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E-commerce Website Quality Evaluation Using Triangular Neutrosophic with TODIM Under Uncertainty Environment

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Abstract

E-commerce website evaluation is a complex multiple-criteria decision-making problem because of the interconnectedness and interdependence of multiple criteria. This problem involves vast amounts of uncertainty, imprecision, incompleteness, and contradictory evaluation data. Therefore, this study proposes a multi-criteria e-commerce website quality evaluation model to overcome this problem to select the best websites according to certain criteria. This study proposes a hybrid model that combines Triangular Neutrosophic Number (TNN) with Entropy and the TODIM method. The Triangular Neutrosophic Number is used to address all uncertainty and complex evaluation information. Entropy is used to assign weight to each criterion, and TODIM is used to rank the e-commerce website. The case study was conducted through eleven criteria and five international e-commerce websites to illustrate the feasibility and effectiveness of the proposed hybrid model. To validate the proposed model, we compare it with other MCDM methods. Furthermore, we check the stability and robustness of the proposed model through sensitivity analysis with two different approaches. Finally, the results of the TNN with the Entropy and TODIM models are analyzed, indicating that the superiority of the proposed model is due to the competence of the acquired results, and the rankings are sufficiently stable.

Keywords: E-commerce; Website Quality Evaluation; MCDM; Triangular Neutrosophic Numbers; Entropy; TODIM

1. Introduction

Over the last thirty years, websites have emerged as a crucial platform on the Internet for sharing and distributing information, as well as delivering services to the public [1] . These websites are considered the main medium for educational institutions [2] , entertainment [3], businesses [4], governments [5-7], e-banking [8] . There are a massive number of websites that exist on the internet today, especially after COVID-19 pandemic which influences online shopping behavior where people tend to reach this purchase without leaving their homes and risking themselves during pandemics[9, 10]. Based on statistics by [11], online shoppers in 2025 reached 2.77 billion and it tends to increase every year. Website quality has been widely recognized as a crucial factor in driving e-commerce success [12, 13]. Website quality has no formal definition. [1] mentioned that website quality can be considered the ability of a website to meet the expectations of its users and owners, as determined by a set of measurable attributes/criteria. Many other studies view website quality in terms of multiple dimensions, such as content, user-friendliness, functionality, and design and is often measured through quantitative and qualitative methods [14, 15].

Website quality evaluation is considered assessing a website's performance based on predefined quality criteria. This evaluation is inherently complex due to the interdependence of multiple criteria—such as loading speed, security, information quality, user experience, and the subjectivity of user perceptions[16, 17]. Multi-Criteria Decision-Making (MCDM) methods like Analytic Hierarchy Process (AHP), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution),[18-20] have been employed to address this complexity. However, these methods often fail to capture the uncertainty, vagueness, and inconsistency inherent in expert judgments, particularly in dynamic e-commerce fields [21]. This MCDM limitation in dynamic e-commerce fields is due to the real-time data that are changing rapidly. The hesitation in experts preference and judgment, i.e., experts provide inconsistent and vague evaluations because of incomplete data. Also, consumer attitudes change quickly due to the change in product reviews, promotion campaigns, and trending. In addition, due to the massive dimensional data, MCDM faces computational and scalability challenges.

The evaluation of website quality is considered a multi criteria challenge due to the numerous interconnected criteria that require careful assessment. Many studies employed diverse methodologies to evaluate website quality such as LDA-FDEMATEL-FTOPSIS Method by [22], AHP and Entropy method to assess the quality e-commerce platforms in Poland [23] , intuitionistic fuzzy linguistic MCDM method to evaluate internet shopping malls by [24] , Integrated Fuzzy ANP-TOPSIS approach by [25], and Pythagorean fuzzy set PFAHP-PFTOPSIS methodology [26]. However, many limitations exist in these methodologies. First, the existing evaluation methods for website quality do not consider the end-users' satisfaction. Second, MCDM methods fail to deal with subjectivity, decision-maker bias and uncertainty of complex decision-making problems. Third, due to the existence of multiple criteria in e-commerce website evaluation, decision-making using fuzzy methods has a limitation of computational complexity. Fourth, fuzzy methods struggle to integrate subjective judgments with objective data. Traditional fuzzy methods have difficulty in handling dynamic and real-time data in e-commerce environments. The fuzzy methods do not capture the hesitancy and extra fuzzy information related to the evaluation criteria [27]. In real-world problems, it is difficult for experts to come up with single and unique values for the criteria since multiple values are normally more realistic in evaluating the criteria. Therefore the requirement for extra fuzzy information is essential for the evaluation of the situation [28] . The failure to include these aspects may afford the problems of undermining the accuracy and thoroughness of decisions being made. Uncertainty environments involve decision makers hesitancy, criteria not clearly defined and interdependence. Unlike deterministic and Probabilistic environments, the information in uncertainty environment is incomplete, ambiguous, or imprecise [21, 29].

Therefore, the current study proposes a hybrid model that integrates Triangular Neutrosophic Numbers (TNN) with Entropy and TODIM (TNN-EWT-TODIM) to assess the quality of e-commerce websites in an uncertain environment. The proposed model helps in enhancing decision-making accuracy by capturing the full spectrum of expert judgments (agree, unsure, disagree) through Triangular Neutrosophic Numbers. Also, the proposed model dynamically handling vagueness, incompleteness, and conflicting data, thereby overcoming inconsistencies in multi-criteria evaluations. Besides, the proposed model provides robust criteria weights via Entropy and TODIM integration. Furthermore, the proposed model improves real-world uncertainty by modeling asymmetric and evolving ambiguities that traditional fuzzy or intuitionistic methods fail to address.

The main contributions of the current study are:

1. Propose a hybrid model (TNN-EWT-TODIM) that unifies TNN (for representing uncertainty), Entropy (for objective weighting), and TODIM (for ranking) to handle uncertainty in e-commerce website quality evaluations.

2. The proposed model (TNN-EWT-TODIM) adds the intermediacy membership to the truth and false, thereby overcoming fuzzy/Intuitionistic Fuzzy Methods (IFM) limitations such as hesitancy, subjectivity, and complex uncertainty.
3. Ensuring higher consistency in multi-attribute evaluations under conflicting criteria, addressing vagueness, incompleteness, and inconsistency common in e-commerce website quality evaluations.
4. Validate the proposed model by evaluating and ranking five e-commerce websites based on multi-criteria and demonstrate how neutrosophic MCDM improves precision in real-world evaluations.

The rest of this paper is organized as follows; section 2 provides a review of state-of-the-art studies. In Section 3, the proposed model is presented. In section 4, a case study of the proposed model is applied to e-commerce website quality evaluation problem. The conclusion and future work are presented in section 5.

2. Literature Review

2.1 Website evaluation MCDM techniques

Evaluation of the website quality from the decision maker or experts' opinion may be uncertain, vague and inconsistent. The multicriteria decision making (MCDM) techniques based on the fuzzy logic set such as Analytic Hierarchy Process(AHP) [30, 31], (MCDM-AHP) model[32], re-AHP[33],fuzzy-AHP(FAHP)[34], technique for order of preference by similarity to ideal solution (TOPSIS) [35, 36], Hierarchal TOPSIS [37], Fuzzy TOPSIS [19, 38], ELimination and Choice Expressing REality (ELECTRE) [39], Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) [40], PROMETHEE II[36], VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) [18, 36], Characteristic Objects Method (COMET)[36],intuitionistic fuzzy VIKOR [41], MEthod based on the Removal Effects of Criteria (MEREC)[42] ,Fuzzy Cognitive Map (FCM)[43], Best Worst Method (BWM) [44], Complex Proportional Assessment (COPRAS)[45], Weighted Aggregated Sum–Product Assessment (WASPAS) [46], Multi- Objective Optimization on the basis of a Ratio Analysis (MULTIMOORA) [47], simultaneous evaluation of criteria and alternatives (SECA)[48] ,Measurement of alternatives and ranking according to COmpromise solution (MARCOS) [49], evaluation based on distance from average solution (EDAS) [50, 51], Combined Compromise Solution (CoCoSo)[52] , combinative distance-based assessment (CODAS)[53] , Decision-Making Trial and Evaluation Laboratory(DEMATEL)[54, 55] ,and Fuzzy DEMATEL[56, 57] were appropriate to deal with this problem.

Also, some studies integrate fuzzy methods to deal with the website quality evaluation problem. AHP-TOPSIS [58-61] , AHP-ELECTRE [61, 62], AHP-PROMETHEE[61, 63], AHP-DEA[61], ELECTRE-VIKOR[64] ,DEMATEL with Generalized Choquet Fuzzy Integral (GCFI)[65], (AHP-FuzzyPROMETHEE)[66], (SWARA-G-MARCOS-G) [67] ,Fuzzy VIKOR[18], PROMETHEE-GAIA[68] ,(Fuzzy AHP & Fuzzy TOPSIS)[69, 70], (Delphi Shannon's -Entropy-PROMETHEE-GAIA)[71] , Interval-Valued Intuitionistic Fuzzy Sets (IVIFS)-TOPSIS[72], FAHP-TOPSIS[73, 74], (FAHP SAW-TOPSIS-VIKOR)[75] , (FuzzyAHP-VIKOR) [20] ,DEMATEL-MABAC[76], Fuzzy DEMATEL and COPRAS[77],and interval type-2 fuzzy AHP and TOPSIS (IT2FAHP-TOPSIS)[78].

Linguistic variables play a significant role especially in fuzzy logic [79]. A linguistic variable is defined as a variable whose values are expressed through expressions in natural language. The decision makers used linguistic variables to express their opinion and preferences. In MCDM methods the linguistic variables could be converted to fuzzy numbers by using fuzzy sets[80, 81] . But the fuzzy set only considered the truth membership not the ideal to deal with uncertainty problem, because it is failed to tackle the indeterminacy preferences. Even the intuitionistic fuzzy sets that considered the truth and false membership fails to tackle the uncertainties and indeterminacy in the decision maker preference that is exit in real world.

More studies that evaluate the quality of e-commerce websites in multi-attribute evaluation such as [66] who presented a quality evaluation model for measuring the performance of hospital Web sites. The model combined PROMETHEE and AHP methodologies to develop a fuzzy preference-ranking model for a quality evaluation of hospital web sites in Turkey. In [31], used AHP for investigating the effect of website quality on e-business success. The authors used System quality, Information quality, Service quality and Vendor-specific quality criteria for the study which involved 156 online customers and 34 managers/designers as participants. The results showed that the website with the highest quality was associated with the highest business performance. The relative importance of website quality criteria was ranked using the AHP model. In [38] ,evaluated the competitive advantages of websites through three main factors (technology acceptance, website service quality, and specific holdup costs). The study used twelve criteria to apply experiments to rank four Taiwanese shopping websites by using the fuzzy TOPSIS method. The results outline that security and trust are the most important criteria for enhancing competitive advantage. In [82], provided a model based on fuzzy AHP-TOPSIS methodology for evaluating multi-attribute e-commerce websites in Turky. The study used nine criteria grouped into four categories to evaluate three e-commerce websites. Fuzzy AHP was used to assign weight to each criterion, while Fuzzy TOPSIS was used to rank alternatives. In [83], proposed a fuzzy AHP and fuzzy VIKOR methodology to evaluate three e-commerce websites in Turkey. The decision-makers assigned their references to each factor through a triangular fuzzy scale. They used AHP to assign weight to the criteria and to rank the alternatives. In [37], proposed a new approach to evaluate B2C e-commerce websites that combines the E-S-QUAL model and the fuzzy hierarchical TOPSIS method for 6 Korean e-commerce websites. The comparison with other methods, such as VIKOR and GRA, was applied to validate the results, showing that the hierarchical structure of evaluation criteria is better captured by the proposed method, but failed to analyze the causal relationships among criteria in B2C e-commerce. In [84], used fuzzy AHP and hierarchical fuzzy TOPSIS to evaluate e-commerce websites. According to their results, the most important factors were security and privacy followed by trust, loading time, easy transaction, and e-payment support. In [85], proposed a method based on fuzzy logic to find out the importance of key factors affecting the consumers' intention to purchase from B2C e-commerce websites. The results showed that higher security leads to higher trust, which in turn increases the likelihood of making a purchase. In [86], Integrated both AHP and Intuitionistic Fuzzy Techniques (IFT) algorithms to evaluate three e-commerce websites in Turkey by using four criteria through four decision makers. The results show that the model is efficient in comparable situations and resolves the problems of uncertainty in MCDM. In [87], used Fuzzy VIKOR to rank the e-commerce design platforms. Through categorizing the criteria to four benefits and three cost criteria. They applied the algorithm on six platforms. triangular fuzzy numbers (TFNs) were used to reflect expert linguistic ratings. The results provided a list of major criteria to evaluate e-commerce design platforms. In [88], proposed a hybrid MCDM model to investigate the B2C e-commerce factors of websites. Fuzzy AHP was used to calculate the weight for each criterion, and TOPSIS-Grey was used to rank the alternatives in China. In [25], proposed a hybrid model based on the fuzzy Analytic Network Process (fuzzy ANP) and fuzzy TOPSIS methods to rank and assess e-commerce websites. The proposed model was carried out on several online shopping websites to identify their strengths and weaknesses.

During the COVID-19 lockdown ,the E-S-QUAL model was employed in [59] to evaluate and rank the e-commerce websites of the leading coffee-chain companies in the Greek market using the AHP-TOPSIS technique. The results show that system availability and fulfillment were the most important dimensions, followed by privacy, while efficiency ranked the lowest in importance. In [89] , used a fuzzy TOPSIS algorithm to rank five e-commerce websites using eight positive criteria and two negative criteria. Fuzzy triangular numbers were used to express the experts' ratings. They used the fuzzy analytical hierarchy process (FAHP) to detect the weights of each criterion. The results indicate that the weights of the criteria are important in evaluating e-commerce websites. In [90] ,used FAHP with triangular fuzzy numbers in the Western Balkans region to study the factors that affect the success of e-commerce platform design during the COVID-19 pandemic. The authors used five dimensions and 19 criteria. The results show that the most significant criteria for successful e-commerce platform design are trust and loyalty, safe payment, exchange or return, and account security. In addition, during COVID-19 pandemic, [19] proposed a method to evaluate the quality of online shopping services through 25 qualities. The research employed fuzzy set theory and TOPSIS to reduce the subjectivity of customer judgment. The data collected from 819 questionnaires from online shoppers found that product availability, products with excellent quality, confidence in online shopping processes, and ease of buying online were the most positively perceived quality attributes. The study also highlighted the importance of online shopping services during the pandemic.

In [26], combined the Pythagorean fuzzy set (PFS) with AHP and TOPSIS to evaluate five e-commerce websites in Turkey through seven criteria. Pythagorean fuzzy AHP (PFAHP) was used to determine the weights of the criteria, while Pythagorean fuzzy TOPSIS (PFTOPSIS) was used to rank the websites.

2.2 Gaps of previous research on evaluating e-commerce websites

Based on the above-mentioned studies, the following conclusions were drawn:

1. The fuzzy theory methods take into consideration only the truth membership degree, neglecting the indeterminacy and falsity membership degree. Therefore, previous fuzzy models failed to represent reality efficiently.
2. Fuzzy methods demonstrate a limited capacity to represent ambiguity in the evaluation of the website quality in e-commerce where decision-makers' preferences are flexible. This static membership function failed to represent the decision maker's, especially in an uncertain environment, leading to simple representations of complicated human evaluations.
3. There are inconsistencies between the judgments related to the model using triangular fuzzy numbers (TFNs). TFNs are considered linear and symmetric membership functions, whereas uncertainty in the real world is nonlinear and asymmetric, making TFNs inadequate. Also, TFN shapes are lost when certain operations are performed, such as multiplication, resulting in distorted results. Moreover, the sharp boundaries of TFNs result in membership not being right at their boundaries, contradicting the principle of gradual transition inherent in fuzzy logic.
4. Some methods by intuitionistic fuzzy methods (IFM) relations were proposed to enhance consistency. This method adds a new membership falsity beside the truth membership. While IFM did not tackle all indeterminacy in an uncertain environment because it has challenges in consistency in multi-attribute methods like e-commerce evaluations.

We addressed the previously mentioned constraints by introducing a hybrid model within a neutrosophic environment. This study focuses on tackling the uncertainty issues that arise from expert evaluations concerning multi-attribute website quality in the realm of e-commerce. This uncertainty is due to vagueness, incompleteness, inconsistency, and insufficient knowledge inherent in e-commerce website evaluation challenges. The central issue discussed in this paper pertains to multi-criteria decision-making problems involving conflicting and non-quantifiable criteria. The hybrid model depends on the triangular neutrosophic theory integrated with the entropy and TODIM algorithm. The neutrosophic set was proposed by[91] , which has the truth, false, and indeterminacy membership functions. We use the triangular neutrosophic [92, 93] in the proposed hybrid model with a 3-member function to solve a lack of knowledge, conflicting viewpoints, vagueness, and subjectivity problems that associate with expert evaluation in an uncertain environment. The entropy algorithm was used as an objective approach to assign weight to each criterion in our MCDM problems[94, 95] . TODIM was proposed by[96] . We use TODIM in our proposed hybrid model to rank the alternatives. The proposed hybrid model that integrates TNN-EWT-TODIM is validated through a case study to solve the problem of evaluating e-commerce website quality.

3. Methodology

3.1. Preliminaries

This subsection provides theories behind neutrosophic sets, EWT, and TODIM.

3.1.1. Neutrosophic set

This subsection provides theories behind neutrosophic sets, EWT, and TODIM Neutrosophic logic and sets have an important attention for addressing real-world problems characterized by uncertainty[97], impreciseness[98], vagueness [99, 100], incompleteness[101, 102], inconsistency[103], and indeterminacy[104-106]. Neutrosophic theory was proposed by Florentin Smarandache in 1998. Neutrosophic set (NS)[107] categorizes classical set, fuzzy set (FS)[108], interval-valued fuzzy set [109], and intuitionistic fuzzy set[110] not only as truth membership and falsity membership but also considers indeterminacy function, which is very important in real-life problems. In contrast to FS and its extensions, the NS was demonstrated as more flexible. Below we present theories for neutrosophic sets, single-valued neutrosophic sets, triangular neutrosophic numbers, and operations on triangular neutrosophic numbers. Neutrosophic sets were applied in many fields such as MCDM, artificial intelligence, computer vision, engineering, and healthcare. [91, 111-117] .

Definition 1: A neutrosophic set (NS) S in X is given by a truth $T_S(x)$, indeterminacy $I_S(x)$ and a falsity $F_S(x)$ membership functions. Where X be a set of points and $x \in X, T_S(x), I_S(x)$ and $F_S(x)$ are real-standard or real nonstandard subsets of $]-0,1+[$. That is $x \in X, T_S(\text{x}): X \rightarrow]-0,\ 1+[, I_S(\text{x}): X \rightarrow]-0,1+[$ and $F_S(\text{x}): X \rightarrow]-0,1+[$. The sum of $T_S(\text{x}), I_S(\text{x})$ and $F_S(\text{x})$ is unrestricted [118-121].

Definition 2: A single valued neutrosophic set (SVNS) S over X, takes the form $\text{N} = \{\langle x,\ T_S(x),\ I_S(x), F_S(x)\rangle : x \in X\}$, where $T_S(x): X \rightarrow [0,1]$, $I_S(x): X \rightarrow [0,1]$ and $F_S(x): X \rightarrow [0,1]$ with $0 \le T_S(x) + I_S(x) + F_S(x) \le 3$ for all $x \in X$. For simplicity, a SVN number is repersented by $\text{S} = (c_1, c_2, c_3)$, where $c_1, c_2, c_3 \in [0,1]$ and $c_1 + c_2 + c_3 \le 3$ [120-123]. where $\alpha_{\tilde{n}}, \theta_{\tilde{n}}$ and $\beta_{\tilde{n}} \in [0,1]$, exemplify the upper degree of truth, lower degrees of indeterminacy and falsity respectively.

Definition 3: A Single Valued Triangular Neutrosophic Number $\tilde{S} = \langle (S_1, S_2, S_3); T_S(x), I_S(x), F_S(x)\rangle$ is a neutrosophic set where the membership functions for truth T_S, indeterminacy I_S, and falsity F_S are represented as:

$$T_S(x) = \begin{cases} \alpha_S\left(\dfrac{x - S_1}{S_2 - S_1}\right) & \text{if } S_1 \le x \le S_2, \\ \alpha_S & \text{if } x = S_2, \\ \alpha_S\left(\dfrac{S_3 - x}{S_3 - S_2}\right) & \text{if } S_2 < x \le S_3, \\ 0 & \text{otherwise.} \end{cases} \quad (1)$$

$$I_S(x) = \begin{cases} \dfrac{S_2 - x + \beta_S(x - S_1)}{S_2 - S_1} & \text{if } S_1 \le x \le S_2, \\ \theta_S & \text{if } x = S_2, \\ \dfrac{x - S_2 + \beta_S(S_3 - x)}{S_3 - S_2} & \text{if } S_2 < x \le S_3, \\ 1 & \text{otherwise.} \end{cases} \quad (2)$$

$$F_S(x) = \begin{cases} \dfrac{S_2 - x + \theta_S(x - S_1)}{S_2 - S_1} & \text{if } S_1 \le x \le S_2, \\ \beta_S & \text{if } x = S_2, \\ \dfrac{x - S_2 + \theta_S(S_3 - x)}{S_3 - S_2} & \text{if } S_2 < x \le S_3, \\ 1 & \text{otherwise.} \end{cases} \quad (3)$$

where α_S, θ_S, and $\beta_S \in [0,1]$, representing the maximum truth-membership degree, minimum indeterminacy-membership degree and minimum falsity-membership degree respectively [119, 124].

Definition 4: Let $\tilde{a} = \langle (a_1, a_2, a_3); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \rangle$ and $\tilde{b} = \langle (b_1, b_2, b_3); \alpha_{\tilde{b}}, \theta_{\tilde{b}}, \beta_{\tilde{b}} \rangle$ be two single valued triangular neutrosophic numbers and $\gamma \neq 0$ be any real number [124] . Then:

1- Addition of two triangular neutrosophic numbers

$$\tilde{a} + \tilde{b} = \langle (a_1 + b_1, a_2 + b_2, a_3 + b_3); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \rangle \quad (4)$$

2- Subtraction of two triangular neutrosophic numbers

$$\tilde{a} - \tilde{b} = \langle (a_1 - b_3, a_2 - b_2, a_3 - b_1); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \rangle \quad (5)$$

3- Inverse of a triangular neutrosophic number

$$\tilde{a}^{-1} = \left\langle \left(\frac{1}{a_3}, \frac{1}{a_2}, \frac{1}{a_1}\right); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \right\rangle, \quad \text{Where } (\tilde{a} \neq 0) \quad (6)$$

4- Multiplication of triangular neutrosophic number by constant value

$$\gamma\tilde{a} = \begin{cases} \langle (\gamma a_1, \gamma a_2, \gamma a_3); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \rangle \text{ if } (\gamma > 0) \\ \langle (\gamma a_3, \gamma a_2, \gamma a_1); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \rangle \text{ if } (\gamma < 0) \end{cases} \quad (7)$$

5- Division of triangular neutrosophic number by constant value

$$\frac{\tilde{a}}{\gamma} = \begin{cases} \left\langle \left(\frac{a_1}{\gamma}, \frac{a_2}{\gamma}, \frac{a_3}{\gamma}\right); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \right\rangle \text{ if } (\gamma > 0) \\ \left\langle \left(\frac{a_3}{\gamma}, \frac{a_2}{\gamma}, \frac{a_1}{\gamma}\right); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{a} \right\rangle \text{ if } (\gamma < 0) \end{cases} \quad (8)$$

6- Multiplication of two triangular neutrosophic numbers

$$\tilde{a}\tilde{b} = \begin{cases} \langle (a_1 b_1, a_2 b_2, a_3 b_3); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \rangle & \text{if } (a_3 > 0, b_3 > 0) \\ \langle (a_1 b_3, a_2 b_2, a_3 b_1); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}}, \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \rangle & \text{if } (a_3 < 0, b_3 > 0) \\ \langle (a_3 b_3, a_2 b_2, a_1 b_1); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \rangle & \text{if } (a_3 < 0, b_3 < 0) \end{cases} \quad (9)$$

7- Division of two triangular neutrosophic numbers

$$\frac{\tilde{a}}{\tilde{b}} = \begin{cases} \left\langle \left(\frac{a_1}{b_3}, \frac{a_2}{b_2}, \frac{a_3}{b_1}\right); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}} \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \right\rangle & \text{if } (a_3 > 0, b_3 > 0) \\ \left\langle \left(\frac{a_3}{b_3}, \frac{a_2}{b_2}, \frac{a_1}{b_1}\right); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \right\rangle & \text{if } (a_3 < 0, b_3 > 0) \\ \left\langle \left(\frac{a_3}{b_1}, \frac{a_2}{b_2}, \frac{a_1}{b_3}\right); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}\vee} \vee \beta_{\tilde{b}} \right\rangle & \text{if } (a_3 < 0, b_3 < 0) \end{cases} \quad (10)$$

Score function:

$$S(A) = \left(\frac{1}{8}\right)(\ a_1 + b_1 + c_1)(2 + \mathrm{a} - \ \mathrm{q} - \ \mathrm{b}) \quad (11)$$

Accuracy function:

$$A(A) = \left(\frac{1}{8}\right)(\ a_1 + b_1 + c_1)(2 + \mathrm{a} - \ \mathrm{q} - \ \mathrm{b}) \quad (12)$$

3.1.2 Entropy Weighting Technique (EWT)

The entropy weighting technique is a commonly used method for determining the weight of criteria by analyzing the differences among them, without relying on any subjective or further information. The differences The differences are measured by information-theoretic entropy[95, 125]. In EWT, the weight of attributes is calculated by the entropy-based difference of the j-th attribute between alternatives. When the difference between two alternatives on the j-th attribute is small, then this attribute does not provide enough information to rank or distinguish between the two alternatives[126]. The mathematical equations of EWT are presented in equations [13-16] in section 3.2

3.1.3 TODIM

The Interactive Multi-Criteria Decision Making (TODIM) model, proposed by [96], is an effective tool for investigating MCDM problems and has been widely utilized in industrial, commercial, and management science fields. Based on prospect theory (PT), the TODIM technique considers the subjectivity of experts' evaluations. The mechanism of TODIM depends on providing the dominance of one alternative over others using mathematical equations, making it more acceptable and scientific in its application to MCDM problems [127-129] . The mathematical equations of EWT are presented in equations [17-21] in section 3.2

3.2 The Proposed Model

The proposed hybrid triangular neutrosophic model which integrates entropy weighting and TODIM methodology for evaluating and comparing e-commerce website quality across multiple criteria is presented in Fig 1. The proposed model includes three phases as follows:

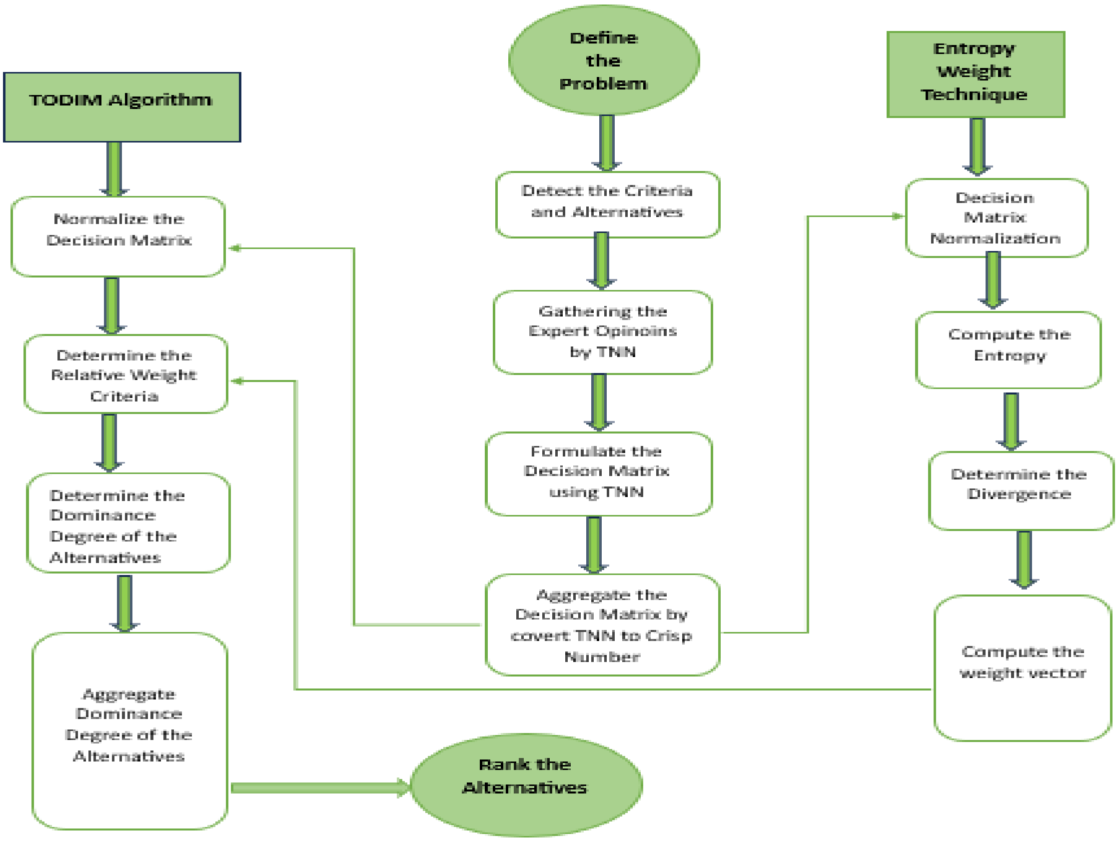

Figure 1: The proposed model flowchart

Phase 1. Construct the Decision Matrix with TNN

Step 1.1 Define the Criteria and the Alternatives

Criteria represented as $C1$, $C2$, $C3$, …, $C11$ and Alternatives represented as $A1$, $A2$, $A3$, $A4$, $A5$

Step 1.2 Collect Expert Opinions.

Step 1.3 Create the Decision Matrix through the score function in Eq. (11), we can convert the TNNs into crisp numbers.

Step 1.4 Aggregate the Decision Makers' Matrix.

Phase 2. Apply the Entropy Weight Method (EWM):

Below are the mathematical equations of EWT:

Step 2.1 Decision Matrix Normalization

To ensure comparability between different criteria, normalize the triangular neutrosophic set decision matrix as follows:

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad \text{Where } 1 \le i \le m, 1 \le j \le n \qquad (13)$$

$$\sum_{i=1}^{m} x_{ij}\ refers\ to\ the\ sum\ of\ all\ values\ for\ each\ criterion$$

$$in\ the\ aggregated\ matrix, calculated\ for\ each\ column.$$

Step 2.2 Calculate the Entropy for Each Criterion

Calculate the entropy value for each criterion j using the normalized decision matrix, as follows:

$$e_j = -t\sum_{i=1}^{m} \left(r_{ij} \cdot \ln r_{ij}\right) \text{ Where } 1 \le j \le n \text{ and } t = \frac{1}{\ln m}\ Where\ \ m \longrightarrow$$

$$Number\ of\ Alternatives \text{ of ecommerce websites} \quad (14)$$

Step 2.3 Determine the Divergence of Degree: Compute the degree of divergence for each criterion as follows:

$$d_j = \left|1 - e_j\right| \text{ Where } 1 \le j \le n \quad (15)$$

Step 2.4 Calculate the Criteria's Weights: Calculate the weights of the criteria using the following equation:

$$\mathcal{W}_j = \frac{d_j}{\sum_{i=1}^{m} d_j} \quad (16)$$

Phase 3. Apply TODIM Method

Below are the mathematical equations of TODIM to rank the alternatives based on the weight of each criterion[130] :

Step 3.1 Formulation of the decision matrix.

Step 3.2 Normalization of the decision matrix: the decision matrix is normalized as follows for the beneficial criteria, and the non-beneficial criteria:

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad \text{, for Beneficial criteria} \quad (17)$$

$$r_{ij} = \frac{1/x_{ij}}{\sum_{i=1}^{m} 1/x_{ij}} \quad \text{, for Non} - \text{Beneficial criteria} \quad (18)$$

Step 3.3 Determine the relative weight criteria using the global weights of the criterion obtained from the following equation:

$$\bar{w}_J = \frac{w_j}{\breve{w}} \quad (19)$$

Where, $\breve{\mathcal{W}}$ is the maximum value of weights

Step 3.4 Determine the dominance degree of the alternatives, for each pair of alternatives $\left(\mathcal{A}_i, \mathcal{A}_j\right)$ calculate the $\delta\left(\mathcal{A}_i, \mathcal{A}_j\right)$ as:

$$\boldsymbol{\delta}\left(\mathcal{A}_i, \mathcal{A}_j\right) = \sum_{j=1}^{m} \Phi\left(\mathcal{A}_i, \mathcal{A}_j\right) \quad \forall (i, j)$$

$$\Phi(\mathcal{A}_i,\mathcal{A}_j)=\begin{cases}\sqrt{\frac{w_j(r_i-r_j)}{\sum_{j=1}^{n}\bar{w}_j}} & \text{if } (r_i-r_j)>0\\ 0 & \text{if } (r_i-r_j)=0\\ \frac{-1}{\theta}\sqrt{\frac{\sum_{j=1}^{n}\widetilde{w}_j(r_i-r_j)}{w_j}} & \text{if } (r_i-r_j)<0\end{cases} \quad (20)$$

Where, θ the attenuation factor of the losses value ranges from 1 to 10.

Step 3.5 Determine the overall dominance degree of each alternative as follows:

$$\zeta_i=\frac{\sum_{j=1}^{n}\delta(\mathcal{A}_i,\mathcal{A}_j)-\min\sum_{j=1}^{n}\delta(\mathcal{A}_i,\mathcal{A}_j)}{\max\sum_{j=1}^{n}\delta(\mathcal{A}_i,\mathcal{A}_j)-\min\sum_{j=1}^{n}\delta(\mathcal{A}_i,\mathcal{A}_j)} \quad (21)$$

Step 3.6 Rank the alternatives based on their overall dominance values to detect the best alternative.

4. Case Study

To test the effectiveness of the proposed model, this section presents a case study for evaluating the quality of five leading e-commerce websites. Fig 2. presents the hierarchical structure for evaluating these e-commerce websites.

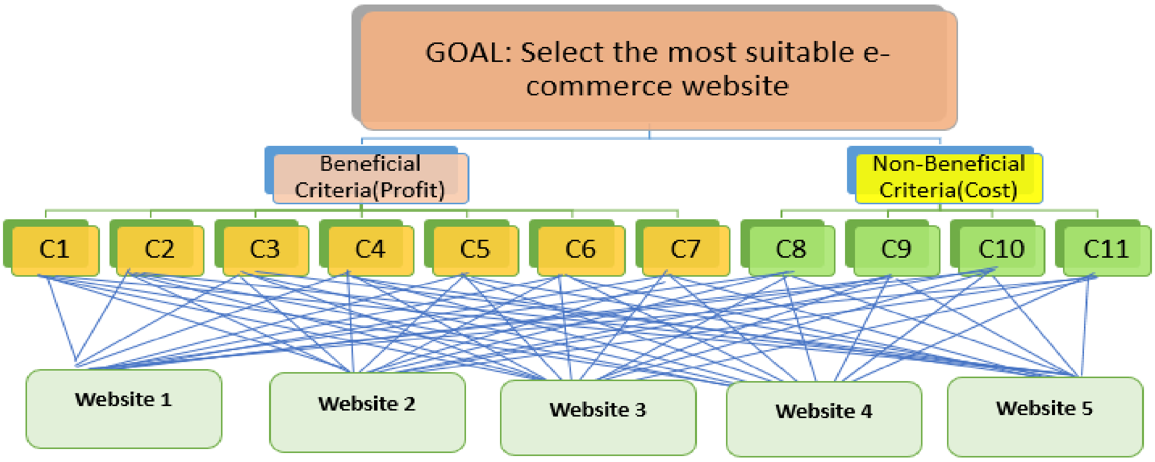

Figure 2. The hierarchical structure of ecommerce websites evaluation.

4.1 Construct the Decision Matrix with TNNs

Step 4.1.1. Define the Criteria and the Alternatives:

Criteria represented as $C1, C2, C3, \ldots, C11$ and alternatives represented as $A1, A2, A3, A4, A5$. Five leading e-commerce websites in USA, China, Japan, Egypt, and Russia that provides consumers with a wide range of technology and appliance options. Based on studies by[36, 131-135], eleven criteria were identified as the most appropriate for evaluating e-commerce websites. Eight of these criteria are considered beneficial (profit) criteria, while the remaining criterion is related to non-beneficial. High rankings in the beneficial criteria are interpreted as indicators of a website's high performance, whereas higher evaluations in the non-beneficial criterion signify lower performance. Table 1 represents the criteria used in evaluating the five e-commerce websites.

Table 1. The selected criteria for evaluation of the alternatives

C_i	Criterion	Type	Description	Importance	References
C_1	Usability and Navigation	Beneficial	This criterion guarantees a uniform user experience when navigating the website and/or accessing functionality. It has user-intuitive navigation, great searching capability, and it is overall very good to use.	It affects the degree of simplicity with which users can search, buy products, and their satisfaction.	[134, 136]
C_2	Reliability	Beneficial	This criterion indicates the availability and reliability of accurate service according to the promise.	Increase user satisfaction	[135]
C_3	Privacy and Security	Beneficial	This criterion involves protecting the personal data of the customer and the financial transactions. Also, this criterion includes payment options that have payment methods available.	User flexibility, building customer trust, and guaranteeing legal compliance.	[25, 83, 135, 136]
C_4	Graphic Design and Layout	Beneficial	This criterion refers to the visual layout design and structural organization of the website.	Improves user interaction	[86]
C_5	Customer Service	Beneficial	This criterion refers to the ability to provide high customer service and quick responsiveness, assisting customers before, during, and after their purchases.	Builds robust customer loyalty and reliable trust.	[83, 137]

C_6	Information Quality	Beneficial	This criterion points to the accuracy, completeness, clarity, and broad coverage of information, including the quality of images and videos that belong to the website. Also, this criterion refers to the evaluation of search tools, the relevance of search results, and the availability of filtering options.	Enables informed decision-making and reduces the probability of returns. Improves the visibility of products. Enhances user satisfaction. Builds trust and credibility, influencing the purchasing decisions.	[86, 131, 134]
C_7	Trustworthiness and Reputation	Beneficial	This criterion refers to the overall trust in the website, which is determined by its strong brand reputation, positive customer reviews, and credible recommendations. Display of industry awards, certification, and trust seals boosts the reliability and website brand reputation.	Increases customer confidence and boosts the brand reputation.	[86, 135]
C_8	**Loading Speed**	**Non-Beneficial**	This criterion refers to the required time for web pages to load.	The higher speeds increase system performance and raise user experience.	[86]
C_9	**Price**	**Non-Beneficial**	This criterion refers to the pricing of products and services offered on the website.	Lower prices are generally more attractive to customers. Competitive pricing is necessary for attracting and keeping customers. Promotions can boost quick sales and	[36, 138, 139]

				increase customer loyalty. Clear pricing builds trust and reduces cart abandonment.	
C_{10}	**Shipping and Delivery Options**	**Non-Beneficial**	This criterion refers to the postal and dispatch prices and lead times, range, and security of shipping options provided.	Faster delivery and cheaper shipping options are preferred. On-time deliveries help achieve customer expectations.	[139-141]
C_{11}	**Return and Refund Policies**	**Non-Beneficial**	This criterion includes the exchange/return of the product and the refund process being nice and simple, which has a bearing on the purchase decision. It also consists of the visibility and reasonableness of your return and refund policies.	Reduces purchase risk and enhances trust, thereby increasing sales.	[131, 142]

Step 4.1.2. Collect Expert Opinions

Table 2. contains demographic data about the experts who evaluated the criteria in this study. Six experts were engaged to assess these websites based on the selected criteria.

Table 2. List of experts and their expertise

Expert	Job Title	Age and gender	Experience	Expertise
1	Web Designer	42 ,Male	20 years	Web Design
2	IS Manager	40 ,Male	18 years	R&D
3	Web Developer	35, Female	13 years	Website Design
4	Software Developer	36, Female	14 years	Website Security
5	Business Analyst	32, Female	12 years	Trust, Website Reputation, Digital Marketing

6	Software Developer	30, Female	10 years	System Engineering

Gather expert evaluations of each alternative against each criterion, represented as TNN $\tilde{A}1$ = ⟨⟨a1,a2,a3⟩;T1,I1,F1⟩ using linguistic terms as represented in Table 3 to get the matrix as shown in Tables (4-9).

Table 3. Linguistic Scale translated to Neutrosophic Triangular Scale

Scale	Linguistic Scale	Neutrosophic Triangular Scale
1	Low influential	1=⟨⟨1,1,1⟩;0.50,0.50,0.50⟩
3	Moderately influential	3=⟨⟨2,3,4⟩;0.30,0.75,0.70⟩
5	High influential	5=⟨⟨4,5,6⟩;0.80,0.15,0.20⟩
7	Very high influential	7=⟨⟨6,7,8⟩;0.90,0.10,0.10⟩
9	Absolutely high (Extreme)	9=⟨⟨9,9,9⟩;1.00,1.00,1.00⟩
2,4,6,8	Sporadic values between two close scales (Intermediate values)	2=⟨⟨1,2,3⟩;0.40,0.60,0.65⟩ 4=⟨⟨3,4,5⟩;0.35,0.60,0.40⟩ 6=⟨⟨5,6,7⟩;0.70,0.25,0.30⟩ 8=⟨⟨7,8,9⟩;0.85,0.10,0.15⟩

Table 3 indicates that each linguistic term represents a qualitative evaluation of a criterion's relative influence, while the triangular neutrosophic scale (⟨⟨a,b,c⟩; T, I, F⟩) captures three dimensions of uncertainty. The triangular neutrosophic scale is composed of triangular fuzzy numbers (a, b, c): value range (truth, indeterminacy, falsity) where, T: Truth-membership (confidence in the evaluation), I: Indeterminacy-membership (hesitation or doubt), F: Falsity-membership (disagreement).

For instance, moderately influential represented as 3=⟨⟨2,3,4⟩;0.30,0.75,0.70⟩ means that the triangular neutrosophic number is ⟨2,3,4⟩ (most likely 3, but could range between 2 and 4). While T=0.30: low confidence in "moderate influence," I=0.75: high uncertainty (experts are not very sure), and F=0.70: high chance that it might not be moderately influential. From Table 4 to Table 9, this indicates the expert's opinions.

Table 4. Decision matrix of Expert's 1 opinion

	A1	**A2**	**A3**	**A4**	**A5**
C1	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩

C2	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩
C3	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩
C4	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩
C5	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩
C6	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩
C7	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩
C8	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩
C9	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩
C10	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨1,1,1⟩;0.50,0.50,0.50⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩
C11	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩

Table 5. Decision matrix of Expert's 2 opinion

	A1	**A2**	**A3**	**A4**	**A5**
C1	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩
C2	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩
C3	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩
C4	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩
C5	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩
C6	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩
C7	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩
C8	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩
C9	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩

C10	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩
C11	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩

Table 6. Decision matrix of Expert's 3 opinion

	A1	**A2**	**A3**	**A4**	**A5**
C1	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩
C2	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩
C3	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩
C4	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩
C5	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩
C6	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩
C7	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩
C8	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩	⟨⟨1,1,1⟩;0.50,0.50,0.50⟩
C9	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨1,1,1⟩;0.50,0.50,0.50⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩
C10	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨1,1,1⟩;0.50,0.50,0.50⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩
C11	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩	⟨⟨1,1,1⟩;0.50,0.50,0.50⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩

Table 7. Decision matrix of Expert's 4 opinion

	A1	**A2**	**A3**	**A4**	**A5**
C1	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨1,1,1⟩;0.50,0.50,0.50⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩
C2	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩
C3	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩
C4	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨1,1,1⟩;0.50,0.50,0.50⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩

C5	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩
C6	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨1,1,1⟩;0.50,0.50,0.50⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩
C7	⟨⟨1,1,1⟩;0.50,0.50,0.50⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩
C8	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨1,1,1⟩;0.50,0.50,0.50⟩
C9	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨1,1,1⟩;0.50,0.50,0.50⟩
C10	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨1,1,1⟩;0.50,0.50,0.50⟩
C11	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩

Table 8. Decision matrix of Expert's 5 opinion

	A1	**A2**	**A3**	**A4**	**A5**
C1	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩
C2	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩
C3	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩
C4	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩
C5	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩
C6	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩
C7	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩
C8	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩
C9	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩
C10	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩
C11	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩

Table 9. Decision matrix of Expert's 6 opinion

	A1	A2	A3	A4	A5
C1	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨7,8,9⟩;0.85,0.10,0.15⟩
C2	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩
C3	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩
C4	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨9,9,9⟩;1.00,1.00,1.00⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩
C5	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩
C6	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩
C7	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨6,7,8⟩;0.90,0.10,0.10⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩
C8	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨5,6,7⟩;0.70,0.25,0.30⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨1,1,1⟩;0.50,0.50,0.50⟩
C9	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨1,1,1⟩;0.50,0.50,0.50⟩
C10	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨4,5,6⟩;0.80,0.15,0.20⟩	⟨⟨1,1,1⟩;0.50,0.50,0.50⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩
C11	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨3,4,5⟩;0.35,0.60,0.40⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨2,3,4⟩;0.30,0.75,0.70⟩	⟨⟨1,2,3⟩;0.40,0.60,0.65⟩

Step 4.1.3. Aggregate the decision maker's matrix to get the matrix represented in Table 10 computed by using Eq. (4) and Eq.(8).

Table 10: Triangular Neutrosophic Numbers Aggregated Decision Matrix.

	A1	A2	A3	A4	A5
C1	⟨(6.17,7.00,7.83);0.35,1.00,1.00⟩	⟨(6.50,7.50,8.50);0.35,1.00,1.00⟩	⟨(5.83,6.83,7.83);0.35,1.00,1.00⟩	⟨(7.17,8.17,9.17);0.35,1.00,1.00⟩	⟨(6.83,7.83,8.83);0.35,1.00,1.00⟩
C2	⟨(5.50,6.50,7.50);0.30,0.75,0.70⟩	⟨(5.83,6.83,7.83);0.35,0.60,0.40⟩	⟨(5.17,6.17,7.17);0.35,0.60,0.40⟩	⟨(4.83,5.83,6.83);0.35,0.60,0.40⟩	⟨(5.83,6.83,7.83);0.35,0.60,0.40⟩
C3	⟨(6.17,7.17,8.17);0.35,0.75,0.70⟩	⟨(6.50,7.50,8.50);0.35,0.75,0.70⟩	⟨(5.83,6.83,7.83);0.35,0.60,0.40⟩	⟨(6.17,7.17,8.17);0.35,0.60,0.40⟩	⟨(8.17,9.17,10.17);0.35,1.00,1.00⟩
C4	⟨(6.17,7.17,8.17);0.35,0.75,0.70⟩	⟨(5.83,6.83,7.83);0.35,0.60,0.40⟩	⟨(4.83,5.83,6.83);0.35,0.60,0.40⟩	⟨(5.17,6.17,7.17);0.35,0.60,0.40⟩	⟨(5.83,6.83,7.83);0.35,0.60,0.40⟩
C5	⟨(5.50,6.50,7.50);0.30,0.75,0.70⟩	⟨(6.50,7.50,8.50);0.35,0.75,0.70⟩	⟨(5.83,6.83,7.83);0.35,0.60,0.40⟩	⟨(5.17,6.17,7.17);0.35,0.60,0.40⟩	⟨(5.83,6.83,7.83);0.35,0.60,0.40⟩

C6	⟨(6.17,7.17,8.17);0.35,0.75,0.70⟩	⟨(5.83,6.83,7.83);0.35,0.60,0.40⟩	⟨(5.17,6.17,7.17);0.35,0.60,0.40⟩	⟨(5.17,6.17,7.17);0.35,0.60,0.40⟩	⟨(5.83,6.83,7.83);0.35,0.60,0.40⟩
C7	⟨(6.17,7.17,8.17);0.35,0.75,0.70⟩	⟨(6.50,7.50,8.50);0.35,0.75,0.70⟩	⟨(6.50,7.50,8.50);0.35,0.75,0.70⟩	⟨(6.17,7.17,8.17);0.35,0.60,0.40⟩	⟨(8.17,9.17,10.17);0.35,1.00,1.00⟩
C8	⟨(2.17,3.17,4.17);0.30,0.75,0.70⟩	⟨(2.17,3.17,4.17);0.30,0.75,0.70⟩	⟨(2.83,3.83,4.83);0.35,0.60,0.40⟩	⟨(3.83,4.83,5.83);0.35,0.60,0.40⟩	⟨(2.17,3.17,4.17);0.30,0.75,0.70⟩
C9	⟨(2.50,3.50,4.50);0.30,0.75,0.70⟩	⟨(3.83,4.83,5.83);0.35,0.60,0.40⟩	⟨(2.50,3.50,4.50);0.30,0.75,0.70⟩	⟨(4.17,5.17,6.17);0.35,0.60,0.40⟩	⟨(2.17,3.17,4.17);0.30,0.75,0.70⟩
C10	⟨(2.50,3.50,4.50);0.30,0.75,0.70⟩	⟨(1.83,2.83,3.83);0.35,0.60,0.40⟩	⟨(3.17,4.17,5.17);0.35,0.60,0.40⟩	⟨(2.17,3.17,4.17);0.30,0.75,0.70⟩	⟨(2.50,3.50,4.50);0.30,0.75,0.70⟩
C11	⟨(2.50,3.50,4.50);0.30,0.75,0.70⟩	⟨(3.17,4.17,5.17);0.35,0.60,0.40⟩	⟨(2.50,3.50,4.50);0.30,0.75,0.70⟩	⟨(2.50,3.50,4.50);0.30,0.75,0.70⟩	⟨(2.17,3.17,4.17);0.30,0.75,0.70⟩

Step 4.1.4 Calculate the score function of each TNNs using Eq. (11) as represented in table 11.

Table 11. Aggregated Decision Matrix

Alternative	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
A1	1.79	1.89	2.14	2.39	1.89	2.14	2.14	1.19	1.43	1.43	1.31
A2	1.79	2.29	2.39	2.29	2.14	1.96	2.39	1.19	1.79	1.31	1.54
A3	1.69	2.04	2.04	2.04	2.04	2.04	2.14	1.54	1.43	1.54	1.31
A4	2.04	1.89	2.14	2.04	1.89	1.89	2.14	1.54	1.79	1.19	1.19
A5	2.04	2.29	2.39	2.04	1.96	1.96	2.39	1.19	1.43	1.19	1.19

Table 10 shows the aggregated decision matrix based on triangular neutrosophic numbers. Then the deneutrosophic phase was applied by using Eq. 11 to convert the triangular neutrosophic number into a crisp number in the aggregated decision matrix, as shown in Table 11.

4.2. Apply the Entropy Weight Technique

Step 4.2.1. using Eq. (13) to normalize the aggregated decision matrix in Table 11 to get the EWT normalized matrix shown in Table 12.

Table 12: Normalization Decision Matrix

Alternative	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
A1	0.191444	0.181731	0.192793	0.221296	0.190524	0.214214	0.191071	0.178947	0.181703	0.214715	0.200306
A2	0.191444	0.220192	0.215315	0.212037	0.215726	0.196196	0.213393	0.178947	0.227446	0.196697	0.235474
A3	0.180749	0.196154	0.183784	0.188889	0.205645	0.204204	0.191071	0.231579	0.181703	0.231231	0.200306

A4	0.218182	0.181731	0.192793	0.188889	0.190524	0.189189	0.191071	0.231579	0.227446	0.178679	0.181957
A5	0.218182	0.220192	0.215315	0.188889	0.197581	0.196196	0.213393	0.178947	0.181703	0.178679	0.181957

Step 4.2.2. Determine the Entropy of each criterion e_j through Eq. (14) as shown in Table 13.

Table 13: Entropy of each criterion Table

e_j	0.998177	0.997681	0.998706	0.998512	0.999284	0.999436	0.999078	0.994911	0.99615	0.996747	0.997108

Step 4.2.3. By applying Eq. (15), we determine the degree of divergence d_j as represented in Table 14.

Table 14. Divergence Degree

$1\text{-}e_j$	0.001823	0.002319	0.001294	0.001488	0.000716	0.000564	0.000922	0.005089	0.00385	0.003253	0.002892

Step 4.2.4. Evaluate the weights of criteria using Eq. (16). As shown in Table 15 and Figure 4.

Table 15: Criteria Weights

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
Wj	0.075303	0.095796	0.053454	0.06145	0.029578	0.023299	0.038098	0.210192	0.159025	0.134352	0.119453

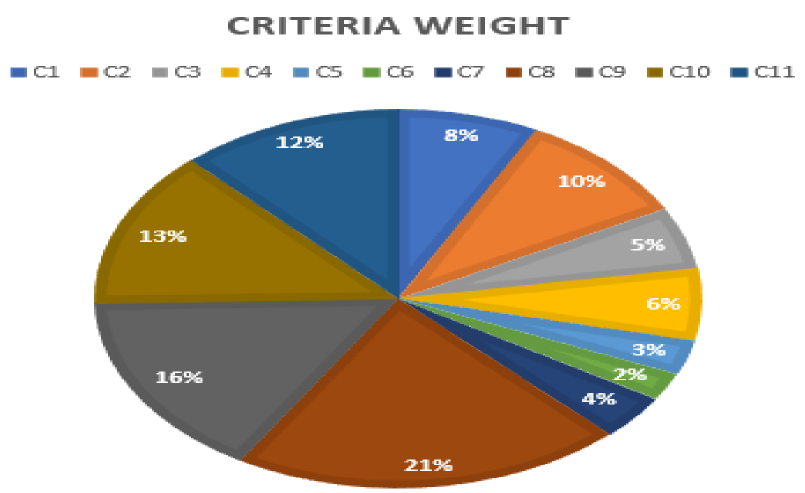

Figure 3. Criteria Weights Value.

Then apply the entropy weight method to assign weight to each criterion. Using Eq. 13 to convert Table 11 into an entropy-normalized matrix, as shown in Table 12, to make criteria comparable by eliminating the scale effects between criteria. To measure the lack of useful information in each criterion, use Eq. 14 to detect the entropy of each criterion, ej, as shown in Table 13. By using Eq. 15 in Table 14, determine the divergence of degree (1-ej) that shows the presence of useful information (variability) in each criterion. By using Eq. 16, it assigns relative importance based on divergence from the criterion. The high criterion variability, reflecting substantial divergence, results in a higher weighting for the criterion. Thereby, Table 15 and Fig. 3 indicate the weight of each criterion w_j; Criterion C8 (loading speed) and C9 (price) are superior to other criteria, and Criterion C6 (information quality) has the lowest weight.

4.3. Apply the TODIM Method

Step 4.3.1. Determine the normalized decision matrix using Eq. (17), and Eq. (18). The beneficial criteria are C1, C2, C4, C5, C6, and C7 and the non-beneficial criteria are C8, C9, C10 and C11, Table 16 represent the TODIM normalized matrix.

Table 16: TODIM normalized matrix.

	Beneficial									**Non-Beneficial**	
Alternative	C1	C2	C3	C4	C5	C6	C7	**C8**	**C9**	**C10**	**C11**
A1	0.191444	0.181731	0.192792793	0.221296296	0.190524	0.21421	0.191071	0.22	0.217	0.184382	0.191444
A2	0.191444	0.220192	0.215315315	0.212037037	0.215726	0.1962	0.213393	0.22	0.174	0.201271	0.191444
A3	0.180749	0.196154	0.183783784	0.188888889	0.205645	0.2042	0.191071	0.17	0.217	0.171211	0.180749
A4	0.218182	0.181731	0.192792793	0.188888889	0.190524	0.18919	0.191071	0.17	0.174	0.221568	0.218182
A5	0.218182	0.220192	0.215315315	0.188888889	0.197581	0.1962	0.213393	0.22	0.217	0.221568	0.218182

Step 4.3.2. Using Eq. (19) to calculate the relative weight as shown in Table 17, by using the EWT weight in Table 11.

Table 17: Relative Weight.

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**
Wcr	0.358258	0.455756	0.254310417	0.292350507	0.140721	0.11085	0.181254	1	0.757	0.639187	0.568306

Step 4.3.3. Determine the dominance degree by using Eq. (20) as shown in Table 18.

Table 18: Dominance Degree of Alternatives

A1	-9.2651396
A2	-6.7460989
A3	-13.519856
A4	-13.378862
A5	-2.8076295

Step 4.3.4. Calculate the aggregation of the dominance degrees by using Eq. (21) as shown in Table 19.

Table 19: Overall, Dominance Degree of Alternatives.

A1	0.397183197
A2	0.632338858

A3	0
A4	0.013161999
A5	1

Step 4.3.5. Rank the alternatives. Table 20 shows that the ranking of the alternatives is based on their overall dominance values.

Table 20: Ranking the Alternatives

A1	3
A2	2
A3	5
A4	4
A5	1

After applying the integrated model TNN-BWT-TODIM, Website 5 is the highest quality ecommerce website, followed by Website 2 and Website 1. While Website 3 has the lowest quality.

In the next step, apply the TODIM method. Converting Table 11 into Table 16 to determine the TODIM normalized decision matrix by using Eq. (17) and Eq. (18) to ensure fair aggregation of criteria with different units. For beneficial criteria, higher values are desirable, whereas, for non-beneficial criteria, lower values are better. By applying Eq. 19, determine the weights relative to the most important criterion (C8: loading speed), as shown in Table 17. Following this step, the dominance degree is constructed by using Eq. 20 (see Table 18). After determining the dominance degree of alternatives, Eq. 21 is used to aggregate the overall dominance degree of alternatives (ζi) to convert the dominance matrix into a single score between 0 and 1, as shown in Table 19. Finally, the websites are ranked by their overall dominance degree (ζi) as shown in (Table 20). The results of the integrated model TNN-EWT-TODIM show that Website 5 is the optimal e-commerce website, followed by Website 2 and Website 1. While Website 3 has the lowest performance.

4.4 Comparative study with MCDM Methods

To validate the effectiveness of TNN-EWT-TODIM model, the results of our proposed model is compared with the results by other MCDM method, such as TOPSIS[35, 36], CORPAS[45], SPOTIS[143], EDAS[50, 51], and CODAS[53].

Table 21: The ranking of websites with comparative methods.

Alternatives	Proposed Model	TOPSIS	CORPAS	SPOTIS	EDAS	CODAS
Website 1	3	1	2	1	2	2
Website 2	2	3	1	3	4	5
Website 3	5	4	4	5	5	4
Website 4	4	5	5	4	1	1
Website 5	1	2	3	2	3	3

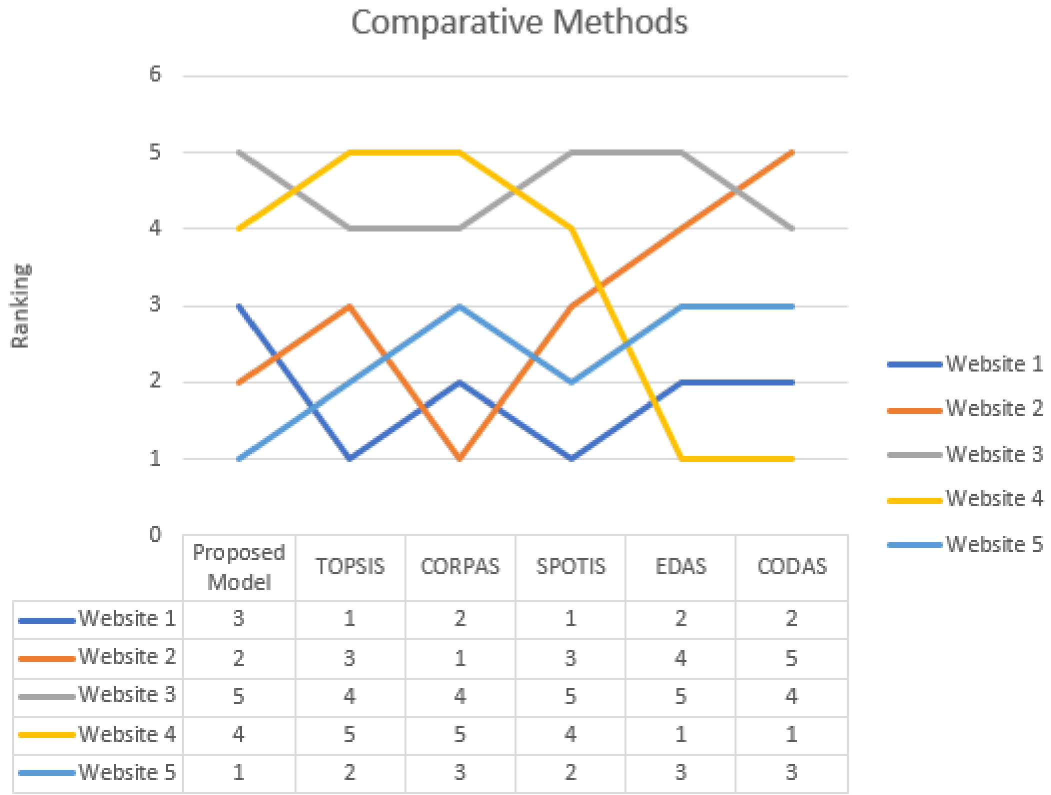

Figure 4. Ranking of websites with comparison methods.

As shown in Table 21 and Fig. 4, there are some differences between the proposed model and the other comparative MCDM methods. Website 5 is the top alternative in the proposed model. While in the TOPSIS and SPOTIS methods, website 1 is ranked highest, website 5 is ranked second, and website 2 is ranked third. However, websites 4 and 5 are interchangeable in the fourth and fifth orders. In the CORPAS method, website 2 is the first order, and website 4 is the last order. Website 4 is ranked highest in CODAS and EDAS methods, followed by website 1 in the second order, and website 5 in the third order. While website 2 ranked lower in CODAS, website 4 ranked lower in the EDAS method.

These results indicate that the proposed model is unique in handling the criteria in an uncertain environment due to TNN. Also, the balancing between the criteria evaluation is offered by the proposed model. In addition, we take the strengths of the Entropy and TODIM methods and produce a coherent model. Thereby, these inherent characteristics of the proposed model are remarkably different, thus yielding distinct rankings of websites. The comparison reveals that the proposed model is valid, robust, effective, and provides more informed and balanced output.

4.5 Sensitivity Analysis

The sensitivity analysis is conducted to ensure the robustness of TNN-EWT-TODIM model among ecommerce websites to changes in the criteria weights.

Table 22: Different cases of criteria weights.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11

Our Case	0.075303	0.095796	0.053454	0.06145	0.029578	0.023299	0.038098	0.210192	0.159025	0.134352	0.119453
Case 1	0.0178	0.1516	0.0008	0.153	0.0497	0.0517	0.0584	0.4273	0.0569	0.0196	0.0132
Case 2	0.1608	0.0176	0.0957	0.1298	0.0166	0.022	0.106	0.0848	0.1409	0.128	0.0978
Case 3	0.0849	0.0161	0.1045	0.0107	0.0399	0.1813	0.1304	0.1342	0.0896	0.0618	0.1466
Case 4	0.0023	0.0304	0.1206	0.064	0.1552	0.1612	0.0278	0.1104	0.0286	0.0747	0.2248
Case 5	0.1035	0.1659	0.0248	0.1103	0.1242	0.0572	0.0642	0.2145	0.0191	0.1048	0.0115
Case 6	0.21	0.1	0.0703	0.176	0.2253	0.1352	0.0792	0.001	0.001	0.001	0.001

As shown in Table 22, website 5 is the top in case 1, and in case 5, the weight of the criteria loading speed (C8) is the highest criterion weight, as in our case. Website 2 becomes the best e-commerce website quality in case 2 and in case 6. In case 2, the weight of the usability and navigation (C1) criterion is relatively higher, while in case 6, the criterion of usability and navigation (C1) and customer services (C5) are the highest weights. In Case 3 and Case 4, due to the changes in the weights of criteria C6 and C11, website 1 has become the highest-quality website. Sensitivity analysis illustrates that websites are quite sensitive to changes in the criteria weights.

Table 23 shows the changes in θ values in the TODIM for applying sensitivity analysis to conduct the robustness of the proposed model. Figure 5 indicates that website 5 is the best website when θ=1 in the proposed model. When θ=1.5, website 5 is still the best website, as in our case. The ranking of websites is changed due to the changes in θ values. Thereby, θ values impact the final rankings of e-commerce websites.

Table 23: Different θ values for applying sensitivity analysis on TODIM.

θ	Website 1	Website 2	Website 3	Website 4	Website 5
θ = 1	3	2	5	4	1
θ = 1.5	3	2	5	4	1
θ = 4	2	3	5	4	1
θ = 6.5	1	3	4	5	2
θ = 8.5	1	2	4	5	3
θ = 10	1	2	4	5	3

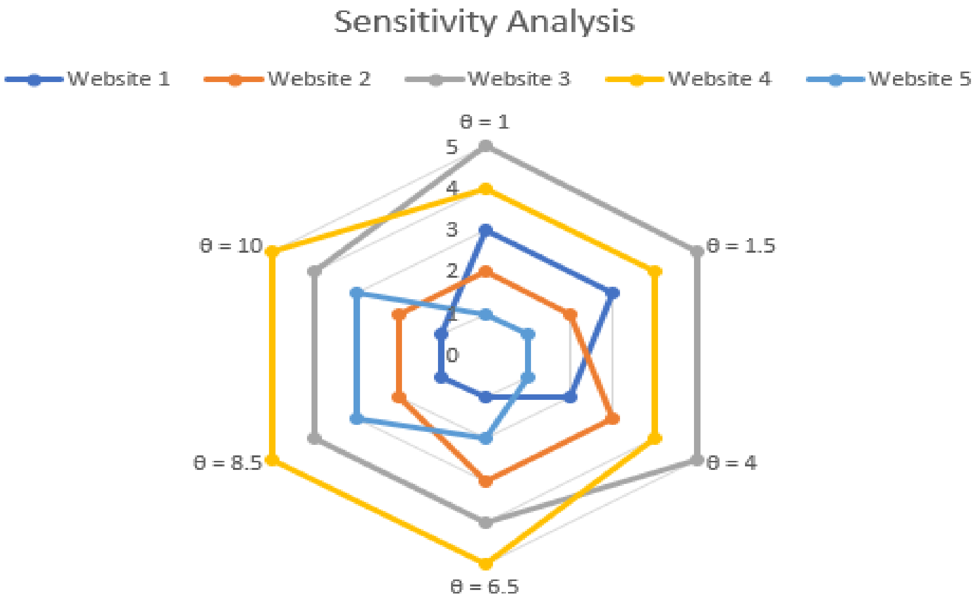

Figure 5. Different θ values for applying sensitivity analysis on TODIM.

The sensitivity analysis on the θ value in the TODIM, where the values range from 1 to 10, shows that higher θ values indicate greater sensitivity to losses relative to gains. This sensitivity analysis allows decision-makers to select the best e-commerce website based on priorities and risk preferences. Finally, decision-makers can make decisions that balance between gains and losses in MCDM, revealing the robustness of websites under different ranking approaches.

5. Conclusions

In this study, a model for evaluating the quality of e-commerce websites has been proposed. The proposed model is based on triangular neutrosophic numbers that have a three-member function: truth, false, and indeterminacy. The indeterminacy function added an advantage to solve a lack of knowledge, conflicting viewpoints, vagueness, and subjectivity problems that are associated with expert evaluation in an uncertain environment. The proposed model integrates TNN with the entropy method to assign weight to each criterion in our MCDM problems and TODIM to rank the e-commerce websites. Five leading e-commerce websites were used within eleven criteria to conduct the case study. The proposed model produces more accurate, realistic results and reduces hesitancy and bias in the expert's opinion. We compare the proposed model with other MCDM methods, and the results showed that the proposed model was verified and efficient. Sensitivity analysis indicated that the ranking between e-commerce websites is quite sensitive to the changes between criteria weights, revealing the robustness of websites under different ranking approaches. For future work, the proposed model may be applied to other websites like hotels, e-government, airlines, e-banking, tourism, and health. Moreover, the proposed TNN-EWT-TODIM model can be applied in other fields like supplier selection, supply chain, sustainability of manufacturing-based industries, project selection, group decision-making, renewable energy, and cloud computing.

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