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A model for evaluating green credit rating and its impact on sustainability performance

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ABSTRACT

The development of economic activities and social progress index leads to the governmental considerations for the environmental challenge's issues. The Green Credit Policy (GCP) in China for manufacturing, as a part of a sustainable finance package, initiatives restrictions with suppliers to reduce harmful pollution for the environment. The study mainly validates the impact of GCP on manufacturing for diminishing the emerged pollution to the environment. The study develops Neutrosophic Multiple-Criteria Decision-Making Framework (N-MCDMF) according to neutrosophic theory and various MCDM methods of grey relational analysis (GRA), analytic network process (ANP), the Decision-Making Trial and Evaluation Laboratory technique (DEMATEL), and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to support the decision-makers with highly systematic procedures in the uncertain and inconsistent environmental conditions. The N-MCDMF evaluates the conditions of GCP and recommends the optimal Supply Chain Management (SCM) in manufacturing alternatives. A case study is presented for the validation of the issues of applicability and flexibility for the proposed N-MCDMF. The results obtained from the implementation of the N-MCDMF indicates the applicability and flexibility of the proposed approach. In addition, results show that SCM in manufacturing can provide more cooperation for the environment to reduce harmful pollution and to attain sustainability for achieving motivations under the restrictions of GCP.

1. Introduction

The advancement of the world economy leads to prominent obstacles in environmental issues all over the world. The economic growth with retaining the development of sustainability is the concern of many countries (Kudratova et al., 2018). Improving sustainable development can be the only way to handle most of the global problems like climate change, poverty, global warming, hunger, and inequality (Sherafati et al., 2020). In China, the advancements of manufacture lead to huge environmental pollution. Due to the extreme use of energy, and massive emissions of carbon in the previous decades (Xu and Lin, 2017). According to Shen and Lin, 2020, the manufacture is the largest consuming sector of energy in China, and the government decided to control the use of energy. The government in China, imposed incentives and punishments to encourage manufacturers to make efforts to reduce pollution (Kang et al., 2020). The manufacturers' production and transportation activities have an extreme influence on the environment and the development level among the elements of the supply chain (Sherafati et al., 2020). According to Kang et al. (2020), the government and the manufacturer have an important role in the supply chain for the sake of pollution reduction. The participants in the supply chain can obtain the incentive to reduce pollution emitted to the environment (Castellacci and Lie, 2017).

Supply chain management (SCM) is a network of multiple companies that collaborate to convert raw materials into final products and/or services. In China, the government applies policies that offer acceptable incentives for market participants and supply chain partners to reduce pollution emitted to the environment (Wang et al., 2019). GCP is an incentive system that provides financial benefits for environmental performance (Kang et al., 2020). According to the guidelines of the GCP in China, banks and other financial institutions may give more loans or financial support for

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environmentally friendly or energy-saving companies (Liu et al., 2017). Regulations encourage corporations to concentrate on environmental problems in the procedures of the SCM in manufacturing (Zhu et al., 2007). The SCM applies a suitable strategy for the decrease of environmental pollution, prevent regulations retribution, and attain governmental incentives. According to Yang et al. (2019), sustainable development encompasses many economic, environmental, and social aspects. During the application of green credit, the manufacturing companies direct resource allocation to reduce pollution for the purpose of attaining sustainability.

The green credit rating of companies is a MCDM problem. The researchers used MCDM methods to determine trade-offs among environmental, social, and economic criteria (Banasik et al., 2018). The MCDM is a formal method of decision-making that can handle the conflict criteria and complex problems (Nabeeh, 2020). In MCDM, the experts may provide confusing perspectives because of the real-life environmental conditions of vague, impression, inconsistency, and uncertainty (Abdel-Basset et al., 2019a). Hence, the MCDM should be extended with advanced mathematical sets to handle the current environmental challenges. Consequently, the Fuzzy set is used to deal with vague or imprecise of MCDM (Abdel-Basset et al., 2019a). Traditionally, the Fuzzy set used the membership function to find preference relations, however, there are technical difficulties to create membership functions that reflect all problem's aspects in real situations of indeterminate cases (Abdel-Basset and Mohamed, 2020a; Abdel-Basset et al., 2018a; Abdel-Basset et al., 2019b).

Neutrosophic sets are used to model real-world problems regarding the conditions of all situations of decision-making (Victor et al., 2018). According to Nabeeh et al. (2019a) the neutrosophic is a novel aspect of philosophy that concentrates on the study of the origin and scope of neutralities. Due to the decision-maker confusion and real-life situations, the relationships between numerous criteria and alternatives cannot be efficiently defined. Neutrosophic can handle both the misjudgments of decision-makers and environmental factors of uncertainty conditions. According (Nabeeh et al., 2019a), the neutrosophic theory can handle the indeterminate cases by illustrated a systematic methodology to obtain the measurable form for such indeterminate cases. The neutrosophic sets powerfully handled the indeterminate and inconsistent data through including three aspects which are truth, indeterminate, and false degrees (Nabeeh et al., 2019b). Recently, the integration of MCDM methods used in complicated problems with various criteria and alternatives (Alam-Tabriz et al., 2014; Kuan and Chen, 2014; Shen et al., 2014).

The proposed N-MCDMF integrates the neutrosophic with MCDM to support the decision-makers with a highly systematic framework in the uncertain and inconsistent environmental conditions. The N-MCDMF integrated the GRA to evaluate the degree of interrelation among the criterion of GCP. The DEMATEL method is used to analyze the preferences among the criterion of GCP. The ANP is applied to obtain the final weights for the GCP criterion. The N-MCDM is focused on ranking alternatives of the SCM in manufacturing that meets the objectives of GCP. The TOPSIS is used in the N-MCDMF to attain optimal SCM in manufacturing solutions.

The rest of this study is structured as follows. Section 2 presents the literature review and related studies. Section 3 presents the main procedures for the proposed framework and the integration neutrosophic with MCDM methods to attain optimal solutions according to GCP conditions. Section 4 presents an effective case study to ensure the applicability and flexibility of N-MCDMF. Section 5 illustrates the discussion and results for the proposed N-MCDMD. Section 6 mentions the managerial insights. Section 7 concludes the study and benefits of applying N-MCDMF, in addition, plans future trends for the next studies.

2. Research background

In literature, environmental issues attract a lot of attention. (Kang et al., 2020). In manufacture, the raw material is transformed into useful products through a series of value and non-value-added processes. The manufacturing process is utilized by eliminating non-value-added activities and reducing the environmental effect to assess the sustainable performance for companies (Aigbedo, 2021). In literature, the sustainability is the growth that meets the needs of the current generation with the province of the chance and the ability for forthcoming generations (Abdel-Basset and Mohamed, 2020a; Abdel-Basset et al., 2020b; Tsalis et al., 2020; Seuring et al., 2008). In addition, sustainability has a multi-dimensional focus on the 'triple-bottom-line' of economic, environmental, and social dimensions (Seuring et al., 2008). The business around the world introducing certain strategies such as "clean production" and "eco-efficiency" approaches to respond to sustainability (Tsalis et al., 2020).

The SCM cooperated to overcome the negative effect of the activities of manufacturing for reducing environmental pollution and minimizing the harmful waste of industries (Zhu et al., 2017). Many researchers (Klassen and Vachon, 2003; Hollos et al., 2012) have tried to determine the relationship between the supply chain to reduce the emitted pollution to the environment. The manufacturing process improved environmental performance and productivity for small and medium-sized enterprises to attain such a proper sustainable performance (Choudhary et al., 2019).

The governments restricted many policies regarding the issues of the environment and corporations of GCP. The GCP, as an effective incentive system, is a form of policy to reduce pollution (Zhang et al., 2011; Zhang et al., 2019). In South Korea, GCP allows manufacturers to reduce pollution by cooperating with suppliers to apply environment-friendly regulation (Kang et al., 2020). Governments applied many policies such as tax programs and incentives to motivate companies to decrease pollution (Kang et al., 2020). Fan et al. (2017) studied empirically the reduce energy consumption on the aspects of financial performance and efficiency in China. While Choudhary et al. (2019) used an integrated lean and green approach for improving sustainability performance. Kang et al. (2020) studied the effect of the GCP on manufacturers' efforts to reduce pollution in the supply chain in South Korea. The manufacturers used the optimal control theory to create additional value by reducing their suppliers' pollution at the desirable levels. Kannan et al. (2020) evaluated and prioritized sustainable suppliers in circular supply chains in Iran by integrating the Fuzzy set best-worst method and the interval VIKOR method. Recently, China has accomplished many achievements in economic, however caused high energy consumption and high pollution to the environment (Fan et al., 2017). Since there exist only a few cities that have adequate fresh air which is only eighty-three from three hundred thirty-eight cities in China. The government concerns increased to recover environmental pollution.

Previous studies that deal with pollution have concentrated on the maximization of individual profits in isolation (Kang et al., 2020). There is a gap in the research that reflects the efforts of the manufacturer to decrease pollution in the supply chain. Furthermore, the manufacturer's attempts to use the GCP have not been fully investigated. The green credit rating of corporations is a MCDM problem. To evaluate and rank multiple attributes, it is recommended to use the MCDM model to provide these characteristics (Yang et al., 2019). The MCDM problems deal with the conditions of vague, impression, inconsistency, and uncertainty (Zhang et al., 2018). The MCDM is integrated with Fuzzy set to handle the existing challenges of MCDM techniques. However, the membership function could be represented in all problems (Abdel-Basset et al., 2018a).

The neutrosophic theory is proposed to handle the environmental conditions of uncertainty and inconsistency (Abdel-Basset et al., 2019b). The neutrosophic theory can fully deal with indeterminant cases, while fuzzy cannot deal with indeterminate cases. The intuitionistic fuzzy theory can deal only partially with independent cases. Hence, indeterminacy is an independent component in neutrosophic theory in other sets (fuzzy, intuitionistic fuzzy, etc.) indeterminacy is dependent or does not exist. The while neutrosophic theory is used in many disciplines such as supplier selection, cloud services, smart city, and personnel selection to handle the indeterminate solution into a suitable form (Abdel-Basset et al., 2018b; Abdel-Basset and Mohamed, 2018; Abdel-Basset et al., 2019b). The neutrosophic theory can model the indeterminant cases to represent an accurate decision maker's perspective in different neutrosophic scales to attain optimal solutions for different objectives (Nabeeh, 2020; Nabeeh et al., 2020a; Nabeeh et al., 2020b).

In recent years, researchers have widely used a hybrid MCDM model in several fields. According to Yang et al. (2019) ANP and VIKOR (TOPSIS) method based on DEMATEL are the most common hybrid MCDM model uses to solve confused between criterion. The model of MCDM presents the DEMATEL method to analyze and examine the relationships and strengths among evaluation criteria by using a questionnaire. To determine the relative weights of the evaluation criteria, the study applied a hybrid model of DEMATEL and ANP technique. Finally, VIKOR (TOPSIS) was used to get the alternatives' final ranking. Ou Yang et al. (2013) integrated ANP, DEMATEL, and VIKOR to assess the risk conditions. While the supplier selection problem, Alam-Tabriz et al., (2014) integrated ANP, DEMATEL, and TOPSIS. To evaluate the technological innovation capabilities of companies Kuan and Chen (2014) integrated ANP, DEMATEL, and VIKOR. Whereas, the research used ANP, DEMATEL, and VIKOR to choose the most appropriate stock. Both the TOPSIS and VIKOR methods are suitable for solving decision-making problems (Shen et al., 2014). However, many researchers (Stanujkic et al., 2013; Ding and Kamaruddin, 2014; Yang et al., 2019; Rani et al., 2020) stated that TOPSIS is known to be from the most known and popular methods of MCDM.

Therefore, this study aimed to combine the neutrosophic theory and different MCDM methods of GRA, DEMATEL, ANP, and TOPSIS in an integrated N-MCDMF to evaluate the GCP conditions and to rank the SCM in manufacturing candidate alternatives. The N-MCDMF works on decrease pollution to the environment and attains sustainability performance.

3. Model formulation framework

The GCP and SCM are regarded to be a confusing MCDM problem, hence the study integrates a high quality of systematic N-MCDMF to evaluate the GCP conditions and to recommend proper automatic suggestions of optimal SCM in the aspect of manufacture with respect to environmental challenges of uncertainty and inconsistency. The N-MCDMF integrates various MCDM techniques such as GRA, DEMATEL, ANP, and TOPSIS with auspices of neutrosophic theory to achieve the optimal recommended solutions. In Fig. 1, an abstraction for the N-MCDMF is modeled such that the four major parts for the research are modeled as follows: 1) Identify study objectives, 2) Collect and integrate expert's knowledge in the proper format, 3) Evaluate the criteria of GCP, 4) Recommend optimal alternatives of SCM. First, the study objectives include the collecting and integrating of decision maker's judgments, criteria, and alternatives. The study objectives identify the main criteria and alternatives for the study. Second, the decision maker's judgments and experiences are included in the study in the form of a neutrosophic triangular scale that adopted true, indeterminate, and false cases of decisions. Third, for the N-MCDMF criteria, the GRA is an essential statistical analysis method that could evaluate multiple objective functions and detect the optimum objects with various performance attributes (Bademlioglu et al., 2020). The GRA relies on the similarities among alternatives, the closet distances between alternatives and optimal solution refers to the degree of correlation (Yang et al., 2019). The DEMATEL mainly developed to scientific and human issues of complex and interrelated problems to achieve better comprehension for real-life situations (Nabeeh, 2020). The DEMATEL formulate problems into comprehensive relationships among the problem's criteria to achieve to most proper solutions. The ANP method is a general form that uses comparison matrices for MCDM problems to evaluate the influence of the indicated calculated weights and priorities between criteria (Adel-Basset and Mohamed, 2019). Fourth, for the N-MCDMF alternatives, the TOPSIS depends on detecting the positive and negative candidate of solutions and recommending optimal solutions by computing relative closeness between the two groups (Nabeeh et al., 2019a). The MCDM as a popular methodology aids decision-makers to evaluate and achieve the ideal candidate of solutions (Ou, 2016). The flowchart in Fig. 2, depicts the flowchart of proposed N-MCDMF that combines more than one method of MCDM under the generalization of neutrosophic theory to achieve ideal solutions as mentioned in the next step:

Step 1: Detect the study objectives, alternatives, and criteria. The expert's perspectives and judgments are gathered surveys by the aid of reviews, vis-a-vis meetings of advices, and questioner to formulate in an appropriate form, more details in Appendix A.

Step 2: The neutrosophic theory can specify the perspectives and judgments of decision-makers. In situations of multiple decision-makers, apply the aggregation function to achieve to aggregated pairwise comparison matrix (Nabeeh et al., 2019a). The study recommends formulating decision judgments as a triangular neutrosophic scale to overcome the uncertain and inconsistent cases of environment real-life conditions (Nabeeh et al., 2019b; Nabeeh, 2020)

Step 3: The neutrosophic judgments for GCP criteria have been converted to crisp values between zero and three by applying the score function illustrated in (Abdel-Basset et al., 2019b). The formulation of neutrosophic decision-makers' judgments to crisp values provides a degree of flexibility and simplicity for the following practical steps. The score function is mentioned as follows:

$$s(z_{ij}) = \left| (l_{ij} \times m_{ij} \times u_{ij}) \frac{T_{ij} + I_{ij} + F_{ij}}{9} \right| \tag{1a}$$

, such that l, m, u refers to the lower, median, upper of the scale neutrosophic numbers, and T, I, F are representing the truth-membership, indeterminacy, and falsity membership functions respectively for triangular neutrosophic number.

Step 4: The N-MCDMF primarily used the method of GRA to evaluate the relations between various criteria. The relationships among criteria are commonly strong, hence the GRA is recommended to evaluate GCP criteria. In addition, the GRA has the capability to perform flexible computations in real-life situations of uncertainty and inconsistency (Yang et al., 2019). The GRA involved two cardinal models: the local and global GRA models (Huang et al., 2019). According to the strength and weakness index mentioned in (Wang, 2009), the study decided to perform the global GRA to the N-MCDMF to evaluate the effectiveness GCP on the SCM in manufacturing. The steps of global GRA are mentioned as follows:

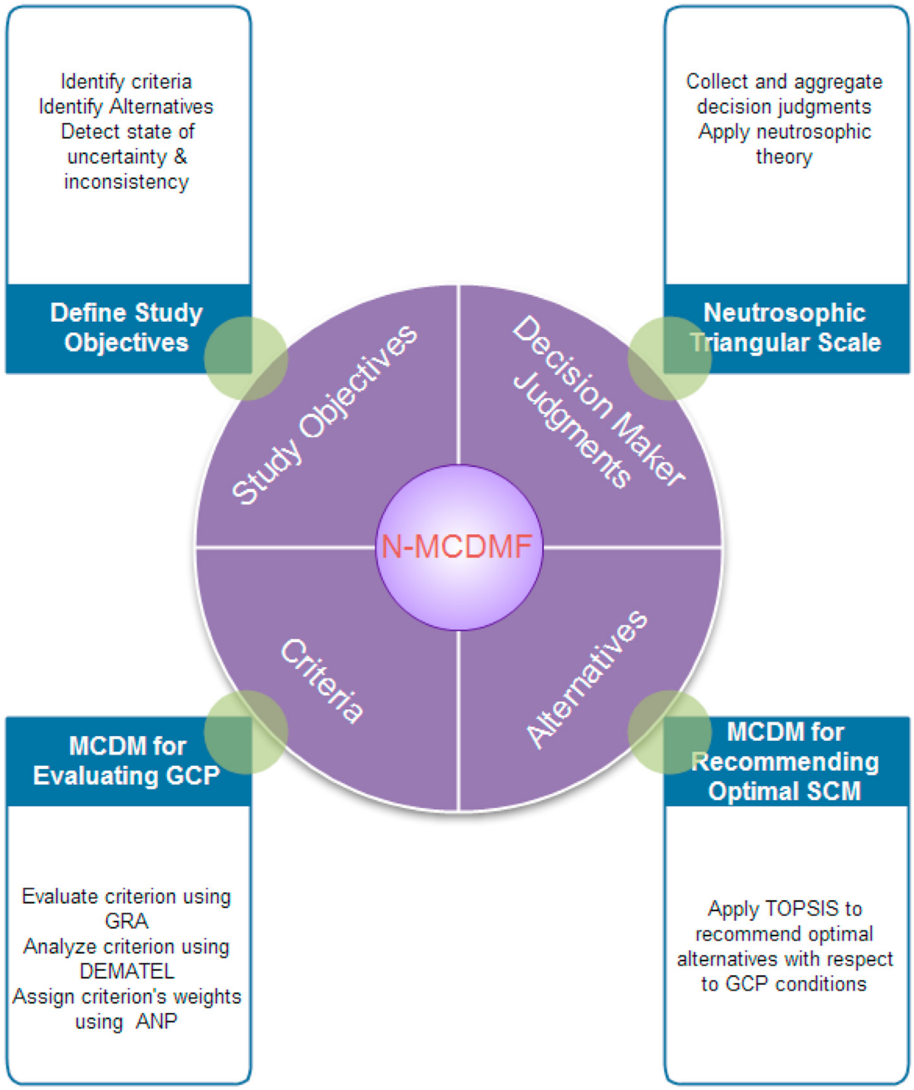


Fig. 1. The framework of the N-MCDMF.

Step 4.1: Create the original sequence for GCP criterions

$Z_j = \{z_1(1), \cdots, z_j(L)\}$, such that $j = 1, 2, \cdots m$, $L = 1, 2, \cdots n$.

Step 4.2: The data preprocessing and data normalization for GRA is classified according to the original sequence into two classes, first-class refers to the Larger-the-better for infinite or maximum data, second class refers to the smaller-the- better for finite or minimum data (Sa et al., 2018). The equations for data preprocessing are mentioned as follows:

(1) **Larger-the-better:** the effective measure for upper-bound is represented as

$$z_j^*(L) = \frac{z_j(L) - min[z_j(L)]}{max[z_j(L)] - min\ [z_j(L)]} \tag{1b}$$

, such that, $z_j^*(L)$is the resulted preprocessing values, $z_j(L)$is the original sequence for the criteria, $max[z_j(L)]$, $min\ [z_j(L)]$ represents the maximum, and minimum values respectively for the original sequences.

(2) **Smaller-the-better:** the effective measure for lower-bound is represented as

$$z_j^*(L) = \frac{max[z_j(L)] - z_j(L)}{max[z_j(L)] - min\ [z_j(L)]} \tag{2}$$

Step 4.3: compute the grey relation coefficient (GRC) to detect the relations between the reference sequence $z_j(L)$, and comparative sequence denoted as $z_i(L)$. The GRC is mentioned as in the next equation:

$$\gamma(z_j(L),\ z_i(L)) = \frac{\Delta_{min} + \delta\Delta_{max}}{\Delta_{ji}(L) + \delta\Delta_{max}} \tag{3}$$

Such that $\Delta_{ji}(L) = |z_j(L) - z_i(L)|$, $\Delta_{min} = \forall minj\ \forall minL|z_j(L) - z_i(L)|$, $\Delta_{max} = \forall maxj\ \forall maxL|z_j(L) - z_i(L)|$, $L = 1, 2, \cdots m.j = 1, 2, \cdots n$, $i \in L$, The δ represents a distinguishing coefficient with a value between [0,1] and set to be 0.5 (Yang et al., 2019; Sa et al., 2018).

Step 4.4: Compute the grey relational grade for the sequence of z_j illustrated as follows (Deng, 1982):

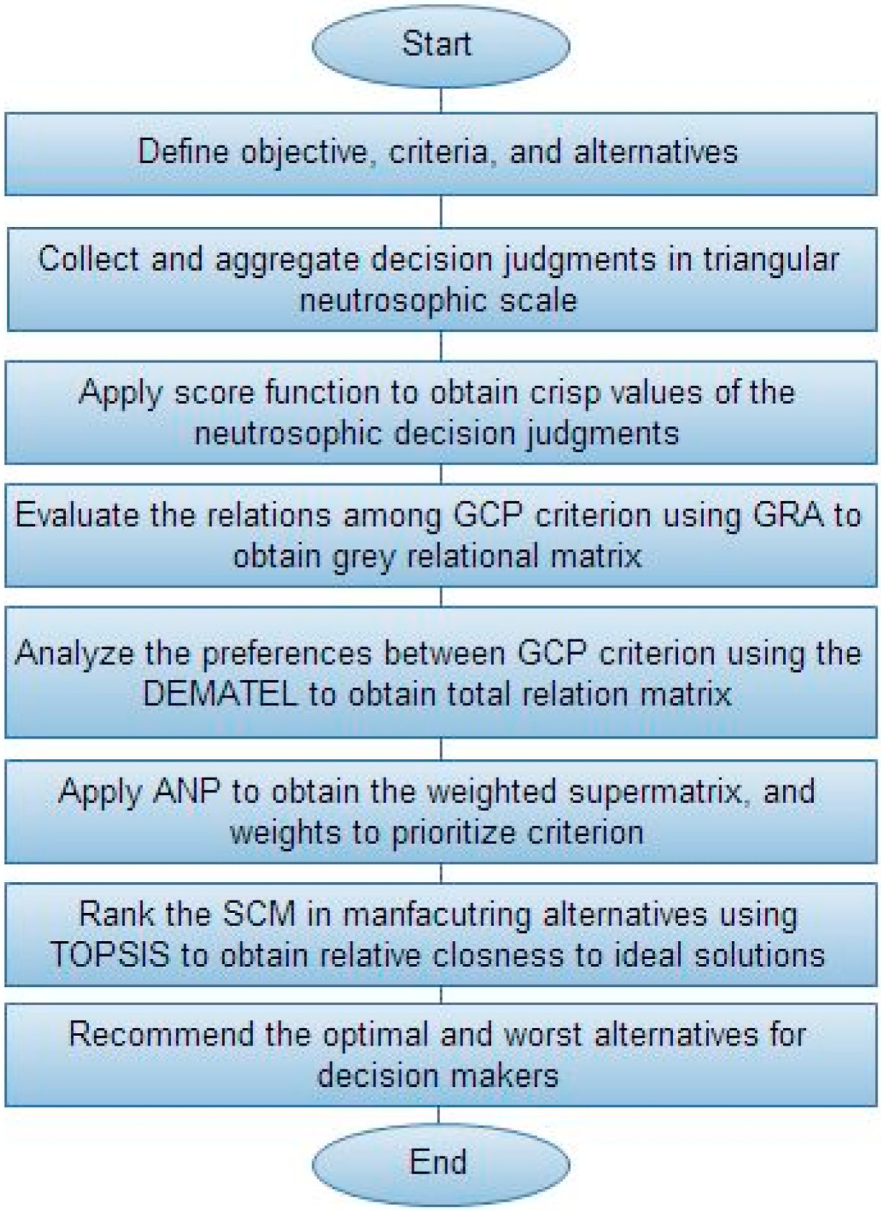


Fig. 2. The flowchart of N-MCDMF.

$$G_{ji=}G(z_j,\ z_i)=\frac{1}{m}\sum_{L=1}^{m}\gamma(z_j(L),\ z_i(L)) \tag{4}$$

, where m represents the number of criterions.

Step 4.5: Compute the grey relational matrix from the previous step of grey relational grade:

$$S_{n\times m=}G_{11}\ G_{12}\ G_{1m}\ G_{21}\ G_{22}\ G_{2m}\ G_{n1}\ G_{n2}\ G_{nm} \tag{5}$$

, such that G_{ji} represents the relation between the sequences of $z_j(L),\ and\ z_i(L)$.

Step 5: The DEMATEL is adopted to study the relation among structured criteria (Deng, 1982). The study extends DEMATEL with GRA to combine valuable advantages of step 4 of the grey relational matrix. The procedures for DEMATEL are illustrated in the following steps:

Step 5.1: Build an initial direct relation matrix

The initial matrix in DEMATEL is substituted with a grey relational matrix in Eq. (5) and reflected the degree of criteria j on criteria i. The general vision matrix is represented in form (6), and the values of N (γ_{ji}(refer to the effect of criteria j on criteria i.

$$N=\begin{bmatrix} 0 & \gamma_{12} & \gamma_{13} & \cdots & \gamma_{1n} \\ \gamma_{21} & 0 & \gamma_{23} & \cdots & \gamma_{2n} \\ \gamma_{31} & \gamma_{32} & 0 & \cdots & \gamma_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \gamma_{m1} & \gamma_{m2} & \gamma_{m3} & \cdots & 0 \end{bmatrix} \tag{6}$$

Step 5.2: Determine the normalized direct relation matrix

The current matrix built up from the previous step of initial direct relation matrix form (6). The following equations are used to obtain the normalized direct relation matrix:

$$B = 1 \Big/ \max_{1 \le i \le m} \sum_{i=1}^{m} \gamma_{ji}; i = 1, 2, 3, \ldots m; j = 1, 2, 3, \ldots, n \quad (7)$$

$$Y = B \times N \quad (8)$$

Step 5.3: Build the total relation matrix

The total relation matrix can be computed using the general normalized direct relation matrix as follows (Qi et al., 2020):

$$T_g = Y \times (I - Y)^{-1}, \quad (9)$$

where I denote identity matrix, and T_g denotes total relation extended with GRA.

Step 6: Construct weighted supermatrix of ANP

The ANP is constructed based on the resulted preceding methods of GRA and DEMATEL to produce the supermatrix of ANP.

$$T_g = \begin{bmatrix} n_{11} & \cdots & n_{1j} & \cdots & n_{1m} \\ \vdots & & \vdots & & \vdots \\ n_{i1} & \cdots & n_{ij} & \cdots & n_{im} \\ \vdots & & \vdots & & \vdots \\ n_{n1} & \cdots & n_{nj} & \cdots & n_{nm} \end{bmatrix} \quad (10)$$

, where T_g is the total relation resulted from applying previous methods of GRA and DEMATEL, and n_{ij}denoted to indirect effects that criteria i has on criteria j.

Step 6.1: The total matrix relation T_g that resulted from the integration of GRA and DEAMTEL would be normalized to supermatrix T_s matrix (Hao et al., 2018). Such that, $d_i = \sum_{j=1}^{m} n_{ij}$

$$Ts = \begin{bmatrix} n_{11}/d_1 & \cdots & n_{1j}/d_1 & \cdots & n_{1m}/d_1 \\ \vdots & & \vdots & & \vdots \\ n_{i1}/d_i & \cdots & n_{ij}/d_i & \cdots & n_{im}/d_i \\ \vdots & & \vdots & & \vdots \\ n_{n1}/d_n & \cdots & n_{nj}/d_n & \cdots & n_{nm}/d_n \end{bmatrix} = \begin{bmatrix} n^s_{11} & n^s_{1j} & n^s_{1m} \\ n^s_{i1} & n^s_{ij} & n^s_{im} \\ n^s_{n1} & n^s_{nj} & n^s_{nm} \end{bmatrix} \quad (11)$$

Step 6.2: Obtain the unweighted supermatrix

The supermatrix denotes to be W matrix by transposing the normalized supermatrix as follows:

$$W = (t^{\circ}_s) = \begin{bmatrix} n^s_{11} & n^s_{i1} & n^s_{n1} \\ n^s_{1j} & n^s_{ij} & n^s_{nj} \\ n^s_{1m} & n^s_{im} & n^s_{nm} \end{bmatrix} = \begin{bmatrix} w_{11} & \cdots & w_{ij} & \cdots & w_{n1} \\ \vdots & & \vdots & & \vdots \\ w_{1j} & \cdots & w_{ij} & \cdots & w_{nj} \\ \vdots & & \vdots & & \vdots \\ w_{1m} & \cdots & w_{im} & \cdots & w_{nm} \end{bmatrix} \quad (12)$$

Step 6.3: Compute the weighted supermatrix

The weight of supermatrix can be calculated as mentioned:

$$W_s = \begin{bmatrix} n^s_{11} \times w_{11} & n^s_{1j} \times w_{i1} & n^s_{1m} \times w_{n1} \\ n^s_{i1} \times w_{1j} & n^s_{ij} \times w_{ij} & n^s_{im} \times w_{nj} \\ n^s_{n1} \times w_{1m} & n^s_{nj} \times w_{im} & n^s_{nm} \times w_{nm} \end{bmatrix} \quad (13)$$

Step 6.4: Detect weights for the candidate's criteria

The priorities for GCP criterion are computed as mentioned:

3.1. Compute the summation for row mean

$$fw_i = \frac{\sum_{j=1}^{n} (S_{ij})}{n}; i = 1, 2, 3, \ldots m; j = 1, 2, 3, \ldots, n \quad (14)$$

, where, S_{ij} represents the values of weighted matrix W_s (e.g. S_{11} denoted to $n^s_{11} \times w_{11}$).

3.2. Apply normalization as mentioned

$$fw^m_i = \frac{fw_i}{\sum_{i=1}^{m} fw_i}; i = 1, 2, 3, \ldots, m. \quad (15)$$

Step 7: TOPSIS method is used to detect optimal solutions by detecting two areas for solutions denoted as negative and positive range (Nabeeh et al., 2019a). In order to inform decision-makers with the optimal decision, TOPSIS is used to recommend SCM in manufacturing that well-applied the GCP criteria. The optimum manufacturing SCM alternative is selected to reduce pollution in the environment, in addition, attain sustainability under the rapid economic growth and environmental degradation.

Step 7.1: Collect decision judgments for alternatives. Formulate decision judgments on a triangular neutrosophic scale (Abdel-Basset et al., 2019b). Aggregate decision judgments in case of more than one decision-maker in the study (Nabeeh et al., 2019a)
Step 7.2: The triangular neutrosophic scale of decision judgments is transformed into crisp values using score function mentioned in (Nabeeh et al., 2019b).
Step 7.3: The normalization has been applied on the crisp value x_{ij} as mentioned:

$$s_{i\,j} = \frac{x_{i\,j}}{\sqrt{\sum_{i-1}^{m} x_{i\,j}^2}}; i = 1, 2, 3 \dots m; j = 1, 2, 3 \dots n \quad (16)$$

Step 7.4: Compute weighted normalized decision-making matrix

$$wn_{ij} = w_j \times s_{ij} \quad (17)$$

, where w_j refers to the weights for criteria resulted from construction of weighted supermatrix of ANP.

Step 7.5: Calculate the positive and negative region of solutions as the following:

$$R^+ = \left\{ \begin{array}{l} < \max(wn_{i\,j} | i = 1, 2, \dots, m) | s \in s^+ >, \\ < \min(wn_{i\,j} | i = 1, 2, \dots, m) | s \in s^- > \end{array} \right\} \quad (18)$$

$$R^- = \left\{ \begin{array}{l} < \min(wn_{i\,j} | i = 1, 2, \dots, m) | s \in s^+ >, \\ < \max(wn_{i\,j} | i = 1, 2, \dots, m) | s \in s^- > \end{array} \right\} \quad (19)$$

, where s^+ denotes a positive area s^- denotes a negative area.

Step 7.6: Detect separation measures by computing the Euclidean distance between positive (d_i^+) and negative ideal area of solutions (d_i^-) to alternatives as follows:

$$d_i^+ = \sqrt{\sum_{i=1}^{n} \left(wn_{i\,j} - wn_j^+\right)^2}, i = 1, 2, \dots, m \quad (20)$$

$$d_i^- = \sqrt{\sum_{i=1}^{n} \left(wn_{i\,j} - wn_j^-\right)^2}, i = 1, 2, \dots, m \quad (21)$$

Step 7.7: Calculate the relative closeness to ideal solutions

$$RC_i = \frac{d_i^-}{d_i^+ + d_i^-}; 1 = 1, 2, \dots, m \quad (22)$$

, such that the RC_i solutions values included between zero and one. The largest value of RC_i refers to the optimum solution.

Step 8: Rank solutions based on the N-MCDMF methods to achieve the optimum decision that meets GCP objectives and attain sustainability.

4. An illustrative example

The illustrative example applied the N-MCDMF in China, it is pretended to evaluate the criteria of GCP, and to rank the alternatives of SCM in manufacturing. Common international ratings of GCP indicators is used to evaluate the sustainability conditions (Hao et al., 2018), and details mentioned in appendix A. As a result, the case study is covered the current issues for GCP in chine as considering the following factored criteria: Management Authority, Anthropogenic Pollutants, Ingredients, Energy Efficiency, Water Efficiency, Modernization, Waste and pollution environment, and Epidemic diseases. The evaluation of GCP is confined into nine main criteria as mentioned in Table 1, and the rank of SCM alternatives is highlighted on five alternatives. The five alternatives are corresponding to SCM of software companies $SCM_{1:}$ Oracle, SCM_2: SAP, SCM_3: Copa Software, $SCM_{4:}$ Manhattan Associates. SCM_5: JDA. The problem formulation for criteria and alternatives has been detected from the perspectives of expertise in GCP, production experts, sales managers, quality control managers, and manufacturing managers. The N-MCDMF is used the hybrid MCDM methods of GRA, DEMATEL, ANP, and TOPSIS to recommend optimal ranked alternatives to meet the evaluated GCP criteria. Consequently, the step by step implementation for the proposed N-MCDMF:

Step 1: Detect the study objectives, alternatives, and criteria. In the proposed study decision-makers include experts in GCP, SCM, manufacture selection, business administrators, and technological administrators as mentioned in Table 2. Collect perspectives of decision experts and gather the resulted judgments in the appropriate form.

Step 2: The decision judgments from experts about the criteria for evaluating the GCP are specified and aggregated by aggregation function. The aggregated decision judgments are formulated in a triangular neutrosophic scale as mentioned in Table 3.
Step 3: The neutrosophic triangular scale for aggregated decision judgments is converted to crisp values using Eq. (1) as illustrated in Table 4.

Step 4: The N-MCDMF applies the GRA method to evaluate the relationship of criteria. The original sequence for GRA is the neutrosophic aggregated decision judgments from the previous step. The case study assigned the criteria $A_{2,}$ $Wp_{8,}$ and Ed_9 to the equation of preprocessing smallest-the better using eq. (1). The rest of the criterions is assigned to the largest-the-better using eq. (2). The results of data preprocessing and normalization are depicted in Table 5. The grey relational grade is obtained by applying Eq. (3), eq. (4), and the results are mentioned in Table 6. The last step in the GRA is to compute the grey relational matrix by eq. (5) the results are mentioned in Table 7.

Step 5: The DEMATEL is applied in the grey relational matrix to analyze the complex relations between criteria. Construct the initial direct relation matrix by eq. (6), and the results are mentioned in Table 8. Compute the normalized direct relation matrix by eq. (7), and (8). The total relation matrix is achieved by applying eq. (9), and the results are depicted in Table 9.

Step 6: The ANP is applied to the previous MCDM methods of GRA and DEMATEL. Construct the supermatrix of ANP using eq. (10). The total matrix of relation T_g is achieved in eq. (11) as in Table 10. The unweighted super detected by eq. (12), the weighted supermatrix is computed by Eq. (13). The results of the

Table 1
The description for the main criteria of the GCP.

Criteria	Code	Description
Management Authority	Ma_1	The coordination of activities to achieve the targeted objectives, such as sustainable procurement (Al-Jebouri et al., 2017), and stockholder participation (Liou, 2015)
Anthropogenic Pollutants	A_2	Refers to the total human exposure to air pollution, such as combustions, building new materials, allergens, viruses, and bacteria (Stiborova et al., 2020).
Ingredients	I_3	The materials included in manufacturing such as source, recycled, and new materials (Darko et al., 2017).
Energy Efficiency	E_4	The energy efficiency is mainly focused on reducing the carbon dioxide emission to the environment (Kong et al., 2020), in addition reducing the energy needed for operating, and reducing costs to the manufacturing economy
Water Efficiency	W_5	The minimum amount of water consumed to accomplish a specific task (Al-Jebouri et al., 2017).
● Modernization	M_6	The transition from traditional to smart methods, such as smart grids, smart cities (Zhang et al., 2011).
Habits and Cite Ecology	H_7	Habits and cite ecology include the public transport, outdoor space, Cyclist landscaping, etc. (Al-Jebouri et al., 2017).
Waste and Pollution Environment	Wp_8	Waste and pollution environment radioactive wastes, plastic, garbage, and etc. (Darko et al., 2017).
Epidemic diseases	Ed_9	Is infectious diseases rapidly spread within short for a community of people. e.g. Plague, cholera typhus, malaria, ebola virus disease, small box, Spanish influenzas, SARS, and coronavirus disease (COVID-19) (Fujii et al., 2020).

Table 2
Basic information about decision-makers.

Branch	Job Classes	Experience
GCP	Strategic Managers	10 years
SCM	Middle Managers	5 years
Manufacturing selection	Strategic and Middle managers	5 years
Business administrators	Middle and Operational managers	5–7 years
Technological administrators	Operational managers	5–7 years

ANP weighted supermatrix are mentioned in Table 11. The weights of criteria are achieved by eq. (14), and eq. (15). The final weights and priorities are mentioned in Table 12. The priorities of weights are rearranged in importance as follows: A_2, H_7, M_6, E_4, I_3, W_5, Wp_8, Ma_1, and Ed_9.

Step 7: The alternatives of SCM in manufacturing are represented and aggregated in a triangular neutrosophic scale from decision experts. The alternatives include five candidates denoted as follows: SCM_1, SCM_2, SCM_3, SCM_4, SCM_5. The aggregated pairwise comparison matrix for the candidate's alternatives are mentioned in Table 13. For simplicity, the triangular neutrosophic scale is converted to crisp values by applying score function (Nabeeh et al., 2019b) and is mentioned in Table 14. The weighted normalization was achieved by applying eq. (16), eq. (17). The results of weighted data normalization are mentioned in Table 15. The positive and negative region is calculated respectively with eq. (18), and eq. (19). The positive region, negative region, and relative closeness are calculated using eqs. (20)–(22). In addition, the results are depicted in Table 16.

Step 8: The results show that SCM_2 is recommended to be the optimal SCM in manufacturing alternative, while SCM_3 denotes to be the worst alternative.

5. Results and discussion

The proposed N-MCDMF is mainly influenced by the decision judgments of the problem definition either for alternatives or

Table 3
The neutrosophic decision judgments of decision-makers.

Criteria	Ma_1	A_2	I_3	E_4	W_5	M_6	H_7	Wp_8	Ed_9
Ma_1	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\langle 2,3,4\rangle;0.30,0.75,0.70\rangle$	$\langle\langle 3,4,5\rangle;0.60,0.35,0.40\rangle$	$\langle 6,7,8\rangle,0.90,0.10,0.10\rangle$	$\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle\langle 2,3,4\rangle;0.30,0.75,0.70\rangle$	$\langle\langle 3,4,5\rangle;0.60,0.35,0.40\rangle$	$\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$
A_2	$\langle\frac{1}{\langle 4,}5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 2,3,4\rangle;0.30,0.75,0.70\rangle$	$\langle 6,7,8\rangle,0.90,0.10,0.10\rangle$	$\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle 6,7,8\rangle,0.90,0.10,0.10\rangle$	$\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$
I_3	$\langle\frac{1}{\langle 2,}3,4\rangle;0.30,0.75,0.70\rangle$	$\langle\frac{1}{\langle 2,}3,4\rangle;0.30,0.75,0.70\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\langle 2,3,4\rangle;0.30,0.75,0.70\rangle$	$\langle 6,7,8\rangle,0.90,0.10,0.10\rangle$	$\langle 6,7,8\rangle,0.90,0.10,0.10\rangle$	$\langle\langle 3,4,5\rangle;0.60,0.35,0.40\rangle$
E_4	$\langle\frac{1}{\langle 3,}4,5\rangle;0.60,0.35,0.40\rangle$	$\langle\frac{1}{\langle 6,}7,8\rangle;0.90,0.10,0.10\rangle$	$\langle\frac{1}{\langle 4,}5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle\langle 2,3,4\rangle;0.30,0.75,0.70\rangle$	$\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$
W_5	$\langle\frac{1}{\langle 6,}7,8\rangle;0.90,0.10,0.10\rangle$	$\langle\frac{1}{\langle 1,2}3\rangle;0.40,0.65,0.60\rangle$	$\langle\frac{1}{\langle 4,}5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\frac{1}{\langle 1,2}3\rangle;0.40,0.65,0.60\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 2,3,4\rangle;0.30,0.75,0.70\rangle$	$\langle 6,7,8\rangle,0.90,0.10,0.10\rangle$	$\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle 6,7,8\rangle,0.90,0.10,0.10\rangle$
M_6	$\langle\frac{1}{\langle 1,2}3\rangle;0.40,0.65,0.60\rangle$	$\langle\frac{1}{\langle 1,2}3\rangle;0.40,0.65,0.60\rangle$	$\langle\frac{1}{\langle 2,}3,4\rangle;0.30,0.75,0.70\rangle$	$\langle\frac{1}{\langle 4,}5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\frac{1}{\langle 2,}3,4\rangle;0.30,0.75,0.70\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 4,5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\langle 2,3,4\rangle;0.30,0.75,0.70\rangle$	$\langle\langle 3,4,5\rangle;0.60,0.35,0.40\rangle$
H_7	$\langle\frac{1}{\langle 2,}3,4\rangle;0.30,0.75,0.70\rangle$	$\langle\frac{1}{\langle 6,}7,8\rangle;0.90,0.10,0.10\rangle$	$\langle\frac{1}{\langle 6,}7,8\rangle;0.90,0.10,0.10\rangle$	$\langle\frac{1}{\langle 1,2}3\rangle;0.40,0.65,0.60\rangle$	$\langle\frac{1}{\langle 6,}7,8\rangle;0.90,0.10,0.10\rangle$	$\langle\frac{1}{\langle 4,}5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle 6,7,8\rangle,0.90,0.10,0.10\rangle$
Wp_8	$\langle\frac{1}{\langle 3,}4,5\rangle;0.60,0.35,0.40\rangle$	$\langle\frac{1}{\langle 1,2}3\rangle;0.40,0.65,0.60\rangle$	$\langle\frac{1}{\langle 6,}7,8\rangle;0.90,0.10,0.10\rangle$	$\langle\frac{1}{\langle 2,}3,4\rangle;0.30,0.75,0.70\rangle$	$\langle\frac{1}{\langle 1,2}3\rangle;0.40,0.65,0.60\rangle$	$\langle\frac{1}{\langle 2,}3,4\rangle;0.30,0.75,0.70\rangle$	$\langle\frac{1}{\langle 1,2}3\rangle;0.40,0.65,0.60\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 2,3,4\rangle;0.30,0.75,0.70\rangle$
Ed_9	$\langle\frac{1}{\langle 4,}5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\frac{1}{\langle 4,}5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\frac{1}{\langle 3,}4,5\rangle;0.60,0.35,0.40\rangle$	$\langle\frac{1}{\langle 4,}5,6\rangle;0.80,0.15,0.20\rangle$	$\langle\frac{1}{\langle 6,}7,8\rangle;0.90,0.10,0.10\rangle$	$\langle\frac{1}{\langle 3,}4,5\rangle;0.60,0.35,0.40\rangle$	$\langle\frac{1}{\langle 6,}7,8\rangle;0.90,0.10,0.10\rangle$	$\langle\frac{1}{\langle 2,}3,4\rangle;0.30,0.75,0.70\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$

Table 4
The conversion of triangular neutrosophic scale for decision judgments to crisp values.

Criteria	Ma_1	A_2	I_3	E_4	W_5	M_6	H_7	Wp_8	Ed_9
Ma_1	1	1.843627	1.85513	1.848088	2.035986	1.388868	1.85513	1.848088	1.843627
A_2	0.542409	1	1.85513	2.035986	1.388868	1.388868	2.035986	1.388868	1.843627
I_3	0.539046	0.539046	1	1.843627	1.843627	1.85513	2.035986	2.035986	1.848088
E_4	0.5411	0.491162	0.542409	1	1.388868	1.843627	1.388868	1.85513	1.843627
W_5	0.491162	0.720011	0.542409	0.720011	1	1.85513	2.035986	1.388868	2.035986
M_6	0.720011	0.720011	0.539046	0.542409	0.539046	1	1.843627	1.85513	1.848088
H_7	0.539046	0.491162	0.491162	0.720011	0.491162	0.542409	1	1.388868	2.035986
Wp_8	0.5411	0.720011	0.491162	0.539046	0.720011	0.539046	0.720011	1	1.85513
Ed_9	0.542409	0.542409	0.5411	0.542409	0.491162	0.5411	0.491162	0.539046	1

Table 5
GRA preprocessing normalized values.

Criteria	Ma_1	A_2	I_3	E_4	W_5	M_6	H_7	Wp_8	Ed_9
Ma_1	0.017676	−1	1.099209	1.044283	1.303584	0.559252	1.122728	−0.90771	−0.90552
A_2	−0.43992	−0.54241	1.099209	1.232181	0.656466	0.559252	1.303584	−0.68216	−0.90552
I_3	−0.44328	−0.29238	0.244079	1.039822	1.111225	1.025514	1.303584	−1	−0.90771
E_4	−0.44122	−0.26641	−0.21351	0.196195	0.656466	1.014011	0.656466	−0.91117	−0.90552
W_5	−0.49116	−0.39054	−0.21351	−0.08379	0.267598	1.025514	1.303584	−0.68216	−1
M_6	−0.26231	−0.39054	−0.21687	−0.2614	−0.19336	0.170384	1.111225	−0.91117	−0.90771
H_7	−0.44328	−0.26641	−0.26476	−0.08379	−0.24124	−0.28721	0.267598	−0.68216	−1
Wp_8	−0.44122	−0.39054	−0.26476	−0.26476	−0.01239	−0.29057	−0.01239	−0.49116	−0.91117
Ed_9	−0.43992	−0.29421	−0.21482	−0.2614	−0.24124	−0.28852	−0.24124	−0.26476	−0.49116

Table 6
The grey relational coefficient.

Criteria	Ma_1	A_2	I_3	E_4	W_5	M_6	H_7	Wp_8	Ed_9
Ma_1	1	0.333333	1	0.799333	1	0.585288	0.810278	0.363774	0.380424
A_2	0.357325	0.570626	1	1	0.544132	0.585288	1	0.468294	0.380424
I_3	0.355645	0.933873	0.443678	0.795543	0.800617	1	1	0.333333	0.379182
E_4	0.356669	1	0.341897	0.419439	0.544132	0.98282	0.544132	0.362534	0.380424
W_5	0.333333	0.747151	0.341897	0.362553	0.427125	1	1	0.468294	0.333333
M_6	0.476076	0.747151	0.341322	0.333833	0.340367	0.434876	0.800617	0.362534	0.379182
H_7	0.355645	1	0.333333	0.362553	0.333333	0.333902	0.427125	0.468294	0.333333
Wp_8	0.356669	0.747151	0.333333	0.333333	0.369861	0.333333	0.369861	0.618865	0.377237
Ed_9	0.357325	0.929555	0.341673	0.333833	0.333333	0.333681	0.333333	1	1

Table 7
The grey relational matrix.

Criteria	Ma_1	A_2	I_3	E_4	W_5	M_6	H_7	Wp_8	Ed_9
Ma_1	0.111111	0.037037	0.111111	0.088815	0.111111	0.065032	0.090031	0.040419	0.042269
A_2	0.039703	0.063403	0.111111	0.111111	0.060459	0.065032	0.111111	0.052033	0.042269
I_3	0.039516	0.103764	0.049298	0.088394	0.088957	0.111111	0.111111	0.037037	0.042131
E_4	0.03963	0.111111	0.037989	0.046604	0.060459	0.109202	0.060459	0.040282	0.042269
W_5	0.037037	0.083017	0.037989	0.040284	0.047458	0.111111	0.111111	0.052033	0.037037
M_6	0.052897	0.083017	0.037925	0.037093	0.037819	0.04832	0.088957	0.040282	0.042131
H_7	0.039516	0.111111	0.037037	0.040284	0.037037	0.0371	0.047458	0.052033	0.037037
Wp_8	0.03963	0.083017	0.037037	0.037037	0.041096	0.037037	0.041096	0.068763	0.041915
Ed_9	0.039703	0.103284	0.037964	0.037093	0.037037	0.037076	0.037037	0.111111	0.111111

criteria, in addition to the weights of criteria. The values assigned to aggregated decision judgments vary according to the current environmental conditions, and experts. For the sake of analyzing the N-MCDM results, the weights of decision judgments parameter for criteria are re-prioritize to detect the impact of weights on final ranking, while the decision judgments of SCM in manufacturing are fixed. Based on Table 17 the weights of GCP criteria are characterized as follows: A_2, H_7, M_6, E_4, I_3, W_5, Wp_8, Ma_1, Ed_9 as mentioned in Fig. 3. The decision judgments for evaluating GCP are aggregated in the form of a neutrosophic triangular scale and following the N-MCDMF steps to calculate the weights of criteria. The new weights are mentioned as follows in Table 17. The new priorities would characterize as follows: I_3, Ed_9, M_6, E_4, Ma_1, W_5, H_7, A_2 as mentioned in Fig. 4. Indeed, the changing in criteria weights must affect the ranking of SCM in manufacturing alternatives.

The original rank of decision alternatives mentioned as follows: SCM_2, SCM_1, SCM_4, SCM_5, SCM_3. The steps of N-MCDM would apply on the new weights to trace step by step changes in values. Table 18 shows the TOPSIS positive region, negative region, and relative closeness new values. Based on Table 18, the decision alternatives are prioritized as follows: SCM_1, SCM_4, SCM_2, SCM_5, SCM_3. The original and new relative closeness is modeled in Fig. 5. The results obtained that the SCM alternatives affected by interchanging their ranked position are SCM_1, SCM_2, SCM_4. In addition, SCM_3 identified

Table 8
The normalized direct relation matrix.

Criteria	Ma$_1$	A$_2$	I$_3$	E$_4$	W$_5$	M$_6$	H$_7$	Wp$_8$	Ed$_9$
Ma$_1$	0	0.059543	0.178629	0.142784	0.178629	0.10455	0.144739	0.064981	0.067955
A$_2$	0.063829	0	0.178629	0.178629	0.097198	0.10455	0.178629	0.083651	0.067955
I$_3$	0.063529	0.166817	0	0.142107	0.143013	0.178629	0.178629	0.059543	0.067733
E$_4$	0.063712	0.178629	0.061073	0	0.097198	0.17556	0.097198	0.064759	0.067955
W$_5$	0.059543	0.133463	0.061073	0.064762	0	0.178629	0.178629	0.083651	0.059543
M$_6$	0.085041	0.133463	0.06097	0.059632	0.060799	0	0.143013	0.064759	0.067733
H$_7$	0.063529	0.178629	0.059543	0.064762	0.059543	0.059645	0	0.083651	0.059543
Wp$_8$	0.063712	0.133463	0.059543	0.059543	0.066068	0.059543	0.066068	0	0.067386
Ed$_9$	0.063829	0.166046	0.061033	0.059632	0.059543	0.059605	0.059543	0.178629	0

Table 9
Total relation matrix.

Criteria	Ma$_1$	A$_2$	I$_3$	E$_4$	W$_5$	M$_6$	H$_7$	Wp$_8$	Ed$_9$
Ma$_1$	0.276048	0.631798	0.523839	0.524713	0.535553	0.564291	0.664882	0.398154	0.337314
A$_2$	0.337229	0.579621	0.525703	0.55832	0.466068	0.561661	0.690319	0.415111	0.338677
I$_3$	0.348342	0.742293	0.386233	0.541927	0.514246	0.636335	0.713924	0.408579	0.348596
E$_4$	0.298085	0.643509	0.380458	0.344921	0.407898	0.54688	0.548889	0.351787	0.298866
W$_5$	0.291957	0.603261	0.372886	0.397998	0.313128	0.539845	0.608361	0.364674	0.288687
M$_6$	0.279548	0.533412	0.333053	0.350704	0.331095	0.329983	0.514755	0.309177	0.262917
H$_7$	0.251023	0.550166	0.321706	0.344847	0.317589	0.373642	0.371147	0.313339	0.246644
Wp$_8$	0.235342	0.480134	0.297523	0.314567	0.301457	0.347626	0.401687	0.217314	0.237591
Ed$_9$	0.267512	0.572532	0.342376	0.3608	0.337964	0.39649	0.453668	0.416503	0.206851

Table 10
The normalized supermatrix.

Criteria	Ma$_1$	A$_2$	I$_3$	E$_4$	W$_5$	M$_6$	H$_7$	Wp$_8$	Ed$_9$
Ma$_1$	0.061942	0.141767	0.117542	0.117739	0.120171	0.126619	0.149191	0.089341	0.075689
A$_2$	0.075397	0.12959	0.117536	0.124828	0.104203	0.125575	0.15434	0.09281	0.075721
I$_3$	0.075066	0.15996	0.083231	0.116783	0.110817	0.137127	0.153847	0.088047	0.075121
E$_4$	0.078006	0.168401	0.099563	0.090263	0.106743	0.143114	0.14364	0.09206	0.078211
W$_5$	0.077221	0.159559	0.098626	0.105268	0.082821	0.142786	0.160908	0.096454	0.076356
M$_6$	0.086157	0.164398	0.102647	0.108087	0.102043	0.101701	0.158648	0.095288	0.081031
H$_7$	0.081235	0.178041	0.104109	0.111597	0.102776	0.120916	0.120108	0.101401	0.079817
Wp$_8$	0.083065	0.169465	0.105012	0.111027	0.1064	0.122696	0.141777	0.076702	0.083858
Ed$_9$	0.079742	0.170666	0.102059	0.107551	0.100743	0.11819	0.135234	0.124155	0.06166

Table 11
The weighted supermatrix.

Criteria	Ma$_1$	A$_2$	I$_3$	E$_4$	W$_5$	M$_6$	H$_7$	Wp$_8$	Ed$_9$
Ma$_1$	0.003837	0.010689	0.008823	0.009184	0.00928	0.010909	0.012119	0.007421	0.006036
A$_2$	0.010689	0.016794	0.018801	0.021021	0.016627	0.020644	0.027479	0.015728	0.012923
I$_3$	0.008823	0.018801	0.006927	0.011627	0.01093	0.014076	0.016017	0.009246	0.007667
E$_4$	0.009184	0.021021	0.011627	0.008147	0.011237	0.015469	0.01603	0.010221	0.008412
W$_5$	0.00928	0.016627	0.01093	0.011237	0.006859	0.01457	0.016538	0.010263	0.007692
M$_6$	0.010909	0.020644	0.014076	0.015469	0.01457	0.010343	0.019183	0.011691	0.009577
H$_7$	0.012119	0.027479	0.016017	0.01603	0.016538	0.019183	0.014426	0.014376	0.010794
Wp$_8$	0.007421	0.015728	0.009246	0.010221	0.010263	0.011691	0.014376	0.005883	0.010411
Ed$_9$	0.006036	0.012923	0.007667	0.008412	0.007692	0.009577	0.010794	0.010411	0.003802

as the worst decision alternative. In general, the study recommends for decision-makers to collaborate with SCM alternatives SCM$_1$, SCM$_2$, SCM$_4$, that would attain GCP criterion and sustainability, while the study does not recommend SCM$_3$ under any circumstances.

The proposed case study is applied to the MCDM method of AHP and TOPSIS. The study needs to demonstrate that use of different MCDM methods would make reordering in priorities of criteria and ranking of alternatives. The decision judgments for in Table 4 are used to obtain the weights of GCP criteria of GCP. The weights of GCP criteria are mentioned in Table 19. The alternatives of SCM of Table 14 are ranked with TOSIS to make a clear discussion for results between using for various methods of MCDM. Table 20 shows the results for the ranking of alternatives using TOPSIS. The results showed that SCM$_2$ recommends being the best alternatives that meet GCP conditions, while SCM$_3$ is the worst alternative and do not recommend to be selected.

6. Model evaluation

The model evaluation is applied to the proposed N-MCDMF. The proposed model is mainly depending on the neutrosophic theory and MCDM methods. The subject of the study forced researchers to adopt the proper methodologies and algorithms to achieve optimal

Table 12
The weights of criterions using GRA-MATEL-ANP.

Criteria	Ma_1	A_2	I_3	E_4	W_5	M_6	H_7	Wp_8	Ed_9
Priorities	0.0779	0.159	0.10365	0.110	0.10353	0.125	0.146	0.094	0.0769

Table 13
The aggregated pairwise comparison matrix for SCM manufacturing alternatives with respect to GCP criterions.

Criteria	Ma_1	A_2	I_3	E_4	W_5	M_6	H_7	Wp_8	Ed_9
SCM_1	$\langle(1,1,1);0.50, 0.50,0.50\rangle$	$\langle(4,5,6);0.80, 0.15,0.20\rangle$	$\langle(3,4,5);0.60, 0.35,0.40\rangle$	$\langle6,7,8\rangle,0.90, 0.10,0.10\rangle$	$\langle(1,2,3);0.40, 0.65,0.60\rangle$	$\langle(2,3,4);0.30, 0.75,0.70\rangle$	$\langle(3,4,5);0.60, 0.35,0.40\rangle$	$\langle(4,5,6);0.80, 0.15,0.20\rangle$	$\langle(3,4,5);0.60, 0.35,0.40\rangle$
SCM_2	$\langle(2,3,4);0.30, 0.75,0.70\rangle$	$\langle6,7,8\rangle,0.90, 0.10,0.10\rangle$	$\langle(1,1,1);0.50, 0.50,0.50\rangle$	$\langle(1,2,3);0.40, 0.65,0.60\rangle$	$\langle(3,4,5);0.60, 0.35,0.40\rangle$	$\langle(3,4,5);0.60, 0.35,0.40\rangle$	$\langle(2,3,4);0.30, 0.75,0.70\rangle$	$\langle(4,5,6);0.80, 0.15,0.20\rangle$	$\langle6,7,8\rangle,0.90, 0.10,0.10\rangle$
SCM_3	$\langle(3,4,5);0.60, 0.35,0.40\rangle$	$\langle(1,2,3);0.40, 0.65,0.60\rangle$	$\langle(1,1,1);0.50, 0.50,0.50\rangle$	$\langle(4,5,6);0.80, 0.15,0.20\rangle$	$\langle(1,2,3);0.40, 0.65,0.60\rangle$	$\langle(1,2,3);0.40, 0.65,0.60\rangle$	$\langle(1,2,3);0.40, 0.65,0.60\rangle$	$\langle6,7,8\rangle,0.90, 0.10,0.10\rangle$	$\langle(1,2,3);0.40, 0.65,0.60\rangle$
SCM_4	$\langle(3,4,5);0.60, 0.35,0.40\rangle$	$\langle(4,5,6);0.80, 0.15,0.20\rangle$	$\langle6,7,8\rangle,0.90, 0.10,0.10\rangle$	$\langle(1,2,3);0.40, 0.65,0.60\rangle$	$\langle(1,1,1);0.50, 0.50,0.50\rangle$	$\langle(1,2,3);0.40, 0.65,0.60\rangle$	$\langle(3,4,5);0.60, 0.35,0.40\rangle$	$\langle(3,4,5);0.60, 0.35,0.40\rangle$	$\langle6,7,8\rangle,0.90, 0.10,0.10\rangle$
SCM_5	$\langle6,7,8\rangle,0.90, 0.10,0.10\rangle$	$\langle(2,3,4);0.30, 0.75,0.70\rangle$	$\langle(1,2,3);0.40, 0.65,0.60\rangle$	$\langle(3,4,5);0.60, 0.35,0.40\rangle$	$\langle(1,2,3);0.40, 0.65,0.60\rangle$	$\langle(1,2,3);0.40, 0.65,0.60\rangle$	$\langle(3,4,5);0.60, 0.35,0.40\rangle$	$\langle(2,3,4);0.30, 0.75,0.70\rangle$	$\langle(1,1,1);0.50, 0.50,0.50\rangle$

Table 14
The alternatives decision judgments in the form of crisp values.

Criteria	Ma_1	A_2	I_3	E_4	W_5	M_6	H_7	Wp_8	Ed_9
SCM_1	1	1.843	1.848	2.03	1.388	1.85513	1.848	1.843	1.848
SCM_2	1.85513	2.03	1	1.388	1.848	1.848	1.85513	1.843	2.03
SCM_3	1.848	1.388	1	1.843	1.388	1.388	1.388	2.03	1.388
SCM_4	1.848	1.843	2.03	1.388	1	1.388	1.848	1.848	2.03
SCM_5	2.03	1.85513	1.388	1.848	1.388	1.388	1.848	1.85513	1

Table 15
The weighted data normalization matrix.

Criteria	Ma_1	A_2	I_3	E_4	W_5	M_6	H_7	Wp_8	Ed_9
SCM_1	0.019869	0.134679	0.104556	0.118804	0.062471	0.121893	0.126455	0.076401	0.068835
SCM_2	0.068379	0.163396	0.030616	0.055541	0.11074	0.120958	0.127433	0.076401	0.083061
SCM_3	0.067854	0.076389	0.030616	0.097924	0.062471	0.068235	0.071336	0.092691	0.038831
SCM_4	0.067854	0.134679	0.126164	0.055541	0.032426	0.068235	0.126455	0.076816	0.083061
SCM_5	0.081877	0.136458	0.058982	0.098456	0.062471	0.068235	0.126455	0.07741	0.020156

Table 16
Final ranks of alternatives.

	d_i^+	d_i^-	c_i	*Rate*
SCM_1	0.192097	0.382992	0.66597	2
SCM_2	0.189535	0.38555	0.670425	1
SCM_3	0.419711	0.155378	0.270181	5
SCM_4	0.254827	0.320263	0.556892	3
SCM_5	0.295558	0.279531	0.486066	4

solutions. In this section, the proposed N-MCDMF is evaluated and compared with other studies adopted some of the used methodologies and theories. In Yang et al. (2019), the research used hybrid MCDM methods to establish a green credit rating mechanism. Indeed, the current study addressed Yang et al. (2019) drawback as follows: 1) Cannot handle environmental situations of vague, impression, uncertainty, and inconsistency, 2) Cannot handle decision maker's confusion, inconsistent information, 3) Cannot handle the indeterminate cases.

In Kang et al. (2020), the research focused on the GCP in South Korea to allow manufactures to limit the pollution by the cooperation of suppliers in SCM. The Kang et al. (2020), illustrated an optimal control model to reduce the emitted pollution from the supply chain. The proposed study addressed some drawbacks as follows: 1) The research can be improved with aid of MCDM methods, 2) The research can not handle the real-life situations of vague, impression, uncertainty, and inconsistency, 3) The numerical analysis lacked the use fuzzy set theory or neutrosophic theory, 4) The research can handle the uncertain and inconsistent data, 5) The research can not handle the indeterminate cases.

In Ou Yang et al., 2013, using a hybrid MCDM methods for the evaluation of sustainable development performance. The study

Table 17
Th new weights for GCP criteria according to other expert judgments.

Criteria	Ma_1	A_2	I_3	E_4	W_5	M_6	H_7	Wp_8	Ed_9
Priorities	0.10365	0.0769	0.159	0.110	0.10353	0.125	0.0779	0.094	0.146

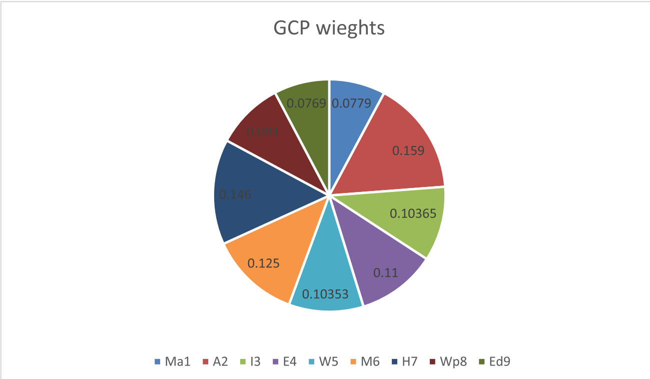


Fig. 3. The N-MCDM weights for the GCP.

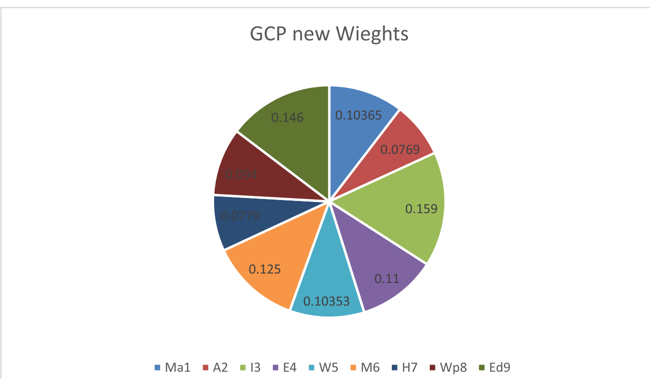


Fig. 4. The N-MCDM new weights for the GCP.

Table 18
New final rates of alternatives.

	d_i^+	d_i^-	c_i	*Rate*
SCM_1	0.19516	0.344257	0.638202	1
SCM_2	0.245922	0.293494	0.544097	3
SCM_3	0.386892	0.152524	0.282757	5
SCM_4	0.244549	0.294867	0.546642	2
SCM_5	0.255192	0.284224	0.526911	4

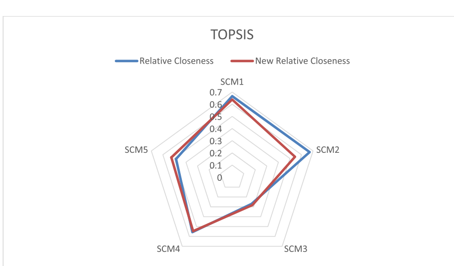


Fig. 5. The original and new relative closeness of SCM in manufacturing alternatives.

Table 20
The ranking for the use of TOPSIS.

	d_i^+	d_i^-	c_i	*Rate*
SCM_1	0.26478	0.364498	0.579232	2
SCM_2	0.241588	0.38769	0.616086	1
SCM_3	0.42326	0.206019	0.327389	5
SCM_4	0.265518	0.36376	0.57806	3
SCM_5	0.294448	0.33483	0.532086	4

addressed some drawbacks as follows: 1) The research samples did not include the decision judgments for experts. 2) The research did not consider the indeterminate situation. 3)The research does not trend to handle the real-life situations of vague, impression, uncertainty, and inconsistency. Stanujkic et al. (2013), adopted a comparative analysis of MCDM methods for ranking. The research adopted various MCDM methods in ranking to demonstrate that resulted orders can sometimes produce a different ranking of candidates. The research drawbacks include 1) Did not include decision judgments in the comparative analysis, 2) did not consider the real-life situations of vague, impression, uncertainty, and inconsistency. 3) Did not focus on the indeterminant cases and how to handle those cases.

The Fuzzy set theory adopted the membership function to detect the preference relations (Abdel-Basset et al., 2017). However, the real situations are surrounded with indeterminate cases that can not be represented with membership function. The MCDM methods are combined with fuzzy set theory to handle the following issues (Nabeeh et al., 2019): 1) Decision maker's different perspectives and experience, in addition, limit biasness situations. 2) Deal with vague and impression information, 3) Help decision makes to valuable cognitive to achieve optimal solutions. Ding and Kamaruddin (2014), illustrated the evolution of integrating a fuzzy set approach to the MCDM method of TOPSIS to produce comparison results between the effectiveness of crisp fuzzy to fuzzy TOPSIS. The drawbacks of the research: the membership function cannot represent the indeterminate cases in addition cannot reflect all overview and perspectives of decisionmakers and experts.

According to the limitations for the previous studies, the study proposed an integrated framework of various MCDM methods, to take the advantages for each MCDM method, with the integration of neutrosophic theory to evaluates the conditions of GCP and recommend the optimal SCM in manufacturing alternatives. The proposed N-MCDMF: 1) Include decision maker's perspectives, 2) Handle the decision maker's less experience and biasness situations, 3) Handle the real situations of vague, impression, uncertainty, and inconsistency, 4) Handle the uncertain and inconsistent data, and 5) handle the indeterminate cases. The neutrosophic theory depends on three membership functions of true, indeterminate, and false respectively. The use of the MCDM method is a variant according to the problem definition. Consequently, the study combined GRA to evaluate the degree of interrelation among the criterion of GCP, DEMATEL to analyze the preferences among the criterion of GCP, ANP to obtain the final weights for the GCP criterion, to attain optimal SCM in manufacturing solution with the integration of neutrosophic theory to evaluate the conditions of GCP and recommends the optimal SCM in manufacturing

Table 19
The weights for the use of the AHP method.

Criteria	Ma_1	A_2	I_3	E_4	W_5	M_6	H_7	Wp_8	Ed_9
Priorities	0.1652	0.1435	0.1442	0.1160	0.1149	0.1023	0.0820	0.0758	0.0557

alternatives.

Moody and Shanks (2003) applied the data model quality function to validate the framework. The study evaluated N-MCDMF according to eight factors illustrated by Moody and Shanks (2003).

1. **Completeness:** the study adopted nine criteria, and five alternatives, in addition, decision maker's judgments.
2. **Integrity:** The framework is consistent and accurate.
3. **Flexibility:** The criteria, alternatives, and decision judgments can be flexibility altered according to the given situations.
4. **Understandability**: The N-MCDMF is modeled with figures and details to ensure reader perception. The framework is understandable.
5. **Correctness:** The N-MCDMF is supplemented with a numerical case study to ensure applicability and correctness. The framework is correct.
6. **Simplicity:** The N-MCDMF is simple to use all procedures are expanded with details and supplemented with a numerical example. The framework is simple.
7. **Integration:** The N-MCDMF is integrated with MCDM methods and neutrosophic theory. The framework is integrated
8. **Implement ability**: the study can be easily implemented the case study, results and discussion show the applicability of the proposed N-MCDMF.

Hence, the proposed framework applied data model quality eight functions. The framework is complete, integrity, flexible, understandable, correct, simple, integrated, and easy to implement. The study involved a sample of people for evaluation for the proposed study more details in Appendix B.

7. Managerial insights

The study adopted an intelligent decision support system so as called N-MCDMF, that merge neutrosophic theory with different MCDM methods to assist decision-makers to achieve optimal solution under the uncertain and inconsistent conditions. Obliviously, the N-MCDMF can assign any decision judgments, criteria, and alternatives according to the case study and application. In addition, the proposed N-MCDMF not only evaluates GCP but also recommends the best SCM in manufacturing. The N-MCDMF takes the advantages of many MCDM methods GRA, DEMATEL, ANP, and TOPSIS under the umbrella of the neutrosophic theory which makes a strengthening point of the study. For example, nowadays N-MCDMF can be used in many real problems. For example, the epidemic disease of coronavirus disease (COVID-19), countries can use the N-MCDMF to recommend the most optimum health care for the audience that applies the safety conditions criteria. The application of N-MCDMF can provide suitable accommodation of alternatives according to the decision maker's judgments to reach an optimum decision. Therefore, the N-MCDMF is a general, practical, and fixable approach in the real-world environmental condition, in addition to the ease of implementation in many applications.

8. Conclusion

Nowadays both economic development and environmental protection are important. The stage of the green revolution, and sustainable have been developed. The GCP is granted with the flow of funds for minimizing the level of pollution and attaining sustainability. The SCM in manufacturing includes all processes from procurement to shipping products to customers that need to be restricted with GCP conditions of reducing environmental pollution and attaining sustainability. Therefore, the study proposed N-MCDMF that integrates neutrosophic theory with various methods of MCDM in order to evaluate the GCP and recommend the optimal alternative of SCM in manufacturing that meets the GCP conditions. The N-MCDMF included the decision judgments and experience in the study to ensure the unexpected conditions in real-life situations of uncertainty and inconsistency to attain the optimal solution.

Results show the applicability and flexibility of the proposed N-MCDMF. The dynamic decision judgments due to environmental conditions would make updates in weights of criteria and consequently the ranks of alternatives. The case study provides the weights of GCP criteria in importance as follows: A_2, H_7, M_6, E_4, I_3, W_5, Wp_8, Ma_1, and Ed_9, and priorities of alternatives as follows: SCM_2, SCM_1, SCM_4, SCM_5, SCM_3. While after changing the decision judgments and fixing decision alternatives, the results showed to be criteria in importance are mentioned as follows: I_3, Ed_9, M_6, E_4, Ma_1, W_5, H_7, A_2. While alternatives mentioned as follows SCM_1, SCM_4, SCM_2, SCM_5, SCM_3. Therefore N-MCDM recommends SCM alternative's SCM_1, SCM_2, SCM_4, but N-MCDM does not advise decisionmaker to deal with SCM alternative's SCM_3 in all circumstances. In general, the NMCDMF is proved to be applicable and flexible in different circumstances. The future work includes analyze the SCM especially stainable circular supplier selection and use evolutionary algorithms to rate the weight of decision judgments. The future work includes make a detailed analysis of GCP conditions using evolutionary algorithms and including more countries around the world to study the effectiveness of GCP for humanity.

CRediT authorship contribution statement

Nada A. Nabeeh: Investigation, Methodology, Resources, Visualization, Validation, Software, Writing - original draft, Writing - review & editing. **Mohamed Abdel-Basset:** Investigation, Methodology, Resources, Visualization, Validation, Software, Writing - original draft, Writing - review & editing. **Gawaher Soliman:** Conceptualization, Methodology, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

The study mainly focused on the evaluation of GCP criteria and recommendation of optimal alternatives of SCM. The study included five branches of decision maker's expert as mentioned in Table 2. The decision maker's judgments are gathered by the aid of reviews and vis-a-vis meetings or remote/online meetings. The decision judgements would be the guidelines for the study to recommend best SCM with respect to GCP criteria. Some investigated questions are demanded for interviewers of decision makers and mentioned as follows:

1. Describe your current job.
2. What is your current position in organization?
3. How do you describe your work experience in years?
4. According to your own perspectives, what the most effective criteria to evaluate GCP?
5. According to your own perspectives, what the best SCM that meets the GCP criteria conditions?

The study milestones are gathered from the valuable data collected and recorded from the interviews of decision makers. The GCP criteria are mentioned in Table 1 based on literature and interviews for decision maker's experts. After that, the decsisoin judgments for degree of importance between the selected criteria are collected in the next table:

Criteria	Ma_1	A_2	I_3	E_4	W_5	M_6	H_7	Wp_8	Ed_9
Ma_1									
A_2									
I_3									
E_4									
W_5									
M_6									
H_7									
Wp_8									
Ed_9									

Consequently, study begins to collect the decision judgements for SCM alternatives that meet the GCP criteria. The five alternatives are corresponding to SCM of software companies SCM_1: Oracle, SCM_2: SAP, SCM_3: Copa Software, SCM_4: Manhattan Associates. SCM_5: JDA The decision makers are asked to inform some analytical questions as follows:

1. What is the best SCM meet the GCP conditions of Management Authority?

o SCM_1.
o SCM_2.
o SCM_3.
o SCM_4.
o SCM_5.

2. What is the best SCM meet the GCP conditions of Anthropogenic Pollutants?

o SCM_1.
o SCM_2.
o SCM_3.
o SCM_4.
o SCM_5.

3. What is the best SCM meet the GCP conditions of Ingredients?

o SCM_1.
o SCM_2.
o SCM_3.
o SCM_4.
o SCM_5.

4. What is the best SCM meet the GCP conditions of Energy Efficiency?

o SCM_1.
o SCM_2.
o SCM_3.
o SCM_4.
o SCM_5.

5. What is the best SCM meet the GCP conditions of Water Efficiency?

o SCM_1.
o SCM_2.
o SCM_3.
o SCM_4.
o SCM_5.

6. What is the best SCM meet the GCP conditions of Modernization?

o SCM_1.
o SCM_2.
o SCM_3.
o SCM_4.
o SCM_5.

7. What is the best SCM meet the GCP conditions of Habits and Cite Ecology?

o SCM_1.
o SCM_2.
o SCM_3.
o SCM_4.
o SCM_5.

8. What is the best SCM meet the GCP conditions of Waste and Pollution Environment?

o SCM_1.
o SCM_2.
o SCM_3.
o SCM_4.
o SCM_5.

9. What is the best SCM meet the GCP conditions of Epidemic Diseases?

o SCM_1.
o SCM_2.
o SCM_3.
o SCM_4.
o SCM_5.

Appendix B

For sake of evaluation of results for the proposed study, 100 people are included to provide their perspectives as feedback to recommend best SCM that meet the conditions of GCP. The sample of people included customers, SCM members (e.g. service providers etc.), and GCP members. The customers are selected as effective members for organizations (e.g. customers whom have the highest number of orders in the recent years). The study included 60 men and 40 women. The samples of people were asked to fill their own perspectives of the best SCM according to the GCP criteria. The questioner is formed as follows:

o Customer
o SCM member
o GCP member

1. What is your current job?
2. According to your own perspectives, what the most effective criteria to evaluate GCP? (Give rank from 1 to 9 such that 1 refers to optimal choice and 9 to worst choice)

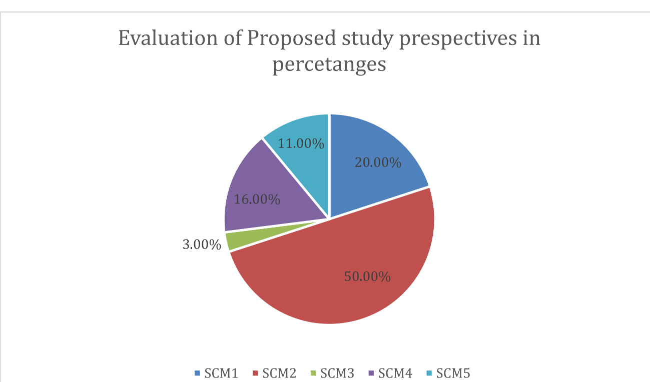
Criteria	Ranking (1–9)
Management Authority	
Anthropogenic Pollutants	
Ingredients	
Energy Efficiency	
Water Efficiency	
Modernization	
Habits and Cite Ecology	
Waste and Pollution Environment	
Epidemic diseases	

3. According to your own perspectives, what the best SCM that meets the GCP criteria conditions? Give rank from 1 to 5 such that 1 refers to optimal choice and 9 to worst choice)

Alternatives	Ranking (1–9)
SCM_1	
SCM_2	
SCM_3	
SCM_4	
SCM_5	

The questioner results for evaluating the proposed study by samples of people showed that SCM_2 is the best choice, while SCM_3 is the worst choice. The SCM_1, SCM_4, SCM_5 is recommended to be second, third, and fourth choices respectively. The percentages are mentioned as follows in Fig. 6.

Fig. 6
The percentages representations for SCM alternatives according to GCP criteria.



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