



The hybrid CoCoSo decision making model with interval value Neutrosophic set for evaluation the digital maturity of firms: Evidence from Vietnam

Truong Thi Thuy Duong

Banking Academy of Vietnam, email: duongtt@hvnh.edu.vn

Abstract. Assessing the digital maturity of businesses plays a crucial role in their development in the digital environment. Neutrosophic sets have been widely applied in many problems to address uncertainty in complex realities. The Combined Compromise Solution (CoCoSo) techniques have been used to address multi-criteria decision making problem. In this paper, an hybrid model combining the CoCoSo technique, entropy, and score function is used to address multi-criteria decision making problem under interval Neutrosophic environment. Information entropy is used to manage the weighted values of criteria in the decision-making model, and the score function is used to transform the evaluation into interval value Neutrosophic in the CoCoSo technique. Finally, the digital maturity level of a business is evaluated using proposed integrated model.

Keywords: Interval Neutrosophic Set, Digital maturity, CoCoSo, entropy, decision making

1. Introduction

The Fourth Industrial Revolution (Industry 4.0), characterized by the emergence of technologies such as artificial intelligence (AI), the Internet of Things (IoT), robotics and robotic process automation (RPA), big data analytics, and blockchain, has created numerous opportunities for the development of new production, distribution, and business models worldwide. This transformation requires organizations to formulate a digitalization strategy that includes a clear action plan and roadmap (Antony et al., 2021). To achieve this, businesses must assess their level of digital readiness or digital maturity (Antony et al., 2021). Such assessment tools enable organizations to understand their current stage of development and progress in the digital transformation journey, providing a comprehensive overview of the changes required to effectively deploy digital technologies across multiple organizational functions (Antony et al., 2021). Furthermore, digital transformation has become a critical driver of business efficiency and competitiveness, as firms increasingly seek innovative solutions to optimize their production and operational processes (Brodny & Tutak, 2021).

In Vietnam, Resolution No. 57/BCT emphasizes breakthroughs in science and technology and national digital transformation as key driving forces for the development of modern productive capacities and sustainable economic growth. However, academic research on digital transformation and the digital economy in Vietnam remains relatively limited, particularly with regard to in-depth assessments at the micro (firm) level. Although several reports examining the role of the digital economy in Vietnam have been published, most adopt descriptive approaches based on surveys and expert interviews, followed by basic statistical analyses of the current situation and trend forecasting.

A notable example is the report “*The Future of Vietnam’s Digital Economy: Towards 2030 and 2045*” by Cameron et al. (2019), which introduces an index to assess business awareness and readiness for digital transformation in the agriculture and manufacturing sectors. This index reflects how firms perceive the necessity of adapting to the evolving digital transformation landscape. Nevertheless, the report does not provide empirical results regarding firms’ digital maturity levels. This gap highlights the need to develop a comprehensive model for evaluating digital maturity among Vietnamese enterprises, which would support firms in assessing, adjusting, and strengthening their digital transformation strategies. This need to consider in a variety of aspects, therefore evaluation the digital maturity level of enterprises is multi-criteria decision making problem. However, there are very few MCDM model that have been developed to solve this problem in Vietnam context. This spurred efforts to fill this research gap. The main objective of this study is to propose a comprehensive model for assessing the digital maturity level of businesses in Vietnam.

This study makes several contributions to existing literature as follows. First, it provides a structured set of criteria for evaluating the level of digital transformation of businesses. Second, the study proposes an integrated multi-criteria decision-making (MCDM) framework based on interval value Neutrosophic sets. Specifically, we build a hybrid model which intergrates entropy, score function into CoCoSo technique. The entropy measures under a Neutrosophic environment are employed to determine the weights of evaluation criteria, while the CoCoSo method combined with entropy is used to rank businesses according to their digital maturity levels. This integrated approach allows for the synthesis of multiple criteria, accommodates uncertainty and ambiguity in expert judgments, and enables a comprehensive assessment of digital maturity across different dimensions. Third, the study offers an empirical assessment of the digital maturity level of

Vietnamese enterprises, thereby providing practical insights for both policymakers and business managers.

The remainder of this paper is organized as follows. Following the introduction, Section 2 reviews the relevant literature. Section 3 presents the proposed research framework and methodology. Section 4 reports the empirical results and discusses the assessment of digital maturity levels among Vietnamese businesses. The final section concludes with the study and outlines directions for future research.

2. Research Overview

2.1. Studies on Measuring Digital Maturity and Evaluation Criteria

There are various approaches to conceptualizing and measuring digital maturity. Digital maturity generally refers to the state in which businesses effectively implement digital technologies to achieve organizational and strategic objectives within the broader economic and social context (Brodny & Tutak, 2021). It reflects the extent to which an organization integrates people, culture, organizational structure, and strategic orientation to fully leverage the potential of its technological infrastructure, both internally and externally.

To assess digital maturity, a wide range of measurement approaches have been developed based on different sets of evaluation criteria. Among these, the most adopted approach involves the use of digital maturity criteria combined with index-based calculation models derived from expert-system questionnaires (Brozzi et al., 2021; Karabegović et al., 2023; Mangus et al., 2024). For example, Karabegović et al. (2023) proposed a structured assessment tool designed to evaluate firms' readiness to adopt Industry 4.0 technologies using an expert-based questionnaire framework. Dai et al. (2020) assessed the data-driven integration capabilities of companies using 172 questionnaires collected from managers. Brozzi et al. (2021) surveyed 65 businesses to develop a set of Key Readiness Indicators (KRIs), which provide a deeper explanation of the overall level of digitalization in companies across specific intervention areas. The KRIs focus on companies' digital readiness in terms of strategy, technology requirements, awareness of digital trends, and employee capabilities, aiming to provide additional information to facilitate the identification of technology deployment strategies in small and medium-sized enterprises (SMEs). Luo and Yu (2022) used structural equation modeling (SEM) and regression analysis to assess the digital transformation readiness of enterprises based on external and internal factors such as customer demand, market competition, government policies, digital technology, digital strategy,

organizational capabilities, and leadership roles. In another study by Zhao et al. (2023), researchers enlisted the support of government officials in distributing questionnaires to company executives and employees. This collaborative effort significantly improved the response rate and effectiveness of the questionnaires. However, Zou et al. (2024) systematized three main methods used to measure the digital transformation readiness of enterprises from previous scholarly studies. The authors argue that while questionnaire methods can gather in-depth information, targeting specific details and subjective perspectives, the results are easily influenced by subjective factors, have a low response rate, insufficient sample size, and are difficult to track dynamic changes over time. Wagire et al. (2021) proposed an Industry 4.0 maturity model, based on practical experience and focusing on technology, to assess the maturity level of manufacturing organizations in India. The model includes 7 aspects and 38 maturity assessment items and was empirically applied at an Indian company to determine the digital maturity level. Furthermore, several studies employ traditional linear regression models to examine digital transformation (Luo & Yu, 2022). However, in practice, data related to digital transformation often violates the linearity assumption, as the relationships among variables tend to be complex and non-linear. Consequently, conventional linear regression models may be inadequate and exhibit limitations in capturing such non-linear dynamics.

Existing literature predominantly concentrates on identifying the determinants and economic consequences of digital transformation. With respect to measurement, a variety of approaches have been applied; however, these methods are typically used in isolation rather than within an integrated analytical framework. Moreover, a key limitation of many existing measurement approaches lies in the difficulty of collecting comprehensive firm-level data over extended periods, which constrains the robustness and generalizability of empirical findings.

2.2. Studies on MCDM Models

Due to the complexity of real-world problems and the multidimensional nature of digital maturity assessment—compassing technological, human, and organizational dimensions—expert evaluations may be neither comprehensive nor fully reflective of actual perceptions when they are expressed solely through Likert-scale measurements, as commonly adopted in previous studies. Moreover, the inherent variability of evaluation criteria and cognitive uncertainty faced by experts

make it difficult to precisely articulate judgments using crisp numerical values in practical assessment settings.

In this context, integrating expert judgments with mathematical decision-support techniques provides a more robust and comprehensive analytical approach, namely multi-criteria decision-making (MCDM) models. MCDM methods have been widely applied across various domains, including economics, social sciences, healthcare, and logistics, to address complex decision problems involving multiple and often conflicting criteria. To effectively handle uncertainty and ambiguity in expert evaluations, these judgments are frequently modeled using fuzzy-based approaches, which enable more flexible and realistic representations of human reasoning.

Numerous studies have applied multi-criteria decision-making (MCDM) models to assess the digital transformation readiness of businesses (Brodny and Tutak, 2021; Zhu et al., 2025.). Erbay and Yildirim (2018) developed a hierarchical framework that decomposes digital transformation criteria into multiple levels, employing expert judgments in combination with the Analytic Hierarchy Process (AHP) to determine the weights of criteria and sub-criteria. Parra-López et al. (2021) highlighted the growing importance of digital transformation in the agricultural sector by proposing an integrated AHP–SWOT–PESTLE model. Kropivšek et al. (2021) introduced a comprehensive approach for evaluating corporate websites by incorporating hierarchical analysis with the TOPSIS method. Furthermore, Büyüközkan and Güler (2020) proposed a decision-support framework based on hesitant fuzzy linguistic terms, combined with hierarchical analysis, to determine criteria weights and rank the digital maturity levels of banks.

To overcome the limitations of uncertainty in the comprehensive evaluation process, Smarandache (1998) introduced a new extended form of fuzzy sets, called neutral sets, which allows simultaneous consideration of three aspects: certainty, uncertainty, and bias. Unlike previous extended approaches, the inclusion of a neutral (uncertain) component in the neutral set helps this model more fully reflect the intermediate characteristics of the evaluated object, thereby solving a core problem that previous methods had not effectively addressed. Zhu et al. (2025) put forward an integrated model which the best–worst method with the entropy model are combined. under a single-valued neutrosophic environment. The Co-compromise Solution (CoCoSo) is a relatively new multi-criteria decision-making method (MCDM) proposed by Yazdani et al. (2019). This method is built on the basis of simultaneously harmonizing three different decision-making techniques to create a more integrated evaluation result, thereby helping to draw more

comprehensive and balanced conclusions. CoCoSo has been effectively applied in many ESG fields, including tourism (Cui and Liu, 2025; Xiao and Zhang, 2025). However, to date, no studies have combined CoCoSo and entropy with interval value Neutrosophic sets in the context of measuring numerical maturity. This motivate to build a novel hybrid model for evaluating the digital maturity level using interval value Neutrosophic sets.

3. Preliminaries and Methodology

In this section, we present some fundamental concepts of Neutrosophic set and its characteristics which is proposed by Smarandache (1998).

Definition 1 (Smarandache, 1998). Given the finite universe set X . A Neutrosophics set (NS) A in X is formed by $A = \{ \langle x, (T_A(x), I_A(x), F_A(x)) \rangle, x \in X \}$, $T_A(x), I_A(x), F_A(x) \subseteq [0,1]$ are truth-membership, indeterminacy-membership and falsity-membership functions, respectively.

For each element x of X , an interval value Neutrosophic set (IVNS) A can be denoted by the following symbol $A = \{ \langle x, [T_A^L(x), T_A^U(x)], [I_A^L(x), I_A^U(x)], [F_A^L(x), F_A^U(x)] \rangle \mid x \in X \}$, in which $[T_A^L(x), T_A^U(x)] \subseteq [0,1]$, $[I_A^L(x), I_A^U(x)] \subseteq [0,1]$ and $[F_A^L(x), F_A^U(x)] \subseteq [0,1]$.

The Neutrosophics set are using in a variety of applications such as distance, similarity measures, models. Some operations are introduced as following.

Definition 2 (Wang and Smarandache, 2005). Let X be the universe set which each element in X . For two IVNSs in X , the operations are defined by:

$$N \oplus P = \left\{ \left(x, \left[T_N^L(x) + T_P^L(x) - T_N^L(x) T_P^L(x), T_N^U(x) + T_P^U(x) - T_N^U(x) T_P^U(x) \right], \left[I_N^L(x) I_P^L(x), I_N^U(x) I_P^U(x) \right], \left[F_N^L(x) F_P^L(x), F_N^U(x) F_P^U(x) \right] \right) \mid x \in X \right\}$$

$$N \otimes P = \left\{ \left(x, \left[T_N^L(x) T_P^L(x), T_N^U(x) T_P^U(x) \right], \left[I_N^L(x) + I_P^L(x) - I_N^L(x) I_P^L(x), I_N^U(x) + I_P^U(x) - I_N^U(x) I_P^U(x) \right], \left[F_N^L(x) + F_P^L(x) - F_N^L(x) F_P^L(x), F_N^U(x) + F_P^U(x) - F_N^U(x) F_P^U(x) \right] \right) \mid x \in X \right\}$$

$$\alpha N = \left\{ \left(\left[1 - (1 - T_A^L(x))^\alpha, 1 - (1 - T_A^U(x))^\alpha \right], \left[(I_A^L(x))^\alpha, (I_A^U(x))^\alpha \right], \left[(F_A^L(x))^\alpha, (F_A^U(x))^\alpha \right] \right) \mid x \in X \right\}, \alpha > 0.$$

$$N^\alpha = \left\{ \left(\left[(T_A^L(x))^\alpha, (T_A^U(x))^\alpha \right], \left[1 - (1 - I_A^L(x))^\alpha, 1 - (1 - I_A^U(x))^\alpha \right], \left[1 - (1 - F_A^L(x))^\alpha, 1 - (1 - F_A^U(x))^\alpha \right] \right) \mid x \in X \right\}, \alpha > 0.$$

For two interval value Neutrosophic sets $N_1 = ([T_{N_1}^L(x), T_{N_1}^U(x)], [I_{N_1}^L(x), I_{N_1}^U(x)], [F_{N_1}^L(x), F_{N_1}^U(x)])$, $N_2 = ([T_{N_2}^L(x), T_{N_2}^U(x)], [I_{N_2}^L(x), I_{N_2}^U(x)], [F_{N_2}^L(x), F_{N_2}^U(x)])$. If $N_1 \subseteq N_2$ then

$$T_{N_1}^L(x) \leq T_{N_2}^L(x), T_{N_1}^U(x) \leq T_{N_2}^U(x), I_{N_1}^L(x) \geq I_{N_2}^L(x), I_{N_1}^U(x) \geq I_{N_2}^U(x), F_{N_1}^L(x) \geq F_{N_2}^L(x), F_{N_1}^U(x) \geq F_{N_2}^U(x).$$

Definition 3 (Ye and Du, 2019). For any interval value Neutrosophic set N in a universe set $X = \{x_1, x_2, \dots, x_n\}$, the function

$$E(N) = 1 - \frac{1}{3n} \sum_{i=1}^n \left[|T_N^L(x_j) - 0.5| + |T_N^U(x_j) - 0.5| + |I_N^L(x_j) - 0.5| + |I_N^U(x_j) - 0.5| + |F_N^L(x_j) - 0.5| + |F_N^U(x_j) - 0.5| \right]$$

determines the entropy of an IVNS N .

For all $x \in X$, for convenience, an interval value Neutrosophic set can be denoted by $[T_A^L, T_A^U], [I_A^L, I_A^U], [F_A^L, F_A^U]$.

A score function is a numeric used for comparison of objects. Let N_1, N_2 be two interval Neutrosophic numbers, AZ be a score function on X . If $AZ(N_2) < AZ(N_1)$ then $N_2 \prec N_1$. If $AZ(N_2) > AZ(N_1)$ then $N_2 \succ N_1$.

Definition 4. (Nafei et al., 2021) Let N be a set of NSs, the score function AZ for ranking the NSs is defined as follow:

$$AZ(N) = \frac{(4 + T_N - 2I_N - F_N)(2 - I_N)(2 - F_N)}{5}$$

In line with the mentioned definition, we modified the score function for interval value Neutrosophic set as follows:

Definition 5. Let N be a set of IVNSs, the score function AZ for ranking the IVNSs is defined as follow:

$$AZ(N) = \frac{(8 + T_N^L + T_N^U - 2I_N^L - 2I_N^U - F_N^L - F_N^U)(4 - I_N^L - I_N^U)(4 - F_N^L - F_N^U)}{5}$$

Theorem 1. Suppose that N_1 and N_2 are two IVNSs. If $N_1 \subseteq N_2$ then $AZ(N_1) \leq AZ(N_2)$.

Proof. Let $N_1 = ([T_{N_1}^L, T_{N_1}^U], [I_{N_1}^L, I_{N_1}^U], [F_{N_1}^L, F_{N_1}^U])$, $N_2 = ([T_{N_2}^L, T_{N_2}^U], [I_{N_2}^L, I_{N_2}^U], [F_{N_2}^L, F_{N_2}^U])$ be two interval value Neutrosophic set.

Considering

$$AZ(N_2) - AZ(N_1) = \frac{(8 + T_{N_2}^L + T_{N_2}^U - 2I_{N_2}^L - 2I_{N_2}^U - F_{N_2}^L - F_{N_2}^U)(4 - I_{N_2}^L - I_{N_2}^U)(4 - F_{N_2}^L - F_{N_2}^U)}{5} - \frac{(8 + T_{N_1}^L + T_{N_1}^U - 2I_{N_1}^L - 2I_{N_1}^U - F_{N_1}^L - F_{N_1}^U)(4 - I_{N_1}^L - I_{N_1}^U)(4 - F_{N_1}^L - F_{N_1}^U)}{5}$$

Because $(8 + T_{N_2}^L + T_{N_2}^U - 2I_{N_2}^L - 2I_{N_2}^U - F_{N_2}^L - F_{N_2}^U)(4 - I_{N_2}^L - I_{N_2}^U)(4 - F_{N_2}^L - F_{N_2}^U)$
 $= (8 + T_{N_2}^L + T_{N_2}^U - 2I_{N_2}^L - 2I_{N_2}^U - F_{N_2}^L - F_{N_2}^U)(4 - I_{N_1}^L - I_{N_1}^U + (I_{N_1}^L - I_{N_2}^L) + (I_{N_1}^U - I_{N_2}^U))(4 - F_{N_1}^L - F_{N_1}^U + (F_{N_1}^L - F_{N_2}^L) + (F_{N_1}^U - F_{N_2}^U))$

Let:

$$x_1 = 8 + T_{N_1}^L + T_{N_1}^U - 2I_{N_1}^L - 2I_{N_1}^U - F_{N_1}^L - F_{N_1}^U > 0, x_2 = 8 + T_{N_2}^L + T_{N_2}^U - 2I_{N_2}^L - 2I_{N_2}^U - F_{N_2}^L - F_{N_2}^U > 0,$$

$$y_1 = 4 - F_{N_1}^L - F_{N_1}^U > 0, a_1 = I_{N_1}^L - I_{N_2}^L, a_2 = I_{N_1}^U - I_{N_2}^U, b_1 = F_{N_1}^L - F_{N_2}^L, b_2 = F_{N_1}^U - F_{N_2}^U, z_1 = 4 - F_{N_1}^L - F_{N_1}^U > 0.$$

Then

$$AZ(N_2) - AZ(N_1) = \frac{x_2(y_1 + a_1 + a_2)(z_1 + b_1 + b_2)}{5} - \frac{x_1 y_1 z_1}{5}$$

$$= \frac{(x_2 - x_1)y_1 z_1}{5} + \frac{x_2 z_1(a_1 + a_2) + x_2(a_1 + a_2)(b_1 + b_2)}{5}.$$

If $N_1 \subseteq N_2$ then

$$T_{N_1}^L \leq T_{N_2}^L, T_{N_1}^U \leq T_{N_2}^U, I_{N_1}^L \geq I_{N_2}^L, I_{N_1}^U \geq I_{N_2}^U, F_{N_1}^L \geq F_{N_2}^L, F_{N_1}^U \geq F_{N_2}^U. \text{ Therefore,}$$

$$a_1 > 0, a_2 > 0, b_1 > 0, b_2 > 0, x_2 - x_1 \geq 0. \text{ It implies that } AZ(N_2) - AZ(N_1) \geq 0.$$

Theorem 1 shows the way transformation the interval value Neutrosophic set to scrip value to compare two interval value Neutrosophic sets.

3.4. Proposed framework

This section proposes a method that integrates MCDM framework for evaluating the digital maturity level of firms. Due to the uncertainty in practice driven by multiple aspects, the decision makers take responsibility to assess the importance of weight and the meet criteria of firms by linguistics variables. The model is structured as follows and is described in Figure 1:

Step 1. The decision makers determine the criteria $C = \{C_1, \dots, C_n\}$ for evaluating the digital maturity level of firms. The criteria reflect the digital maturity level of firms including seven pillars.

Step 2. Determine the pairwise comparison matrix A of criteria to evaluate the importance of criteria using linguistics variables.

For each criterion, the importance is determined by experts using linguistics variables with levels such as unimportant (UI), ordinary important (OI), important (I), very important (VI), absolutely important (AI).

Step 3. Transformation matrix A into IVNSs matrix

To minimize personal bias in evaluations and reduce ambiguity and uncertainty, while increasing flexibility in expert assessments, linguistic variables are converted to interval value Neutrosophic sets for greater accuracy. Each criterion is then represented by an interval value Neutrosophic set $C_j^N = [T_{jN}^L, T_{jN}^U], [I_{jN}^L, I_{jN}^U], [F_{jN}^L, F_{jN}^U]$, for all $j = 1, \dots, n$ which is shown in Table 1.

Table 1. The correlation between the linguistic variables and IVNSs

		Linguistic variables	Interval neutrosophic numbers
For the importance		UI (unimportant)	([0.1, 0.2], [0.7, 0.8], [0.6, 0.7])
		OI (ordinary important)	([0.3, 0.4], [0.6, 0.7], [0.5, 0.6])
		I (important)	([0.4, 0.5], [0.5, 0.6], [0.4, 0.5])
		VI (very important)	([0.6, 0.7], [0.4, 0.5], [0.3, 0.4])
		AI (absolutely important)	([0.7, 0.8], [0.2, 0.3], [0.1, 0.2])
For the assessments		EL (extremely low)	([0.1, 0.2], [0.7, 0.8], [0.6, 0.7])
		FL (fairly low)	([0.3, 0.4], [0.6, 0.7], [0.5, 0.6])
		M (medium)	([0.4, 0.5], [0.5, 0.6], [0.4, 0.5])
		FH (fairly high)	([0.6, 0.7], [0.4, 0.5], [0.3, 0.4])
		EH (extremely high)	([0.7, 0.8], [0.2, 0.3], [0.1, 0.2])

Step 4. Calculate the entropy of IVNSs

$$Entropy_j = 1 - \frac{1}{3n} \sum_{i=1}^n \left[\left| T_{jN}^L - 0.5 \right| + \left| T_{jN}^U - 0.5 \right| + \left| I_{jN}^L - 0.5 \right| + \left| I_{jN}^U - 0.5 \right| + \left| F_{jN}^L - 0.5 \right| + \left| F_{jN}^U - 0.5 \right| \right] \tag{1}$$

Step 5. Compute the weight of criteria

For all $j = 1, 2, \dots, n$, the weight of criterion C_j is

$$\omega_j = \frac{1 - Entropy_j}{\sum_{j=1}^n (1 - Entropy_j)} \tag{2}$$

Step 6. Determine the decision matrix B of firms. The experts evaluate the firms under criteria using linguistic variables to evaluate the level digital transformation. The linguistic variables are extremely low, fairly low, medium, fairly high and extremely high. It is shown in Table 1.

$$B = \begin{matrix} & D & C_1 & C_2 & \dots & C_n \\ \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} & \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \end{matrix}$$

Step 7. Transform matrix B into interval value Neutrosophics sets and decision making value

$$B_T = [x_{ij}(N)], x_{ij}(N) = ([T_{ijN}^L, T_{ijN}^U], [I_{ijN}^L, I_{ijN}^U], [F_{ijN}^L, F_{ijN}^U])$$

The decision making value of firms regards to criteria is defined by using score function form

$$\tilde{B}_T = [\tilde{x}_{ij}(N)], \tilde{x}_{ij}(N) = \frac{(8 + T_{ijN}^L + T_{ijN}^U - 2I_{ijN}^L - 2I_{ijN}^U - F_{ijN}^L - F_{ijN}^U)(4 - I_{ijN}^L - I_{ijN}^U)(4 - F_{ijN}^L - F_{ijN}^U)}{5} \tag{3}$$

Step 8. Compute the sum of IVNS weighted and power weighted comparability sequence for each firm

The sum of IVNSs weighed comparability sequence for each firm: $\tilde{S}_i = \bigoplus_{j=1}^n \omega_j \tilde{x}_{ij}(N)$ (4)

The sum of IVNSs power weighted comparability sequence for each firm: $\tilde{P}_i = \bigoplus_{j=1}^n (\tilde{x}_{ij}(N))^{\omega_j}$ (5)

Step 9. Determine the relative weight of firms

$$\tilde{k}_{ia} = \frac{\tilde{S}_i + \tilde{P}_i}{\sum_{i=1}^m (\tilde{S}_i + \tilde{P}_i)}, \tilde{k}_{ib} = \frac{\tilde{S}_i}{\min \tilde{S}_i} + \frac{\tilde{P}_i}{\min \tilde{P}_i}, \tilde{k}_{ic} = \frac{\lambda \tilde{S}_i + (1 - \lambda) \tilde{P}_i}{\lambda \max \tilde{S}_i + (1 - \lambda) \max \tilde{P}_i} \tag{6}$$

Step 10. Determine the evaluated value of firm

$$k_i = (k_{ia} k_{ib} k_{ic})^{\frac{1}{3}} + \frac{1}{3} (k_{ia} + k_{ib} + k_{ic}) \tag{7}$$

Step 11. Rank firms based on the evaluated value of firms. The higher the evaluated value, the higher the ranking.

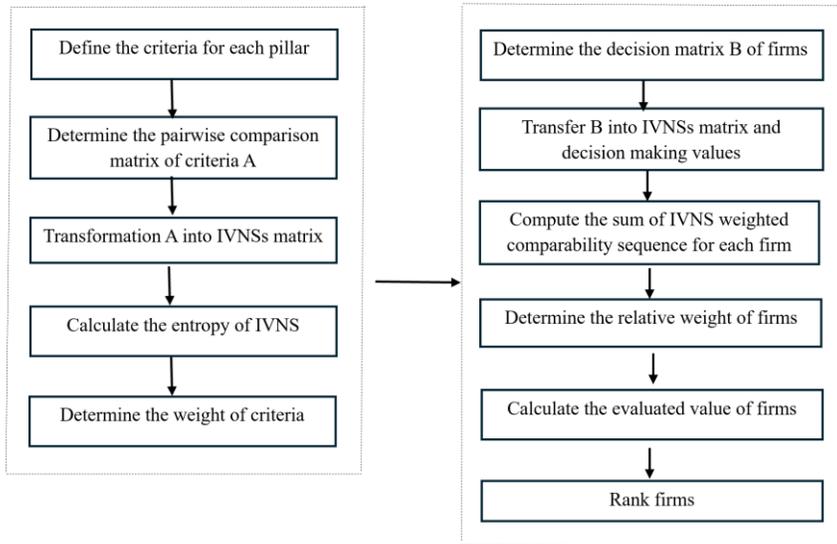


Figure 1. The hybrid CoCoSo decision making model with interval value Neutrosophic set

4. The assessment of the digital maturity transformation of enterprises

With the development of the digital economy, digital transformation has become a topic attracting much attention. This transformation affects the entire organization and brings about changes in many aspects, such as the company's business model, how work is performed, facilities, operations and production techniques, and human resource management. However, in reality, businesses do not easily grasp new concepts such as the Fourth Industrial Revolution because they cannot relate them to their field and business strategy, or they find it difficult to determine their current position in the context of innovation in order to develop appropriate programs and projects.

The concept of digital maturity can be understood as a state of preparation, both psychologically and behaviorally, to take action (Brodny and Tutak, 2021). The level of digital maturity refers to the degree to which an organization, business, or economy understands, applies, and effectively utilizes digital technology and data in its management, operations, and value creation. Digital maturity can be viewed from multiple perspectives, reflecting a company's ability to respond to opportunities and challenges arising from the industry environment.

In this study, a case study applying the proposed decision making model is conducted to assess the digital maturity of 10 small and medium-sized enterprises (SMEs) in Vietnam.

4.1. The criteria for enterprise digital maturity

This study assesses the digital maturity level of small and medium-sized enterprises (SMEs) in Vietnam using a set of criteria issued by the Ministry of Information and Communications of Vietnam, comprising seven pillars. The seven pillars include: strategic orientation (S), customer experience and multi-channel sales (EC), supply schain (SC), digital infrastructure and technology

(DT), operations (O), information systems and data management (ISDM), and people and organization (OR). The criteria are presented in details:

- (1). Strategic Orientation (S): Businesses have been and are applying digital transformation and data analytics solutions to support strategic business decisions such as business model transformation, product and service changes, capital raising, and finding strategic investors.
- (2). Customer Experience and Multi-Channel Sales (EC): Businesses apply technology solutions to analyze customer data, provide customer care, create differentiated customer service, and enhance customer experience.
- (3). Supply Chain (SC): Business processes and core operations have been digitized (production, distribution, etc.).
- (4). Digital Infrastructure and Technology (DT): Businesses use advanced technology solutions (cloud computing, mobile technology, artificial intelligence, machine learning, and big data...).
- (5). Operations (O): Businesses use management software to automate processes, communication, and coordination between departments within the business.
- (6). Information Systems and Data Management (ISDT): The digital transformation solutions for information management and network security that the enterprise is applying are capable of periodically and automatically reviewing and assessing system security risks, and promptly issuing warnings when detecting information system anomalies.
- (7). People and Organization (OR): Employees are trained to enhance their skills, qualifications, and experience. The enterprise digital transformation solution system is capable of sharing information and data in a continuous, timely, and interconnected manner, effectively supporting the management of internal and external activities of the enterprise.

4.2. The weight of criteria of pillars

Four experts in digital transformation, managers and leadership take responsibility for assessing the importance of criteria in digital transformation processes and the satisfaction of enterprises following criteria using linguistic variables. The linguistic variables are transferred into interval value Neutrosophic set following the rules in Table 1, the integrated values are calculated by operations in Definition 2, the entropy of integrated values and the weight of criteria are determined by using Equation (1) and (2). The values are presented in Table 2.

Table 2. The weights of criteria

Criteria	Decision makers				Entropy	Weight
T_1	EH	EH	EH	EH	0.683	0.168
T_2	M	FH	M	FH	0.767	0.124
T_3	M	FH	M	FH	0.767	0.124
T_4	EH	FH	FH	FH	0.833	0.088
T_5	M	M	FH	FH	0.8	0.106
T_6	EH	EH	FH	EH	0.833	0.088
T_7	M	FH	FH	FH	0.433	0.3

The finding in the last column of Table 2 reflexes the weight of criteria. The people and organisation criterion accounts for the largest weight of criteria with 30%. Human resources and organizational capabilities determine an organization's readiness, adaptability, and ability to effectively leverage digital technologies. These are also key factors in determining the extent to which technology is utilized and applied within the organization. While technology provides the infrastructure, it is human resources and organizational culture that transform digital investments into sustainable competitive advantages. The second factor is strategic orientation, account for 16.8 percent. Strategic direction determines the direction, scope, and appropriateness of the digital transformation process. Without strategic alignment, digital investments will be scattered and fail to create a sustainable competitive advantage. Furthermore, strategic direction serves as a compass for the operation of other pillars. The next priority are customer experience and multi-channel sales and supply chain. Customer experience and multi-channel sales enhance market responsiveness, while supply chain digitization improves cost efficiency and flexibility.

Table 3-5 perform the evaluation of experts and the interval value Neutrosophic decision matrix of ten firms regard to seven criteria. The firms's decision making value are calculated based on Equation (3), it is shown in Table 6.

Table 3. The interval value Neutrosophic decision matrix

Firms	Criteria	Decision makers				Interval value Neutrosophic decision matrix
F_1	T_1	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])
	T_2	M	FH	M	FH	([0.51, 0.613], [0.447, 0.548], [0.346, 0.447])
	T_3	M	FH	M	FH	([0.51, 0.613], [0.447, 0.548], [0.346, 0.447])
	T_4	EH	FH	FH	FH	([0.628, 0.729], [0.336, 0.44],[0.228, 0.336])
	T_5	M	M	FH	FH	([0.51, 0.613], [0.447, 0.548], [0.346, 0.447])

	T_6	EH	EH	FH	EH	([0.677, 0.779], [0.238, 0.341], [0.132, 0.238])
	T_7	M	FH	FH	FH	([0.557, 0.659], [0.423, 0.523], [0.322, 0.423])
F_2	T_1	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])
	T_2	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])
	T_3	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])
	T_4	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])
	T_5	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])
	T_6	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])
	T_7	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])
F_3	T_1	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])
	T_2	M	FH	FH	FH	([0.557, 0.659], [0.423, 0.523], [0.322, 0.423])
	T_3	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])
	T_4	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])
	T_5	EH	FH	FH	FH	([0.628, 0.729], [0.336, 0.44],[0.228, 0.336])
	T_6	FH	EH	EH	EH	([0.628, 0.729], [0.336, 0.44],[0.228, 0.336])
	T_7	EH	FH	FH	FH	([0.628, 0.729], [0.336, 0.44],[0.228, 0.336])
F_4	T_1	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])
	T_2	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])
	T_3	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])
	T_4	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])
	T_5	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])
	T_6	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])
	T_7	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])

Table 4. The interval value Neutrosophic number decision matrix

Firms	Criteria	Decision makers				Interval value Neutrosophic decision matrix
F_5	T_1	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])
	T_2	FH	FH	FH	FH	([0.6, 0.7], [0.4, 0.5], [0.3, 0.4])
	T_3	FL	M	M	M	([0.376, 0.477], [0.523, 0.624], [0.423, 0.523])
	T_4	FH	FH	FH	FH	([0.6, 0.7], [0.4, 0.5], [0.3, 0.4])
	T_5	FH	FH	FH	FH	([0.458, 0.56], [0.473, 0.573], [0.372, 0.473])
	T_6	M	M	FH	FH	([0.51, 0.613], [0.447, 0.548], [0.346, 0.447])
	T_7	M	M	M	M	([0.4, 0.5], [0.5, 0.6],[0.4, 0.5])

F_6	T_1	M	FH	FH	FH	([0.557, 0.659], [0.423, 0.523], [0.322, 0.423])
	T_2	M	M	FH	FH	([0.51, 0.613], [0.447, 0.548], [0.346, 0.447])
	T_3	M	M	M	M	([0.4, 0.5], [0.5, 0.6], [0.4, 0.5])
	T_4	FH	FH	FH	FH	([0.6, 0.7], [0.4, 0.5], [0.3, 0.4])
	T_5	M	M	M	FH	([0.458, 0.56], [0.473, 0.573], [0.372, 0.473])
	T_6	EH	EH	EH	EH	([0.7, 0.8], [0.2, 0.3], [0.1, 0.2])
	T_7	M	M	FH	FH	([0.51, 0.613], [0.447, 0.548], [0.346, 0.447])
F_7	T_1	M	FH	FH	FH	([0.557, 0.659], [0.423, 0.523], [0.322, 0.423])
	T_2	EL	EL	EL	EL	([0.1, 0.2], [0.7, 0.8], [0.6, 0.7])
	T_3	EL	EL	EL	EL	([0.1, 0.2], [0.7, 0.8], [0.6, 0.7])
	T_4	FL	FL	FL	FL	([0.3, 0.4], [0.6, 0.7], [0.5, 0.6])
	T_5	EL	EL	EL	EL	([0.1, 0.2], [0.7, 0.8], [0.6, 0.7])
	T_6	EL	EL	EL	FL	([0.155, 0.256], [0.674, 0.773], [0.573, 0.674])
	T_7	EL	EL	FL	FL	([0.206, 0.307], [0.648, 0.748], [0.548, 0.648])
F_8	T_1	FL	FL	FL	FL	([0.3, 0.4], [0.6, 0.7], [0.5, 0.6])
	T_2	EL	EL	EL	FL	([0.155, 0.256], [0.674, 0.773], [0.573, 0.674])
	T_3	EL	EL	EL	EL	([0.1, 0.2], [0.7, 0.8], [0.6, 0.7])
	T_4	F	M	M	M	([0.376, 0.477], [0.523, 0.624], [0.423, 0.523])
	T_5	EL	EL	FL	FL	([0.206, 0.307], [0.648, 0.748], [0.548, 0.648])
	T_6	EL	EL	EL	FL	([0.155, 0.256], [0.674, 0.773], [0.573, 0.674])
	T_7	EL	EL	FL	FL	([0.206, 0.307], [0.648, 0.748], [0.548, 0.648])

Table 5. The interval value Neutrosophic decision matrix

Firms	Criteria	Decision makers				Interval value Neutrosophic decision matrix
F_9	T_1	FL	FL	FL	FL	([0.3, 0.4], [0.6, 0.7], [0.5, 0.6])
	T_2	EL	EL	EL	FL	([0.155, 0.256], [0.674, 0.773], [0.573, 0.674])
	T_3	FL	M	M	FL	([0.352, 0.452], [0.548, 0.648], [0.447, 0.548])
	T_4	FL	FL	FL	FL	([0.6, 0.7], [0.4, 0.5], [0.3, 0.4])
	T_5	FL	FL	FL	EL	([0.628, 0.729], [0.336, 0.44], [0.228, 0.336])
	T_6	M	M	M	FL	([0.458, 0.56], [0.473, 0.573], [0.372, 0.473])
	T_7	M	M	M	M	([0.4, 0.5], [0.5, 0.6], [0.4, 0.5])
F_{10}	T_1	FL	M	M	M	([0.376, 0.477], [0.523, 0.624], [0.423, 0.523])
	T_2	FL	FL	M	M	([0.283, 0.384], [0.596, 0.696], [0.495, 0.596])

T_3	FL	FL	FL	FL	([0.3, 0.4], [0.6, 0.7], [0.5, 0.6])
T_4	FL	FL	FL	M	([0.326, 0.427], [0.573, 0.674], [0.473, 0.573])
T_5	EH	EH	EH	EH	([0.7,0.8], [0.2, 0.3], [0.1, 0.2])
T_6	FH	FH	FH	EH	([0.628, 0.729], [0.336, 0.44],[0.228, 0.336])
T_7	M	M	FH	FH	([0.51, 0.613], [0.447, 0.548], [0.346, 0.447])

Table 6. The decision making value of firms

Firms	The decision making value						
	T_1	T_2	T_3	T_4	T_5	T_6	T_7
F_1	10.619	6.108	6.108	8.018	6.108	9.849	9.849
F_2	10.619	10.619	10.619	10.619	10.619	10.619	10.619
F_3	10.619	6.538	10.619	10.619	8.018	8.017	8.017
F_4	10.619	10.619	10.619	10.619	10.619	10.619	10.619
F_5	10.619	6.956	4.890	6.9564	5.666	6.108	6.108
F_6	6.538	6.108	5.214	6.9564	5.666	10.619	10.619
F_7	6.538	2.7	2.7	3.915	2.7	3.000	3.000
F_8	3.915	3.000	2.7	4.890	3.303	3.000	3.000
F_9	3.915	3.000	4.565	6.9564	8.017	5.666	5.666
F_{10}	4.890	3.932	3.915	4.239	10.619	8.017	8.017

The decision making values of firms are using to compute the sum of IVNS weighted and power weighted comparability sequence for each firm by Equation (4) and (5). The relative weight of firms using Equation (6) in case the parameters change from 0.1 to 0.5, it is presented in Table 7.

Table 7. The relative weight of firms

Firms	S_i	P_i	K_{ia}	K_{ib}	K_{ic}				
					$\lambda = 0.1$	$\lambda = 0.2$	$\lambda = 0.3$	$\lambda = 0.4$	$\lambda = 0.5$
F_1	8.492	9.619	0.110	3.718	0.949	0.931	0.914	0.897	0.880
F_2	10.619	9.954	0.125	4.399	1.000	1.000	1.000	1.000	1.000
F_3	8.824	9.643	0.112	3.821	0.954	0.940	0.926	0.911	0.898
F_4	10.619	9.954	0.125	4.399	1.000	1.000	1.000	1.000	1.000
F_5	6.849	9.264	0.098	3.179	0.900	0.871	0.841	0.812	0.783
F_6	7.854	9.507	0.106	3.512	0.932	0.910	0.888	0.866	0.844
F_7	3.569	8.367	0.073	2.083	0.787	0.734	0.682	0.631	0.580
F_8	3.316	8.314	0.071	2.000	0.780	0.725	0.671	0.618	0.565
F_9	5.269	8.897	0.086	2.659	0.852	0.810	0.769	0.729	0.689
F_{10}	6.419	9.170	0.095	3.038	0.888	0.855	0.822	0.790	0.758

The value of firms is described in Table 8, and the ranking of firms is defined based on the value firms. Although the parameter changed from 0.1 to 0.5, the company's value ranking remained unchanged, demonstrating stability in the valuation table. This confirms the reliable digital maturity ranking and the validity of proposed model. The outcome shows that F_1 is the highest digital maturity level, the second and fourth firms are given priority, following by $F_3, F_1, F_6, F_5, F_{10}, F_9, F_8$.

Table 8. The ranking of firms

Firms	Value firm					Rank
	$\lambda = 0.1$	$\lambda = 0.2$	$\lambda = 0.3$	$\lambda = 0.4$	$\lambda = 0.5$	
F_1	2.322	2.311	2.301	1.697	2.281	3
F_2	2.661	2.661	2.661	2.025	2.661	1
F_3	2.371	2.363	2.354	1.745	2.338	2
F_4	2.661	2.661	2.661	2.025	2.661	1
F_5	2.047	2.030	2.013	1.447	1.978	5
F_6	2.218	2.205	2.192	1.601	2.166	4
F_7	1.473	1.444	1.415	0.960	1.356	8
F_8	1.430	1.400	1.370	0.925	1.309	9
F_9	1.779	1.755	1.732	1.213	1.685	7
F_{10}	1.975	1.956	1.937	1.383	1.899	6

5. Conclusion

The digital transformation plays an important role to boost development and take advantages. Digital maturity reflects the ability to integrate technology and data strategically, systematically, and sustainably. Interval value Neutrosophic set have been recognized as useful tool in many problems such as decision making, classification. This paper proposes the hybrid CoCoSo model under a neutrosophic environment and integrated operators to solve a decision-making problem. Information entropy techniques are used to manage weighted values based on IVNS. A score function is proposed to transform assessments from experts on the IVNS field. The hybrid CoCoSo model are proposed by integrating CoCoSo technique, entropy and score function under interval value Neutrosophic set. Finally, a practical application measuring the digital maturity of businesses in Vietnam is applied using the combined model.

The finding shows the absolutely advantage of people and organisation pillar in judgement of digital maturity as well as digital transformation process, following by strategic orientation. The ranking reflects the maturity of enterprise in digital transformation processes.

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