierarchy process (AHP). This method is based on pairwise comparison between set of criteria to obtain the weight vector. It is an easy and useful method employed in different MCDM problems, such as inventory classification system (Cakir and Canbolat 2008), supplier selection model (Fu 2019), risk assessment (Kokangül et al. 2017), and more.

Moreover, another efficient MCDM technique is VIKOR, initiated by Opricovic. It is efficient to solve discrete decision problems with inconsistent criteria, helping the decision-maker to get the optimal alternative. There are several researches in different field using VIKOR method in MCDM problems, such as safety risk assessment (Gul et al. 2019), measuring manufacturing supply chain (Rajesh 2018), assessing the social, or environmental and economic effects of supply chain (Ali et al. 2019). Technique in Order of Preference by Similarity to Ideal Solution (TOPSIS) is based on comparing number of solutions by the negative ideal solution (least preferred solution) and positive ideal solution (most preferred solution) to select the best. In supply chain problems, dos Santos proposed a model based on a hybrid Entropy-TOPSIS-F to select a green supplier in the furniture industry (dos Santos et al. 2019). The financial performance evaluation process was applied in the sector of technology companies in Turkey (Bulgurcu 2012).

Most of the supply chain problems have uncertain factors that make the problem more complex to consider the optimal decision. That is why, we propose in this study a plithogenic MCDM model to improve the efficiency and accuracy of financial performance evaluation process with high level of consideration to uncertainty. Our contribution is the construction of a consistent and accurate model that ranks the companies in any sector based on a set of financial ratios.

The purpose of this study is to evaluate the financial performance of manufacturing industries based on some financial ratios employing the plithogenic set theory to consider vague information. To achieve this goal, we use the AHP method to find the weight vector of the financial ratios. Then, VIKOR and TOPSIS are utilized to rank the companies comparatively.

The reminder of this paper is organized as follows. In "Literature review" section—a literature review of financial performance measures, MCDM techniques and plithogenic set theory. Information and definitions of methods and principles are presented in "Methods" section. "Proposed model" section describe the proposed integrated model. In "Case study and results" section, a real case study is discussed to evaluate the financial performance of steel industry in Egypt. Finally, in "Results discussion and sensitivity analysis" section, we draw conclusions.

## Literature review

### Financial performance evaluation

In competitive environment, the organizations look forward to be in the top of ranking in their sector and be able to compete in international market. Usually, this ranking is done based on financial performance evaluation of the firms. The financial performance evaluation process is based on financial ratios calculated from financial reports to analyse the firm's financial situation. Financial ratio analysis is an efficient tool that can disclose the financial strength and weakness of the firms. In addition, it assists administrators to obtain appropriate strategies that the company must follows to achieve specific goals. Accounting experts suppose that financial ratios must be divided into several clusters to avoid evaluation by similar financial ratios (Rezaie et al. 2014). In this study, the financial ratios are split up in four main categories, which are: Liquidity ratios, Leverage ratios, Coverage ratios, and Profitability ratios.

A *Liquidity ratios* it presents how fast firms can achieve their commitments. There are two main liquidity ratio, as follows:

- *Current ratio* extracting the relationship of a current asset to current liabilities. It measures whether the organization has enough resources to achieve their commitments.

$$\text{Current ratio} = \frac{\text{Current Assets}}{\text{Current Liabilities}}$$

- *Quick ratio* it is a measurement of a firm ability to use its quick assets to liquidate its current liabilities.

$$\text{Quick ratio} = \frac{\text{Liquid Assets}}{\text{Current Liabilities}}$$

B. *Leverage ratios* it recognizes the fixed financing and how the firm achieves their fixed financing commitments. It is also known as debt ratios because it measures the ability of company to recover the long term debt. The five commonly used leverage ratios are:

- *Debt ratio* it indicates the percentage of firm's assets that are provided by debt.

$$\text{Debt ratio} = \frac{\text{Total Debts}}{\text{Total Assets}}$$

- *Debt to capitalization ratio* it measures the debt to the firm capital structure.

$$\text{Total Debt To Capitalization ratio} = \frac{(\text{STD} - \text{LTD})}{(\text{STD} + \text{LTD} + \text{SE})}$$

where STD: Short Term Debt, LTD: Long Term Debt, SE: Shareholder's Equity

- *Debt to worth ratio* measuring the financial strength of a firm by comparing the level of debt it has with its total net worth.

$$\text{Debt to worth ratio} = \frac{\text{Total Debt}}{\text{Total Net Worth}}$$

- *Debt to equity ratio* it measures the ratio of shareholder's equity and debt used to finance a company's assets.

$$\text{Debt to equity ratio} = \frac{\text{Total Liabilities}}{\text{Equity}}$$

- *Debt to capital ratio* it considers the debt liabilities as a part of a firm's total capital. Total capital means debts and shareholder's equity.

$$\text{Debt to capital ratio} = \frac{\text{Debt}}{\text{Total capital}}$$

C. *Coverage ratios* it is used to evaluate the firm ability to pay its financial obligations such as interest payment.

– *Interest coverage ratio* it is employed to determine the ability of the firm to pay interest on the outstanding debt.

$$\text{Interest coverage ratio} = \frac{\text{Earning before interest and taxes}}{\text{Interest Expense}}$$

– *Debt-service coverage ratio* it measures the ability of the firm to pay its debt by its operating income.

$$\text{Debt} - \text{service coverage ratio} = \frac{\text{Operating Income}}{\text{Total Debt Service}}$$

– *Cash flow coverage* it is used to compare the firm's cash balance and its annual interest expense and to measure its ability to pay its obligations with its cash flow.

$$\text{Cash flow coverage ratio} = \frac{\text{Operating Cash Flows}}{\text{Total Debt}}$$

– *Asset coverage ratio* it measures the ability of the firm to pay the debt from its assets if the income is not enough.

$$\text{Asset coverage ratio} = \frac{(\text{Total assets} - \text{Intangible assets}) - (\text{current liabilities} - \text{STD})}{\text{Total Debt}}$$

D. *Profitability ratios* it expresses how firms use their current assets to generate profit and value for shareholders.

– *Return on assets (ROA)* it measures how successfully a firm has used the total assets at its conductance in order to generate incomes, it is significant for manufacturing industries.

$$\text{ROA} = \frac{\text{Net Income}}{\text{Total Assets}}$$

– *Return on equity (ROE)* it measures the return that administration utilizes from the shareholder's equity.

$$\text{ROA} = \frac{\text{Net Income}}{\text{Shareholder's Equity}}$$

– *Net profit margin* it is a percentage of profit that firm achieves from its total revenue.

$$\text{Net Profit Margin} = \frac{\text{Net Profit}}{\text{Total Revenue}}$$

- *Gross profit margin* it measures how much business earning taking in account the products and services costs and it's useful to evaluate the operational performance of the firm.

$$\text{Gross Profit} = \text{Sales Revenue} - \text{Cost of products sold}$$

- *Asset turnover* it means the firm ability to use its assets in order to generate income or sales.

$$\text{Assets Turnover} = \frac{\text{Net Sales Revenue}}{\text{Average Total Assets}}$$

- *Price earnings ratio (P/E)* analysts use P/E ratio to evaluate the value of the firm shares. It also compare markets against one another or over time.

$$\text{P/E} = \frac{\text{Market value per share}}{\text{Earning per share}}$$

- *Return on invested capital (ROIC)* it measures a firm's qualifications to allocate the capital to profitability investments.

$$\text{ROIC} = \frac{\text{Net Operating profit after tax}}{\text{Invested Capital}}$$

- *Operating profit margin* it evaluates the firm income after paying variable costs and before paying interest or tax.

$$\text{Operating Profit Margin} = \frac{\text{Operating Earning}}{\text{Revenue}}$$

- *Operating cash flow margin* it evaluates how firm converts sales into cash.

$$\text{Operating Cash Flow Margin} = \frac{\text{Cash flow operating activities}}{\text{Sales}}$$

## Multi-criteria decision-making (MCDM)

Most of the business performance evaluations are regarded as multi-criteria decision-making problems. MCDM has many efficient techniques and methods that achieved great results in business evaluation process. The objective of MCDM is to obtain the optimal alternative that satisfies a set of criteria. In this research, we focus on AHP, VIKOR and TOPSIS methods. For years, a large number of studies in the literature proved the significance of MCDM methods in supply chain evaluation problems. Vatankhah proposed a model based on fuzzy AHP method to evaluate the airline business model (Vatankhah et al. 2019). In addition, AHP method was efficiently used in risk assessment of manufacturing supply chain (Butdeea and Phuangsaleeb 2019). Resilience evaluation of electronics manufacturing was studied by efficient model proposed by Rajesh using VIKOR and other clustering methods (Rajesh 2018). In addition, one of the critical supply chain problems is facility location which was solved by VIKOR and AHP methods to determine a military airport location (Sennaroglu and Celebi 2018). In the field of green supply chain management, dos Santos proposed a model based on a hybrid Entropy-TOPSIS-F to select a green supplier in the furniture industry (dos Santos et al. 2019). In addition, evaluation of safety performance of organizations was studied using hybrid TOPSIS method with intuitionistic fuzzy (Yazdi 2018).

One of the most significant obstacle in decision making process is uncertainty and incomplete information of the problem dimensions. Plithogeny is considered a theory that handles uncertainty and provides consistent solutions. It is a generalization of neutrosophy and it was introduced by Smarandache (2017). Plithogenic set is a set of attributes described by values and characterized by two major features which are appurtenance degree and contradiction degree. These features ensure results accuracy, which is the main contribution of this research.

In this study, the proposed model of financial evaluation process will be examined on steel industry. The steel industry plays a fundamental role in any contemporary economy. Steel industry is developing rapidly and needs stronger and consistent supply chain performance. Consequently, measuring financial performance of steel industry became a critical subject in order to evaluate steel companies in competitive environment. As a case study, Egypt steel industry will be evaluated by MCDM techniques based on several financial ratios.

## Methods

### Neutrosophic set

The neutrosophic theory was introduced by Smarandache (1998). Definitions of neutrosophic set are clearly stated in this subsection.

**Definition 1** (Abdel-Baset et al. 2016) Let $X$ be a set of elements and $x \in X$. A neutrosophic set $A$ in $X$ is known by a truth-membership function $T_N(x)$, an indeterminacy-membership function $I_N(x)$ and a falsity-membership function $F_N(x)$, where $T_N(x)$, $I_N(x)$ and $F_N(x)$ are subsets of$]-0, 1+[$. $T_N(x) : X \rightarrow ]-0, 1+[$, $I_N(x) : X \rightarrow ]-0, 1+[$ and $F_N(x) : X \rightarrow ]-0,1+[$. There is no restriction on summation of membership functions. Therefore, $0- \leq \sup T_N(x) + \sup I_N(x) + \sup F_N(x) \leq 3+$

**Definition 2** (Abdel-Basset et al. 2019a, b) Let $X$ be a universe of discourse. A single neutrosophic set $N$ over $X$ is an object with form of $N = \{\langle x, T_N(x), I_N(x), F_N(x)\rangle : x \in X\}$, where $T_N(x) : X \rightarrow [0,1], I_N(x) : X \rightarrow [0,1]$ and$F_N(x) : X \rightarrow [0,1]$ with $0 \leq T_N(x) + I_N(x) + F_N(x) \leq 3$ for all $x \in X$, where $T_N(x)$, $I_N(x)$ and $F_N(x)$ represent the truth-membership function, indeterminacy-membership function, and falsity-membership function, respectively. A single valued neutrosophic (SVN) number is represented as $A = (a, b, c)$where $a, b, c \in [0, 1]$ and $a + b + c \leq 3$.

**Definition 3** (Rivieccio 2008) Let $a = \langle (a1, a2, a3); \alpha, \theta, \beta \rangle$ be a SVN set, with truth membership $T_a(x)$, indeterminate membership $I_a(x)$, and falsity membership function $F_a(x)$ as follows:

$$T_a(x) = \begin{cases} \left(\frac{x-a_1}{a_2-a_1}\right)\alpha_a & \text{if } a_1 \leq x \leq a_2 \\ \alpha_a & \text{if } x = a_2 \\ \left(\frac{a_{3-x}}{a_3-a_2}\right)\alpha_a & \text{if } a_2 \leq x \leq a_3 \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

$$I_a(x) = \begin{cases} \frac{(a_2-x)}{(a_2-a_1)}\theta_a & \text{if } a_1 \leq x \leq a_2 \\ \theta_a & \text{if } x = a_2 \\ \frac{(x-a_3)}{(a_3-a_2)}\theta_a & \text{if } a_2 < x \leq a_3 \\ 1 & \text{otherwise} \end{cases} \tag{2}$$

$$F_a(x) = \begin{cases} \frac{(a_2-x)}{(a_2-a_1)}\beta_a & \text{if } a_1 \leq x \leq a_2 \\ \beta_a & \text{if } x = a_2 \\ \frac{(x-a_3)}{(a_3-a_2)}\beta_a & \text{if } a_2 < x \leq a_3 \\ 1 & \text{otherwise} \end{cases} \tag{3}$$

**Definition 4** (Abdel-Baset et al. 2016) Let $\langle a = (a1, a2, a3); \alpha_a, \theta_a, \beta_a \rangle$ and $\tilde{b} = \langle (b1, b2, b3); \alpha_b, \theta_b, \beta_b \rangle$ be two single valued neutrosophic numbers. Then,

Addition of two triangular neutrosophic numbers:

$$a + \tilde{b} = \langle (a1 + b1, a2 + b2, a3 + b3); \alpha_a \cap \alpha_b, \theta_a \cup \theta_b, \beta_a \cup \beta_b \rangle \tag{4}$$

Subtraction of two triangular neutrosophic numbers:

$$a - \tilde{b} = \langle (a1 - b3, a2 - b2, a3 - b1); \alpha_a \cap \alpha_b, , \theta_a \cup \theta_b, \beta_a \cup \beta_b \rangle \tag{5}$$

Inverse of two triangular neutrosophic numbers:

$$a^{-1} = \left\langle \left( \frac{1}{a3}, \frac{1}{a2}, \frac{1}{a1} \right); \alpha_a, \theta_a, \beta_a \right\rangle, \text{Where}(\ a \neq 0) \tag{6}$$

Multiplication of two triangular neutrosophic numbers:

$$a\tilde{b} = \begin{cases} \langle(a1b1, a2b2, a3b3); \alpha_a \cap \alpha_b, , \theta_a \cup \theta_b, \beta_a \cup \beta_b\rangle & if\ (a3 > 0, b3 > 0) \\ \langle(a1b3, a2b2, a3b1); \alpha_a \cap \alpha_b, , \theta_a \cup \theta_b, \beta_a \cup \beta_b\rangle & if\ (a3 < 0, b3 > 0) \\ \langle(a3b3, a2b2, a1b1); \alpha_a \cap \alpha_b, , \theta_a \cup \theta_b, \beta_a \cup \beta_b)\rangle & if\ (a3 < 0, b3 < 0) \end{cases} \quad (7)$$

Division of two triangular neutrosophic numbers:

$$\frac{a}{\tilde{b}} = \begin{cases} \left\langle\left(\frac{a1}{b3}, \frac{a2}{b2}, \frac{a3}{b1}\right); \alpha_a \cap \alpha_b, , \theta_a \cup \theta_b, \beta_a \cup \beta_b\right\rangle & if\ (a3 > 0, b3 > 0) \\ \left\langle\left(\frac{a3}{b3}, \frac{a2}{b2}, \frac{a1}{b1}\right); \alpha_a \cap \alpha_b, , \theta_a \cup \theta_b, \beta_a \cup \beta_b\right\rangle & if\ (a3 < 0, b3 > 0) \\ \left\langle\left(\frac{a3}{b1}, \frac{a2}{b2}, \frac{a1}{b3}\right); \alpha_a \cap \alpha_b, , \theta_a \cup \theta_b, \beta_a \cup \beta_b\right\rangle & if\ (a3 < 0, b3 < 0) \end{cases} \quad (8)$$

## Plithogenic set

Plithogeny refers to the creation, improvement and growth of new entities from group of contradictory or non-contradictory multiple old entities (Smarandache 2017). A plithogenic set (P, A, V, d, c) is a set that consists of a number of elements defined by a set of attributes $A = \{\alpha_1, \alpha_2, \ldots, \alpha_m\}$, $m \geq 1$, each attribute has a value $V = \{v_1, v_2, \ldots, v_n\}$, for $n \geq 1$ (Smarandache 2018a, b, c). As previously mentioned, plithogenic set is considering uncertainty to improve more accurate results and that due to its two main features contradiction degree and appurtenance degree. Contradiction (dissimilarity) degree function $c(v,D)$ distinguishes between each attribute value and the dominant (most preferred) attribute value, where appurtenance degree function of the element $x$, with respect to set of given criteria is noted as $d(x,v)$ (Smarandache 2018a, b, c). Plithogenic set operations are intersection $\wedge_p$, union $\vee_p$, complement $\neg_p$, inclusion, and equality $\leftrightarrow$. The attribute value contradiction degree function $c(v_1, v_2)$ is $c: V \times V \to [0, 1]$, satisfying the following axioms:

$c(v_1, v_1) = 0$, contradiction degree between the attribute values and itself is zero;

$c(v_1, v_2) = c(v_2, v_1)$, representing the dissimilarity between two attribute values $v_1$ and $v_2$ (Abdel-Basset et al. 2019a, b).

Contradiction degree function can be fuzzy $C_F$, intuitionistic attribute value contradiction function ($C_{IF}$: $V \times V \to [0, 1]^2$), or a neutrosophic attribute value contradiction function ($C_N$: $V \times V \to [0, 1]^3$).

**Definition 5** (Smarandache 2017) Let $a = (a1, a2, a3)$ and $\tilde{b} = (b1, b2, b3)$ be two plithogenic sets; its operations are:

– Plithogenic intersection:

$$\begin{aligned} &\left(\left(a_{i1}, a_{i2}, a_{i3}\right), 1 \leq i \leq n\right) \wedge \mathrm{p} \left(\left(b_{i1}, b_{i2}, b_{i3}\right), 1 \leq i \leq n\right) \\ &= \left(\left(a_{i1} \wedge_F b_{i1}, \frac{1}{2}\left(a_{i2} \wedge_F b_{i2}\right) + \frac{1}{2}\left(a_{i2} \vee_F b_{i2}\right), a_{i2} \vee_F b_{i3}\right)\right), 1 \leq i \leq n. \end{aligned} \quad (9)$$

– Plithogenic union:

$$\left(\left(a_{i1}, a_{i2}, a_{i3}\right), 1 \le i \le n\right) \vee \mathrm{p} \left(\left(b_{i1}, b_{i2}, b_{i3}\right), 1 \le i \le n\right) = \left(\left(a_{i1} \vee_F b_{i1}, \frac{1}{2}\left(a_{i2} \wedge_F b_{i2}\right) + \frac{1}{2}\left(a_{i2} \vee_F b_{i2}\right), a_{i2} \wedge_F b_{i3}\right)\right), 1 \le i \le n. \tag{10}$$

where

$$a_{i1} \wedge \mathrm{p}\, b_{i1} = \left[1 - c\left(v_D, v_1\right)\right].t_{\mathrm{norm}}\left(v_D, v_1\right) + c\left(v_D, v_1\right).t_{\mathrm{conorm}}\left(v_D, v_1\right) \tag{11}$$

$$a_{i1} \vee \mathrm{p}\, b_{i1} = \left[1 - c\left(v_D, v_1\right)\right].t_{\mathrm{conorm}}\left(v_D, v_1\right) + c\left(v_D, v_1\right).t_{\mathrm{norm}}\left(v_D, v_1\right) \tag{12}$$

where,

$$t_{\mathrm{norm}} = \wedge_F b = ab,\ t_{\mathrm{conorm}} a \vee_F b = a + b - ab$$

– Plithogenic complement (negation):

$$\neg\left(\left(a_{i1}, a_{i2}, a_{i3}\right), 1 \le i \le n\right) = \left(\left(a_{i3}, a_{i2}, a_{i1}\right), 1 \le i \le n\right) \tag{13}$$

The appurtenance degree $d(x,v)$ of attribute value $v$ is: $\forall\ x \in P,\ d: P \times V \rightarrow P$ ([0, 1]$^z$), so $d(x, v)$ is a subset of $[0, 1]^z$, and $P([0, 1]^z)$ is the power set of $[0, 1]^z$, where $z = 1, 2, 3$, for fuzzy, intuitionistic fuzzy, and neutrosophic degrees of appurtenance, respectively.

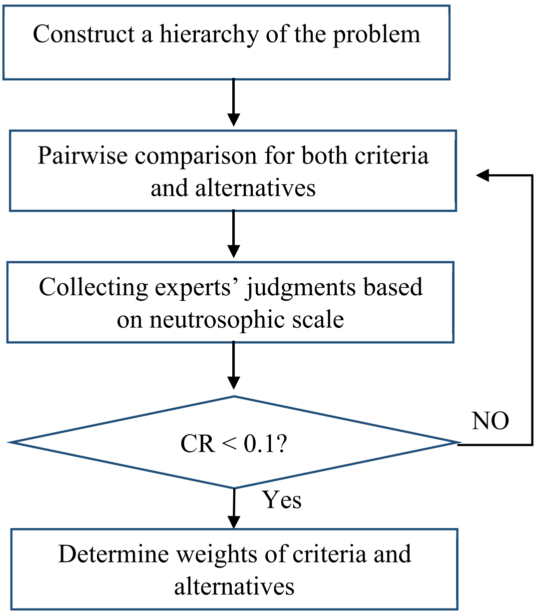


**Fig. 1** AHP steps

## Neutrosophic analytic hierarchy process (AHP)

In various MCDM problems, AHP is a widely used method introduby Saaty (1970). It analyses complex problems into simple and easy sub-problems (Abastante et al. 2019). By applying AHP method on neutrosophic environment that considers truth, falsity, and indeterminacy degrees, the evaluation results will be more accurate with respect to the decision maker insight. The steps are as follows (also represented in Fig. 1):

- *Step 1* Divide the problem into sub-problems.
- *Step 2* Construct the problem hierarchy. The first level is the goal to be achieved, intermediate levels for criteria and sub-criteria, and the final level for alternatives.
- *Step 3* Build the decision matrix (pairwise comparison) based on the neutrosophic evaluation scale according to decision maker's preferences.
- *Step 4* Check the decision matric consistency in order to improve the decision matrix, by calculating consistency index (CI) and consistency ratio (CR)

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{14}$$

  where, $\mathrm{CI} = \frac{\lambda\max_{-n}}{n-1}$, $\lambda_{\max}$ is the mean of weighted sum vector divided by corresponding criteria and $n$ is the number of criteria. RI is a random index which describes a direct function of the number of criteria being considered as shown in Table 1. If the $\mathrm{CR} < 0.1$ is acceptable, otherwise the comparison must be modified.
- Calculate the weight of pairwise comparison of criteria and alternatives.

## Technique in order of preference by similarity to ideal solution (TOPSIS)

Order of Preference by Similarity to Ideal Solution (TOPSIS) is an efficient MCDM techniques which was proposed by Hwang and Yoon (1981). TOPSIS ranks the alternatives based on the distance of alternatives to the positive ideal solution (PIS) and negative ideal solution (NIS) in order to find the optimal solution (Zyoud and Fuchs-Hanusch 2017). The steps of TOPSIS are clearly defined as follows:

- *Step 1* Clarify the MCDM problem with its criteria and alternatives and build a decision matrix that evaluates the alternatives based on the set of criteria
- *Step 2* The decision matrix is normalized using Eq. (15).

**Table 1** Saaty table for RI per number of criteria

| N | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

$$R = \left(r_{ij}\right)_{m\times n} = x_{ij} \Big/ \left(\sqrt{\sum_{i=1}^{m} x_{ij}^2}\right). \tag{15}$$

where $x_{ij}$. is the score of alternative $i$ under criterion $j$.

- *Step 3* Construct weighted normalized decision matrix using Eq. (16):

$$V = \left(v_{ij}\right)_{m\times n} = w_j \times r_{ij} \text{ where } w_j \text{ is the weight of each criterion.} \tag{16}$$

- *Step 4* Using following Eqs. (17)–(20) to recognize the positive ideal solution (PIS) and negative ideal solution (NIS) (de Farias Aires and Ferreira 2019):

$$A^{+} = \left\{v_1^{+}, v_2^{+}, \ldots, v_n^{+}\right\} \tag{17}$$

$$v^{+} = \{(\max_i v_{ij} \big| j \in J_b), (\min_i v_{ij} \left| J \in J_{nb}) \right| \in [1 \ldots m]\}. \tag{18}$$

$$A^{-} = \left\{v_1^{-}, v_2^{-}, \ldots, v_n^{-}\right\} \tag{19}$$

$$v^{-} = \{(\min_i v_{ij} \big| j \in J_b), (\max_i v_{ij} \left| J \in J_{nb}) \right| \in [1 \ldots m]\}. \tag{20}$$

where $J_{\mathrm{nb}}$ is a set of beneficial criteria, and $J_{\mathrm{nb}}$ is a set of non-beneficial criteria

- *Step 5* Compute the distance of each alternative to the PIS and N to measure the separation of alternative $i$ performance using Eqs. (21) and (22) (Chen 2019):

$$d_i^{+} = \sqrt{\sum_{j=1}^{m} \left(V_i - V_j^{+}\right)^2} \tag{21}$$

$$d_i^{-} = \sqrt{\sum_{j=1}^{m} \left(V_i - V_j^{-}\right)^2} \tag{22}$$

- *Step 6* The closeness coefficient of each alternative is calculated based on Eq. (23) in order to rank the alternatives.

$$CC_i = \frac{d_i^{-}}{d_i^{+} - d_i^{-}} \tag{23}$$

## Vlse Kriterijumska optimizacija Kompromisno Resenje (VIKOR)

VIKOR is a viable MCDM method proposed by Opricovic (1998). It is useful and applicable method to solve MCDM with inconsistent criteria that can assist decision maker to find the optimal alternative. The ranking of the alternatives is based on their distance to the ideal alternative. The main steps of VIKOR method are described as follows:

- *Step 1* Build the decision matrix based on decision makers evaluation
- *Step 2* Normalize the decision matrix using Eq. (24).

$$\left(f_{ij}\right)_{m\times n} = {x_{ij}}\Big/\left(\sqrt{\sum_{i=1}^{m} x_{ij}^2}\right) \tag{24}$$

  where $m$ is the number of alternatives and $n$ is the number of criteria.
- *Step 3* Determine the best values $f_j^*$ and worst values $f_j^-$. of criteria. If $f_j$ is beneficial criteria, then $f_j^* = \max\left(f_{ij}\right)$ and $f_j^- = \min\left(f_{ij}\right)$. On the other hand, if $f_j$ is non-beneficial criteria, then $f_j^* = \min\left(f_{ij}\right)$. And $f_j^- = \max\left(f_{ij}\right)$.
- *Step 4* Calculate the values of $S_i$. and $R_i$ by Eqs. (25) and (26):

$$S_i = \sum_{j=1}^{n} w_j * \frac{f_j^* - f_{ij}}{f_j^* - f_j^-} \tag{25}$$

$$R_i = \max\left[w_j * \frac{f_j^* - f_{ij}}{f_j^* - f_j^-}\right] \tag{26}$$

  where $w_j$ id the weight of criteria expressing their importance.
- *Step 5* Calculate the value of $Q_i$. by Eq. (27) (Kim and Ahn 2019).

$$Q_i = \upsilon\left[\frac{S_i - S^*}{S^- - S^*}\right] + (1-\upsilon)\left[\frac{R_i - R^*}{R^- - R^*}\right] \tag{27}$$

  where $S^- = \max_i S_i.$, $S^* = \min_i S_i$, $R^- = \max_i R_i$, $R^* = \min_i R_i$, and $v$ is the weight of strategy of maximum group utility, usually equal to 0.5.
- *Step 6* Rank the alternatives according to $Q_i$. descending order.
- *Step 7* There are two conditions that should be satisfied in regard to this rank:

• Condition 1 (acceptable advantage):

$$Q\left(A^2\right) - Q\left(A^1\right) \geq \frac{1}{m-1} \tag{28}$$

  where $A^1$ is the first alternative in Q ranking and $A^2$. is the second, and $m$ is the number of alternatives.

• Condition 2 (acceptable stability): as the ranking of Q, $A^1$ must the superior in the ranking of S and R. In case that one condition is not satisfied, a set of compromised alternative is proposed:

1 If condition 2 is not satisfied, then $A^1$. and $A^2$ are compromise solution
2 If condition 1 is not satisfied, then $A^1, A^2, \dots, A^m$.. where $A^m$. is determined by Eq. (29).

$$(A^m) - Q\left(A^1\right) < \frac{1}{m-1}. \tag{29}$$

## Proposed model

In this research, we propose a plithogenic MCDM approach for solving financial performance evaluation of manufacturing industries with high consideration of uncertainty. In this section, the suggested plithogenic approach based on AHP, VIKOR and TOPSIS methods will be presented in details.

✓ *Phase 1* Establish a committee of decision makers with experience in finance and manufacturing industry, $DM = \left\{d_1, d_2, \dots, d_k\right\}$.. Define the problem dimensions, consisting in a set of criteria which is a financial ratio that evaluate a firm's financial performance $C = \left\{c_1, c_2, \dots, c_n\right\}$., and the alternatives (firms) that need to be evaluated $A = \left\{a_1, a_2, \dots, a_m\right\}$.
✓ *Phase 2* Using AHP, compute the weight of criteria and sub-criteria of the problem.

- *Step 1* Define the problem as a hierarchy. The main goal (first level) is to rank the companies in a specific manufacturing industry and select the companies that have best financial performance. Therefore, determine the financial ratios that will be used in the evaluation process as main criteria (second level) and sub-criteria (third level). Then, determine the alternatives (firms that will be evaluated) as the last leve
- *Step 2* Construct the pairwise comparison of the second and third levels as Eq. (30)), based on the neutrosophic evaluation scale according to decision maker's eluations as shown in Table 2.

**Table 2** Triangular neutrosophic scale for decision matrix

| Scale explanation | Neutrosophic triangular scale |
|---|---|
| Weakly important WI | ((0.2,0.3,0.4),0.3,0.8,0.7) |
| Equally important EI | ((1,1,1),0.5,0.5,0.5) |
| Strongly important SI | ((0.4,0.5,0.6),0.8,0.15,0.2) |
| Very strongly important VSI | ((0.6,0.7,0.8),0.9,0.1,0.1) |
| Absolutely important AI | ((0.9,0.9,0.9),1,0,0) |

$$\begin{matrix} c_1 \\ c_2 \\ \cdots \\ c_n \end{matrix} \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1n} \\ c_{21} & c_{22} & \cdots & c_{21} \\ \cdots & \cdots & \cdots & \cdots \\ c_{m1} & c_{m2} & \cdots & c_{mn} \end{bmatrix}_{m\times n}. \tag{30}$$

- *Step 3* Aggregate the decision maker's evaluation using plithogenic aggregation operator as mentioned in Eqs. (9, 11, and 12) with consideration to contradiction degree.
- *Step 4* Check the pairwise comparison consistency in order to improve the decision matrix, by calculating consistency index (CI) and consistency ratio (CR) using Eq. (14).
- *Step 5* Calculate the overall weight by multiplying the weight of the second and third level.

✓ *Phase 3* Rank the alternatives based on the weight of the financial ratios using VIKOR and TOPSIS, comparatively.

- *Step 1* Every decision maker $k$ construct the evaluation matrix which compares the alternatives $m$ to criteria $n$.

$$\left[d_{ij}\right]^k_{m\times n} = \begin{bmatrix} d^k_{11} & d^k_{12} & \cdots & d^k_{1n} \\ d^k_{21} & d^k_{22} & \cdots & d^k_{21} \\ \cdots & \cdots & \cdots & \cdots \\ d^k_{m1} & d^k_{m2} & \cdots & d^k_{mn} \end{bmatrix}_{m\times n} \tag{31}$$

- *Step 2* Aggregate the $k$ decision matrices into single decision matrix of all decision makers' evaluations by plithogenic aggregation using Eqs. (9, 11, and 12) (Smarandache 2018a, b, c). In this step, plithogenic set aggregation with contradiction degree ensures more accurate and consistent aggregated decision.
- *Step 3* Transform the aggregated decision matrix into crisp values by using Eq. (32).

$$S(a) = \frac{1}{8}\left(a_1 + b_1 + c_1\right) \times (2 + \alpha - \theta - \beta). \tag{32}$$

- *Step 4* Normalize the decision matrix using Eq. (15).
- *Step 5* Compute $S_i$., $R_i$ and $Q_i$. by Eqs. (25), (26), and (27) respectively, where $w_j$ is the weight of each criterion determined using AHP method in Phase 2.
- *Step 6* Rank the alternatives based on $Q_i$.
- *Step 7* Employ the weight determined using AHP method in Phase 2 in order to construct the weighted matrix using Eq. (16).
- *Step 8* Calculate the distance of alternatives to the PIS and NIS using Eqs. (17–22).
- *Step 9* Rank the alternatives based on the closeness coefficient using Eq. (23).
- *Step 10* Compare the evaluation results from VIKOR and TOPSIS.

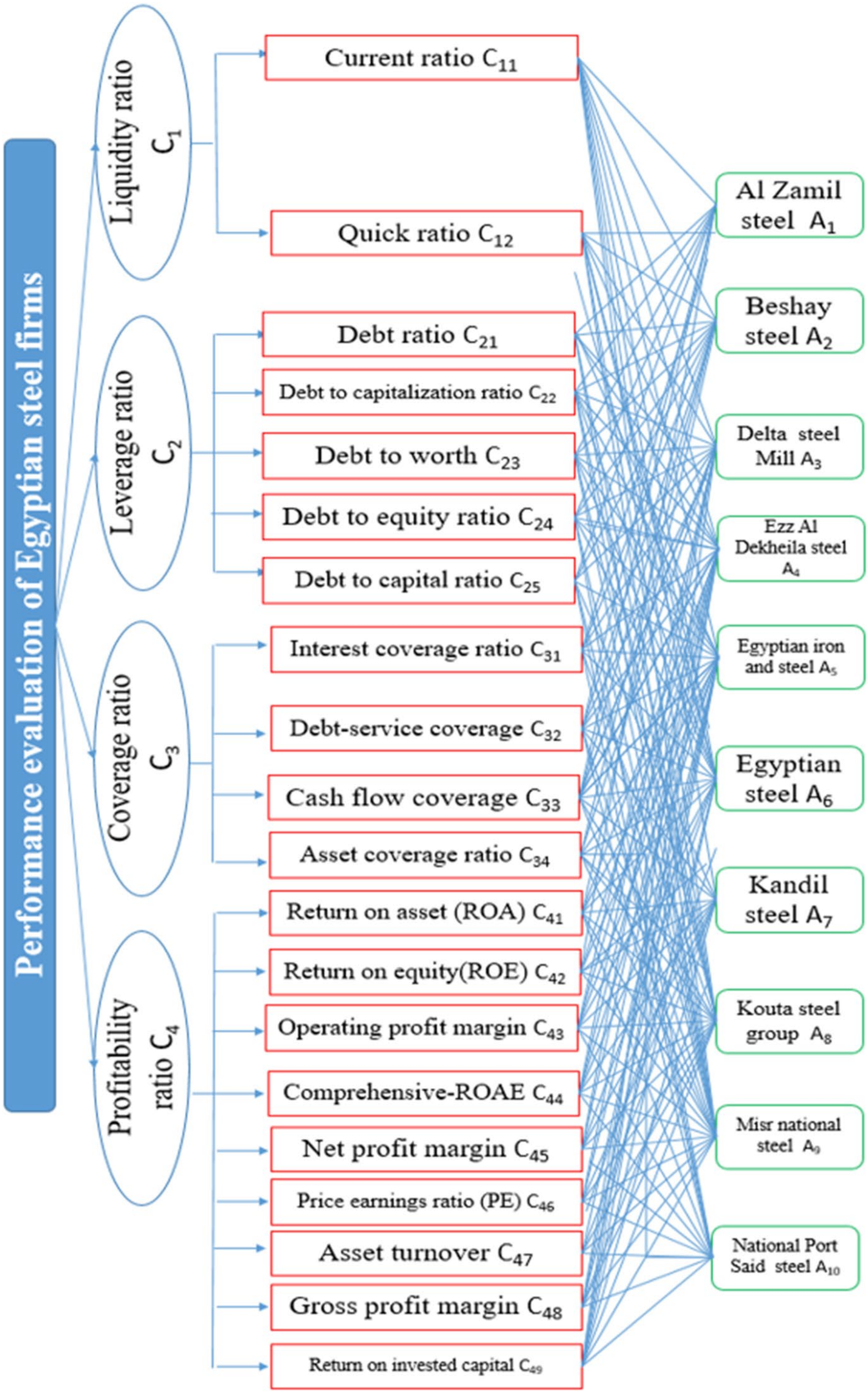


**Fig. 2** Egyptian steel industry

**Table 3** Experts evaluations

| DM1 | C1 | C2 | C3 | C4 |
|---|---|---|---|---|
| C1 | EI | EI | SI | EI |
| C2 | – | EI | VSI | WI |
| C3 | – | – | EI | WI |
| C4 | – | – | – | EI |
| DM2 | C1 | C2 | C3 | C4 |
| C1 | EI | SI | VSI | WI |
| C2 | – | EI | SI | WI |
| C3 | – | – | EI | WI |
| C4 | – | – | – | EI |
| DM3 | C1 | C2 | C3 | C4 |
| C1 | EI | SI | SI | EI |
| C2 | – | EI | SI | WI |
| C3 | – | – | EI | WI |
| C4 | – | – | – | EI |

**Table 4** Aggregated pairwise comparison of level 1

| CD | 0 | 0.25 | 0.5 | 0.75 |
|---|---|---|---|---|
| | $C_1$ | $C_2$ | $C_3$ | $C_4$ |
| $C_1$ | ((1,1,1),0.5,0.5,0.5)) | ((0.35,0.44,0.54),0.54, 0.7,0.23) | ((0.45,0.55,0.65),0.83,0.1,0.1) | ((0.95,0.97,0.96),0.43,0.6,0.6) |
| $C_2$ | – | ((1,1,1),0.5,0.5,0.5) | ((0.45,0.55,0.65),0.83,0.1,0.1) | ((0.33,0.47,0.6),0.3,0.8,0.7) |
| $C_3$ | – | – | ((1,1,1),0.5,0.5,0.5) | ((0.33,0.47,0.6),0.3,0.8,0.7)) |
| $C_4$ | – | – | – | ((1,1,1),0.5,0.5,0.5) |

## Case study and results

### Case study dimensions

Steel industry is the second largest steel market in North Africa region in terms of production and the third in the term of consumption. Due to population growth, steel demand increased in the past decade, and consequently that is why steel industry expanded tremendously in Egypt (Mahmoud and Mahmoud 2019). To measure the financial performance of top 10 Egyptian steel companies, there are four main financial ratios that will be considered, i.e.: Liquidity ratios $C_1$, Leverage ratios $C_2$, Coverage ratios $C_3$, and Profitability ratios $C_4$. They were explained in "Literature review" section. The 20 sub-criteria of the evaluation are depicted in Fig. 2, and were also discussed in details in "Literature review" section. A

**Table 5** Weight of the main criteria (level 2)

| Criteria | $C_1$ | $C_2$ | $C_3$ | $C_4$ |
|---|---|---|---|---|
| Weight | 0.214 | 0.271 | 0.109 | 0.406 |

**Table 6** Local weight, global weight, and ranking of performance ratios

| Main criteria | Weight | Sub-criteria | Local weight | Global weight | Rank |
|---|---|---|---|---|---|
| $C_1$ | 0.214 | $C_{11}$ | 0.319 | 0.0683 | 4 |
| | | $C_{12}$ | 0.681 | 0.1457 | 1 |
| $C_2$ | 0.271 | $C_{21}$ | 0.271 | 0.0734 | 3 |
| | | $C_{22}$ | 0.179 | 0.0485 | 10 |
| | | $C_{23}$ | 0.103 | 0.0279 | 15 |
| | | $C_{24}$ | 0.318 | 0.0862 | 2 |
| | | $C_{25}$ | 0.129 | 0.0350 | 12 |
| $C_3$ | 0.109 | $C_{31}$ | 0.374 | 0.0408 | 11 |
| | | $C_{32}$ | 0.142 | 0.0155 | 20 |
| | | $C_{33}$ | 0.254 | 0.0277 | 16 |
| | | $C_{34}$ | 0.231 | 0.0252 | 18 |
| $C_4$ | 0.406 | $C_{41}$ | 0.149 | 0.0605 | 8 |
| | | $C_{42}$ | 0.154 | 0.0625 | 6 |
| | | $C_{43}$ | 0.159 | 0.0646 | 5 |
| | | $C_{44}$ | 0.123 | 0.0499 | 9 |
| | | $C_{45}$ | 0.150 | 0.0609 | 7 |
| | | $C_{46}$ | 0.064 | 0.0260 | 17 |
| | | $C_{47}$ | 0.078 | 0.0317 | 13 |
| | | $C_{48}$ | 0.076 | 0.0309 | 14 |
| | | $C_{49}$ | 0.047 | 0.0191 | 19 |

group of three experts that have a long experience in finance assisted the evaluation process. The proposed model in previous section will be used to rank the top 10 steel firms in Egypt.

❖ *Phase 1* The problem dimensions, the criteria, sub-criteria, and alternatives to measure the financial performance are clearly illustrated in Fig. 2.
❖ *Phase 2* Applying AHP to determine the weight of criteria. In this phase, in order to deal with uncertainty, the judgments of the three decision-makers were presented using triangular neutrosophic scale as shown in Table 2.

Table 3 shows the decision makers' evaluation for the 4 main financial ratios. Then, by using plithogenic aggregation operator, aggregated evaluation matrix was calculated based on contradiction (dissimilarity) degree (CD) of each criterion to the dominant (most important in this case is liquidity ratios) as shown in Table 4. By calculating consistency ratio, we note that pairwise comparison

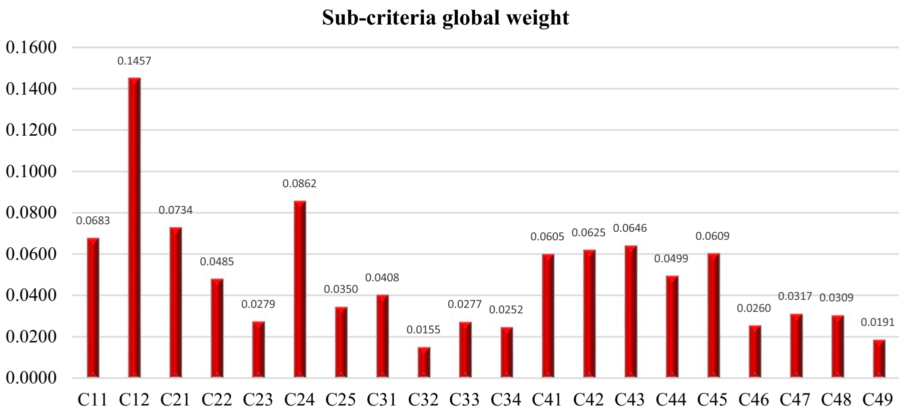


**Fig. 3** Sub-criteria global weight

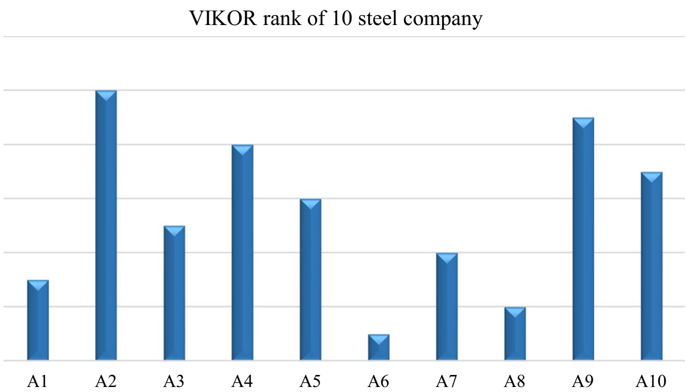


**Fig. 4** VIKOR rank ($v = 0.5$)

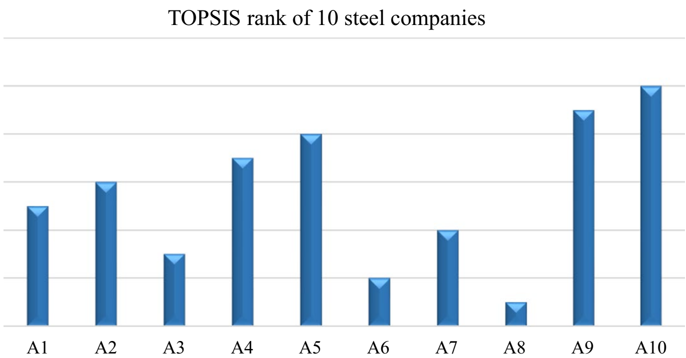


**Fig. 5** TOPSIS rank

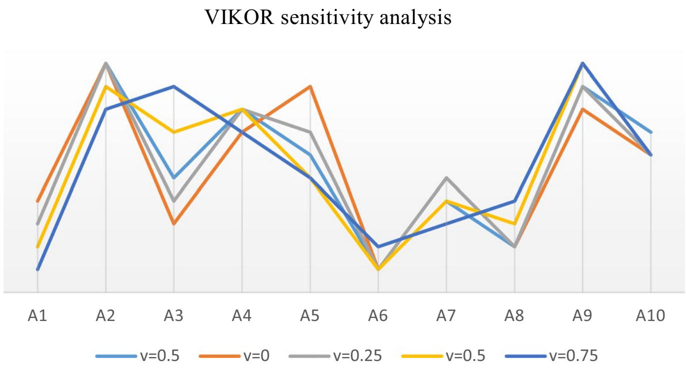


**Fig. 6** Sensitivity analysis of *v*

**Table 7** Importance linguistic scale

| Linguistic scale | Triangular neutrosophic scale |
|---|---|
| Very low impact VLI | ((0.1,0.2,0.3),0.5,0.1,0.3) |
| Low Impact LI | ((0.2,0.3,0.4),0.8,0.2,0.3) |
| Fairly low impact FLI | ((0.3,0.4,0.5),0.1,0.1,0.1) |
| Medium impact MI | ((0.5,0.6,0.7),0.9,0.2,0.1) |
| Fairly high impact FHI | ((0.7,0.8,0.9),0.8,0.3,0.5) |
| High impact HI | ((0.8,0.9,1),0.9,0.2,0.3) |
| Extreme impact EI | ((0.9,1,1),0.1,0.2,0.2) |

is within the acceptable consistency limit (equal to 0.1). The weight of the four main financial ratios (Level 2) are as shown in Table 5 by AHP.

For level 3, the sub-criteria weight the all steps that applied in level 2 are performed. In order to find the overall weight, multiply weight of level 2 by level three as Table 6 and Fig. 3 show (Figs. 4, 5, 6).

*Phase 3* In this phase, the aim is to rank Egyptian steel companies by VIKOR and TOPSIS, comparatively. Using importance linguistic scale in Table 7, the three experts evaluate the 10 firms based on financial ratios.

Then, aggregate the expert's evaluation using plithogenic aggregation operator and de-neutrosophication of the aggregated evaluation using Eq. (32). The result of crisp aggregated evaluation matrix is shown in Table 8. Using Eq. (15), the normalized decision matrix is depicted in Table 9. The best and worst values of criteria are shown in Table 10. The values of $S_i$, $R_i$ and $Q_i$ were calculated as shown in Table 11 using Eqs. (25), (26), and (27) respectively. The $w_j$ values, found by AHP, was determined from Table 6. According to VIKOR conditions, Beshay Steel has the best rank and satisfies condition 2, but it does not satisfy condition 1 (0.0832 – 0.0438 < 1/9). That is why the compromise solution is Beshay Steel, Misr National Steel, and Ezz Al Dekheila Steel.

**Table 8** Aggregated evaluation matrix of the top 10 Egyptian steel companies

| | C11 | C12 | C21 | C22 | C23 | C24 | C25 | C31 | C32 | C33 | C34 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A1 | 0.5355 | 0.5842 | 0.7432 | 0.4885 | 0.2971 | 0.6000 | 0.2827 | 0.5779 | 0.1678 | 0.2624 | 0.2588 |
| A2 | 0.5355 | 0.5842 | 0.5979 | 0.2999 | 0.2971 | 0.6000 | 0.2827 | 0.2902 | 0.1678 | 0.2865 | 0.2588 |
| A3 | 0.7236 | 0.5842 | 0.5515 | 0.5647 | 0.2971 | 0.6000 | 0.2923 | 0.2902 | 0.2665 | 0.2865 | 0.2588 |
| A4 | 0.7236 | 0.7335 | 0.5515 | 0.5647 | 0.2971 | 0.7704 | 0.2923 | 0.5779 | 0.2665 | 0.2865 | 0.2588 |
| A5 | 0.5820 | 0.7335 | 0.7432 | 0.5647 | 0.2869 | 0.7704 | 0.2923 | 0.3529 | 0.2856 | 0.2865 | 0.2588 |
| A6 | 0.7236 | 0.5842 | 0.7432 | 0.2999 | 0.2869 | 0.6444 | 0.5750 | 0.3529 | 0.2856 | 0.2624 | 0.2588 |
| A7 | 0.5355 | 0.5842 | 0.7432 | 0.2999 | 0.2869 | 0.6444 | 0.2759 | 0.2710 | 0.2882 | 0.2865 | 0.2850 |
| A8 | 0.6679 | 0.5842 | 0.5979 | 0.3601 | 0.5684 | 0.6000 | 0.3543 | 0.5779 | 0.2882 | 0.2865 | 0.2850 |
| A9 | 0.7236 | 0.7335 | 0.5979 | 0.5647 | 0.2869 | 0.7704 | 0.2923 | 0.2902 | 0.2665 | 0.2865 | 0.2588 |
| A10 | 0.7236 | 0.7335 | 0.7432 | 0.5647 | 0.2869 | 0.7704 | 0.2759 | 0.2710 | 0.1678 | 0.2624 | 0.2588 |

| | C41 | C42 | C43 | C44 | C45 | C46 | C47 | C48 | C49 |
|---|---|---|---|---|---|---|---|---|---|
| A1 | 0.5868 | 0.5884 | 0.6117 | 0.5906 | 0.5913 | 0.2455 | 0.2799 | 0.2505 | 0.1316 |
| A2 | 0.5868 | 0.5884 | 0.6117 | 0.2809 | 0.5913 | 0.2455 | 0.2599 | 0.2505 | 0.2445 |
| A3 | 0.6081 | 0.8238 | 0.6117 | 0.2809 | 0.8424 | 0.2800 | 0.2599 | 0.2800 | 0.2445 |
| A4 | 0.6043 | 0.8238 | 0.6117 | 0.5002 | 0.8424 | 0.2597 | 0.2799 | 0.2800 | 0.2445 |
| A5 | 0.5868 | 0.8238 | 0.8303 | 0.5906 | 0.8424 | 0.2597 | 0.2799 | 0.2800 | 0.2445 |
| A6 | 0.5868 | 0.8238 | 0.6792 | 0.5906 | 0.6721 | 0.2455 | 0.2799 | 0.2800 | 0.2445 |
| A7 | 0.2837 | 0.7664 | 0.6242 | 0.2809 | 0.5913 | 0.2800 | 0.2447 | 0.2444 | 0.2803 |
| A8 | 0.2837 | 0.7664 | 0.8303 | 0.2809 | 0.5913 | 0.2800 | 0.5920 | 0.2800 | 0.2803 |
| A9 | 0.5868 | 0.8238 | 0.8303 | 0.5906 | 0.8424 | 0.2455 | 0.2799 | 0.2800 | 0.2445 |
| A10 | 0.5868 | 0.8238 | 0.8303 | 0.5906 | 0.8424 | 0.2455 | 0.2447 | 0.2444 | 0.2445 |

In order to rank alternatives using TOPSIS, based on Table 9, calculate the weighted normalized matrix using Eq. (16) as shown in Table 12. Then, rank of alternatives in TOPSIS based on the distance of PIS and NIS using Eqs. (17–22) an calculate closeness coefficient using Eq. (23). Table 13 shows the rank of 10 companies based on TOPSIS.

## Results discussion and sensitivity analysis

- As the results of AHP shows, profitability ratios is the most important metric considered to evaluate the financial performance, with weight 0.406. The second main financial performance measure is leverage ratio, with weight 0.271. The last two criteria are liquidity and coverage ratios, with weights 0.214 and 0.109, respectively.
- Ung VIKOR method, the ranking of companies varies based on parameter $v$. It is important to mention the significance of chaining the weight of the strategy $v$ within interval [0, 1]. The sensitivity analysis on $v$ is illustrated in Table 14.

**Table 9** Normalized evaluation matrix

| | C11 | C12 | C21 | C22 | C23 | C24 | C25 | C31 | C32 | C33 | C34 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A1 | 0.0617 | 0.0674 | 0.0857 | 0.0563 | 0.0343 | 0.0692 | 0.0326 | 0.0666 | 0.0193 | 0.0303 | 0.0298 |
| A2 | 0.0681 | 0.0743 | 0.0761 | 0.0381 | 0.0378 | 0.0763 | 0.0360 | 0.0369 | 0.0213 | 0.0365 | 0.0329 |
| A3 | 0.0809 | 0.0653 | 0.0616 | 0.0631 | 0.0332 | 0.0671 | 0.0327 | 0.0324 | 0.0298 | 0.0320 | 0.0289 |
| A4 | 0.0741 | 0.0751 | 0.0565 | 0.0578 | 0.0304 | 0.0789 | 0.0299 | 0.0592 | 0.0273 | 0.0293 | 0.0265 |
| A5 | 0.0588 | 0.0741 | 0.0751 | 0.0571 | 0.0290 | 0.0779 | 0.0295 | 0.0357 | 0.0289 | 0.0290 | 0.0262 |
| A6 | 0.0768 | 0.0620 | 0.0789 | 0.0318 | 0.0305 | 0.0684 | 0.0610 | 0.0375 | 0.0303 | 0.0279 | 0.0275 |
| A7 | 0.0661 | 0.0722 | 0.0918 | 0.0370 | 0.0354 | 0.0796 | 0.0341 | 0.0335 | 0.0356 | 0.0354 | 0.0352 |
| A8 | 0.0714 | 0.0624 | 0.0639 | 0.0385 | 0.0608 | 0.0641 | 0.0379 | 0.0618 | 0.0308 | 0.0306 | 0.0305 |
| A9 | 0.0739 | 0.0749 | 0.0610 | 0.0576 | 0.0293 | 0.0787 | 0.0298 | 0.0296 | 0.0272 | 0.0293 | 0.0264 |
| A10 | 0.0745 | 0.0755 | 0.0765 | 0.0581 | 0.0295 | 0.0793 | 0.0284 | 0.0279 | 0.0173 | 0.0270 | 0.0266 |

| | C41 | C42 | C43 | C44 | C45 | C46 | C47 | C48 | C49 |
|---|---|---|---|---|---|---|---|---|---|
| A1 | 0.0676 | 0.0678 | 0.0705 | 0.0681 | 0.0682 | 0.0283 | 0.0323 | 0.0289 | 0.0152 |
| A2 | 0.0747 | 0.0749 | 0.0778 | 0.0357 | 0.0752 | 0.0312 | 0.0331 | 0.0319 | 0.0311 |
| A3 | 0.0680 | 0.0921 | 0.0684 | 0.0314 | 0.0942 | 0.0313 | 0.0291 | 0.0313 | 0.0273 |
| A4 | 0.0619 | 0.0843 | 0.0626 | 0.0512 | 0.0862 | 0.0266 | 0.0287 | 0.0287 | 0.0250 |
| A5 | 0.0593 | 0.0833 | 0.0839 | 0.0597 | 0.0851 | 0.0263 | 0.0283 | 0.0283 | 0.0247 |
| A6 | 0.0623 | 0.0875 | 0.0721 | 0.0627 | 0.0714 | 0.0261 | 0.0297 | 0.0297 | 0.0260 |
| A7 | 0.0350 | 0.0947 | 0.0771 | 0.0347 | 0.0730 | 0.0346 | 0.0302 | 0.0302 | 0.0346 |
| A8 | 0.0303 | 0.0819 | 0.0888 | 0.0300 | 0.0632 | 0.0299 | 0.0633 | 0.0299 | 0.0300 |
| A9 | 0.0599 | 0.0841 | 0.0848 | 0.0603 | 0.0860 | 0.0251 | 0.0286 | 0.0286 | 0.0250 |
| A10 | 0.0604 | 0.0848 | 0.0855 | 0.0608 | 0.0867 | 0.0253 | 0.0252 | 0.0252 | 0.0252 |

**Table 10** Positive ideal values and negative ideal values

| | C11 | C12 | C21 | C22 | C23 | C24 | C25 | C31 | C32 | C33 | C34 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $f^*$ | 0.0809 | 0.0755 | 0.0565 | 0.0318 | 0.0290 | 0.0641 | 0.0284 | 0.0666 | 0.0356 | 0.0365 | 0.0352 |
| $f^-$ | 0.0588 | 0.0620 | 0.0918 | 0.0631 | 0.0608 | 0.0796 | 0.0610 | 0.0279 | 0.0173 | 0.0270 | 0.0262 |

| | C41 | C42 | C43 | C44 | C45 | C46 | C47 | C48 | C49 |
|---|---|---|---|---|---|---|---|---|---|
| $f^*$ | 0.0747 | 0.0947 | 0.0888 | 0.0681 | 0.0942 | 0.0346 | 0.0633 | 0.0319 | 0.0346 |
| $f^-$ | 0.0303 | 0.0678 | 0.0626 | 0.0300 | 0.0632 | 0.0251 | 0.0252 | 0.0252 | 0.0152 |

- By ranking the top 10 Egyptian steel companies using TOPSIS, we found that closeness coefficient of National Port Said Steel is the highest, with value 0.582464, while Kouta Steel Group is the lowest closeness coefficient, with value 0.363244.

**Table 11** Weighted normalized matrix

| | C11 | C12 | C21 | C22 | C23 | C24 | C25 | C31 | C32 | C33 | C34 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A1 | 0.0042 | 0.0098 | 0.0063 | 0.0027 | 0.0010 | 0.0060 | 0.0011 | 0.0027 | 0.0003 | 0.0008 | 0.0008 |
| A2 | 0.0047 | 0.0108 | 0.0056 | 0.0019 | 0.0011 | 0.0066 | 0.0013 | 0.0015 | 0.0003 | 0.0010 | 0.0008 |
| A3 | 0.0055 | 0.0095 | 0.0045 | 0.0031 | 0.0009 | 0.0058 | 0.0011 | 0.0013 | 0.0005 | 0.0009 | 0.0007 |
| A4 | 0.0051 | 0.0109 | 0.0041 | 0.0028 | 0.0008 | 0.0068 | 0.0010 | 0.0024 | 0.0004 | 0.0008 | 0.0007 |
| A5 | 0.0040 | 0.0108 | 0.0055 | 0.0028 | 0.0008 | 0.0067 | 0.0010 | 0.0015 | 0.0004 | 0.0008 | 0.0007 |
| A6 | 0.0052 | 0.0090 | 0.0058 | 0.0015 | 0.0008 | 0.0059 | 0.0021 | 0.0015 | 0.0005 | 0.0008 | 0.0007 |
| A7 | 0.0045 | 0.0105 | 0.0067 | 0.0018 | 0.0010 | 0.0069 | 0.0012 | 0.0014 | 0.0006 | 0.0010 | 0.0009 |
| A8 | 0.0049 | 0.0091 | 0.0047 | 0.0019 | 0.0017 | 0.0055 | 0.0013 | 0.0025 | 0.0005 | 0.0008 | 0.0008 |
| A9 | 0.0050 | 0.0109 | 0.0045 | 0.0028 | 0.0008 | 0.0068 | 0.0010 | 0.0012 | 0.0004 | 0.0008 | 0.0007 |
| A10 | 0.0051 | 0.0110 | 0.0056 | 0.0028 | 0.0008 | 0.0068 | 0.0010 | 0.0011 | 0.0003 | 0.0007 | 0.0007 |

| | C41 | C42 | C43 | C44 | C45 | C46 | C47 | C48 | C49 |
|---|---|---|---|---|---|---|---|---|---|
| A1 | 0.0041 | 0.0042 | 0.0046 | 0.0034 | 0.0042 | 0.0007 | 0.0010 | 0.0009 | 0.0003 |
| A2 | 0.0045 | 0.0047 | 0.0050 | 0.0018 | 0.0046 | 0.0008 | 0.0010 | 0.0010 | 0.0006 |
| A3 | 0.0041 | 0.0058 | 0.0044 | 0.0016 | 0.0057 | 0.0008 | 0.0009 | 0.0010 | 0.0005 |
| A4 | 0.0037 | 0.0053 | 0.0040 | 0.0026 | 0.0053 | 0.0007 | 0.0009 | 0.0009 | 0.0005 |
| A5 | 0.0036 | 0.0052 | 0.0054 | 0.0030 | 0.0052 | 0.0007 | 0.0009 | 0.0009 | 0.0005 |
| A6 | 0.0038 | 0.0055 | 0.0047 | 0.0031 | 0.0043 | 0.0007 | 0.0009 | 0.0009 | 0.0005 |
| A7 | 0.0021 | 0.0059 | 0.0050 | 0.0017 | 0.0044 | 0.0009 | 0.0010 | 0.0009 | 0.0007 |
| A8 | 0.0018 | 0.0051 | 0.0057 | 0.0015 | 0.0038 | 0.0008 | 0.0020 | 0.0009 | 0.0006 |
| A9 | 0.0036 | 0.0053 | 0.0055 | 0.0030 | 0.0052 | 0.0007 | 0.0009 | 0.0009 | 0.0005 |
| A10 | 0.0037 | 0.0053 | 0.0055 | 0.0030 | 0.0053 | 0.0007 | 0.0008 | 0.0008 | 0.0005 |

**Table 12** Values of $S_i$ and $R_i$

| Alternatives | $S_i$. | $R_i$. | $Q_i$ ($v$ = 0.5) | Rank |
|---|---|---|---|---|
| A1 | 0.574426 | 0.0883 | 0.6302 | 8 |
| A2 | 0.427169 | 0.0680 | 0.0438 | 1 |
| A3 | 0.426575 | 0.1104 | 0.3146 | 6 |
| A4 | 0.430045 | 0.0821 | 0.1434 | 3 |
| A5 | 0.490906 | 0.0765 | 0.2961 | 5 |
| A6 | 0.543307 | 0.1457 | 0.9036 | 10 |
| A7 | 0.503035 | 0.0862 | 0.3958 | 7 |
| A8 | 0.501052 | 0.1411 | 0.7433 | 9 |
| A9 | 0.413016 | 0.0810 | 0.0832 | 2 |
| A10 | 0.466992 | 0.0848 | 0.2749 | 4 |

**Table 13** Steel companies ranking using TOPSIS

| Alternatives | $d^*$ | $d^-$. | $CC_i$. | Rank |
|---|---|---|---|---|
| A1 | 0.012943 | 0.012222 | 0.485668 | 6 |
| A2 | 0.012522 | 0.012642 | 0.502383 | 5 |
| A3 | 0.013351 | 0.011813 | 0.469444 | 8 |
| A4 | 0.012253 | 0.012911 | 0.51307 | 4 |
| A5 | 0.011718 | 0.013447 | 0.534356 | 3 |
| A6 | 0.013669 | 0.011496 | 0.456826 | 9 |
| A7 | 0.012999 | 0.012165 | 0.483436 | 7 |
| A8 | 0.016024 | 0.009141 | 0.363244 | 10 |
| A9 | 0.011534 | 0.013631 | 0.541665 | 2 |
| A10 | 0.010507 | 0.014657 | 0.582464 | 1 |

**Table 14** Ranking of the firms for different values of $v$

| Alternatives | $v=0$ | | $v=0.25$ | | $v=0.5$ | | $v=0.75$ | | v = 1 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $Q_i$ | Rank | $Q_i$. | Rank | $Q_i$ | Rank | $Q_i$ | Rank | $Q_i$ | |
| A1 | 0.2605 | 7 | 0.4454 | 8 | 0.6302 | 8 | 0.8151 | 9 | 1.0000 | 10 |
| A2 | 0.0000 | 1 | 0.0219 | 1 | 0.0438 | 1 | 0.0658 | 2 | 0.0877 | 3 |
| A3 | 0.5451 | 8 | 0.4299 | 7 | 0.3146 | 6 | 0.1993 | 4 | 0.0840 | 2 |
| A4 | 0.1813 | 4 | 0.1624 | 3 | 0.1434 | 3 | 0.1245 | 3 | 0.1055 | 4 |
| A5 | 0.1096 | 2 | 0.2028 | 4 | 0.2961 | 5 | 0.3893 | 6 | 0.4826 | 6 |
| A6 | 1.0000 | 10 | 0.9518 | 10 | 0.9036 | 10 | 0.8554 | 10 | 0.8072 | 9 |
| A7 | 0.2339 | 6 | 0.3148 | 6 | 0.3958 | 7 | 0.4767 | 7 | 0.5577 | 8 |
| A8 | 0.9412 | 9 | 0.8422 | 9 | 0.7433 | 9 | 0.6444 | 8 | 0.5454 | 7 |
| A9 | 0.1665 | 3 | 0.1248 | 2 | 0.0832 | 2 | 0.0416 | 1 | 0.0000 | 1 |
| A10 | 0.2153 | 5 | 0.2451 | 5 | 0.2749 | 4 | 0.3046 | 5 | 0.3344 | 5 |

## Conclusion

Among several problems in multi-criteria decision-making, one of the most significant is ranking the companies based on their financial performance. In addition, population growth consequently increases the demand of steel. As a result, we proposed an integrated approach to evaluate steel industry in Egypt. Primarily, the proposed approach studies financial performance evaluation under uncertainty and vague information, by solving the problem using MCDM techniques based on plithogenic set. The importance of plithogeny derives from the consideration of all decision making dimensions (i.e. true, indeterminacy, and falsity).

To weight the problem elements, neutrosophic AHP method was used based on plithogenic aggregation operations to ensure consistent results. We used VIKOR and TOPSIS to rank the companies based on their financial performance. First phase of this approach defined the problem dimensions, such as committee of decision-makers, criteria, sub-criteria and the alternatives. The second phase comprised the calculation of weights by using AHP method based on plithogenic set. The final phase, also based on plithogenic set, used VIKOR and TOPSIS comparatively, to rank the alternatives.

Finally, the proposed approach was examined on a real case study of Egyptian steel industry. The top 10 steel company in Egypt were evaluated for their financial performance based on 4 main criteria (financial ratios) and 20 sub-criteria. On one hand, by VIKOR method, Beshay Steel, Misr National Steel, and Ezz Al Dekheila Steel obtained the top ranking. On the other hand, TOPSIS shows that Misr National Steel, National Port Said Steel, and Egyptian Iron and Steel had the best financial performance.

For future works, the proposed approach could be used for financial evaluation problems of other segments. In addition to the proposed methods in this research, other MCDM techniques, e.g. MABAC, BWM, could be used in such evaluation problems.

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## Compliance with ethical standards

**Conflict of interest** Authors declare that there is no conflict of interest about the research.

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