



Multi-Criteria Decision-Making Approach based on Neutrosophic Sets for Evaluating Sustainable Supplier Selection in the Industrial 4.0

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Abstract

Sustainability in supply chain management can be achieved by integrating its applications with Industry 4.0 platforms. Considering the Sustainability and Industry 4.0 criteria for supplier selection, this research creates a new integrated model to improve the performance of the applications. The choice of suppliers is evaluated using a two-stage neutrosophic sets and the EDAS method. The first step of this research is to define all of the terms associated with Industry 4.0 and Sustainability. The neutrosophic EDAS determines the relative relevance of each criterion. The neutrosophic VIKOR method is used to rank the suppliers. The suppliers' performance in meeting the sustainability and Industry 4.0 standards is then nominated in a two-stage neutrosophic sets. A case study of a textile firm is offered to illustrate the usefulness of our integrated approach. The effectiveness of the suggested integrated method is then evaluated via a series of sensitivity assessments. Of the things we learned was that it's best to build a decision-making framework that uses Industry 4.0 and sustainability criteria to assess suppliers individually rather than in a relative fashion in a hazy setting.

Keywords: Decision Support; Industry 4.0; Sustainability; Supplier Selection; MCDM; Entropy; VIKOR; Neutrosophic; EDAS

1. Introduction

Sustainability is the most crucial criterion in today's supply chain (SC) operations. Lately, research has shifted its focus to long-term, so-called sustainability supply chain management (SSCM)[1]–[3]. SSCM in [4] defines it as the management of material, information, and capital flow among SC participants and considers three pillars of Sustainability (i.e., environment, economic, and social). The most crucial strategy in supply chain sustainability (SCS) is to integrate environmental, economic, and social factors to ensure long-term sustainability [5]

Some issues threatening its Sustainability must be dealt with promptly, lest it risks its long-term viability. These issues reflect various perspectives. (i) according to [6], SC becomes more complex and fragmentation. High level of uncertainty in the environment. Instability of economic and political. (ii) in terms of society and government legislation, managers in SC aim to meet environmental and social needs [7]. (iii) The managers of SC in [8] need to acquire the right product or service from the right supplier on time, in the perfect proportion, with the right quality, and at the right price. Hence, Supplier selection (SS) is a vital aspect of the institution's SC's overall decision-making process.

In this study, we are dealing with these issues and improving all key SC chain activities, from planning to delivering for enhancing the performance of SC through converting traditional SC to be smart, sustainable, and resilient. SC's performance has improved and has now become digitized by incorporating the sophisticated industrial revolution I4.0 and its technologies. [7] discussed many benefits of implementing I4.0 in SC as facilitating information sharing, knowledge transfer, and communication among participants. According to [9][10], stated the positive influence of I4.0 in SC.

Another factor that affects the performance of the chain is SS. The operation of the SS-based point of view in [11] is an essential aspect of SSC because of the importance of Sustainability in creating value. Therefore, selecting the most sustainable and smart supplier is essential to gain advantages for SCM to be SSCM. That means the selected supplier adopts new technologies to be sustainable based achieves three pillars of Sustainability according to [12] [13] [14]:

- IoT collects real-time data from different resources to monitor labor and equipment to achieve Justice and safety (social pillar).
- They are making accurate decisions by utilizing BDA by analyzing large volumes to extract new knowledge for clients' satisfaction and optimizing waste materials to be eco-friendly (environment, social, and economic).
- BCT is achieving social pillars that stored and shared data are secure among chain partners.

Performed systematic analysis discussed in the research gaps subsection prompted us to adopt the nation of assessment sustainability of suppliers and select the most sustainable one based on I4.0 criteria through developing an integrated decision framework.

The issue of SS in [5] has received considerable attention in earlier studies. Several scholars have investigated MCDM techniques for SS under conflict criteria. However, scholars in [15] have proven that MCDM techniques failed to handle the challenge of SS in I4.0 due to the large volume of data about some quantitative aspects that is hard to evaluate while making decisions. Furthermore, some qualitative criteria prominent in I4.0 require inaccurate perception or critical decision-relevant information. Even in a fuzzy setting, most SSS models, like the Analytic Network Process (ANP), Decision-Making Trial and Evaluation Laboratory (DEMATEL), Data Envelopment Analysis (DEA), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and Analytic Hierarchy Process (AHP), are considered relative performance assessment methods[16]. Our developed decision support framework (DSF) aims to bridge a gap in the existing literature through robust integration between MCDM techniques and other techniques that can treat such problems. This technique represents neutrosophic theory, which has the main role in strengthening and tackling these methods [17] and entropy weight, EDAS, and VIKOR methods.[18]–[23]

This paper targets textile manufacturing as a case study for validating decisions of developed hybrid frameworks. Historically, the textile business was recognized as one of the most critical industries industrial renaissance. In this regard, the government has devised a plan to strengthen the textile industries and increase rates and quality.

Here is a brief rundown of the rest of this paper: section 2 shows the historical insights on research relevant concepts. Section 3 shows the decision support framework. Results and analysis in section 4. Sections 5 provides the comparative analysis with the previous studies. Finally section 6 provides the conclusions and future work of this study.

2. Historical Insights on Research-Relevant Concepts

The findings and studies on SSS, as well as the implications of I4.0, are summarized in this section. Furthermore, examine the approaches and metrics used to evaluate their sustainability-based I4.0.

2.1 Sustainable Supplier Selection (SSS)

Enterprises may use a variety of ways to enhance Sustainability in the context of SSCM, which tend to range from fostering collaboration to surveillance, regulation, and mitigation [4].

The Sustainability in [24] is related to the triple bottom line (TBL) concept. As [25] abbreviated, in addition to economic aspects, a sustainable system must encompass environmental and social aspects. Consequently, Suppliers and other SC partners should consider enhancing SCM's performance to retain Sustainability. [15] Stated that the SS process is concerned with identifying suppliers with the most significant potential to fulfil a manufacturer's needs while also delivering acceptable overall performance. Hence, SSS in [26] is critical for every organization's SC effectiveness. So,[27] stressed the need to choose suppliers based on all aspects of Sustainability.

2.2 Significance of Sustainable Supplier Selection In the Era of I4.0

According to [12], I4.0 was declared in 2011 at the Hannover Messe. Since its inception in 2011, I4.0 has attracted a lot of attention. In 2016 World Economic Forum named I4.0 thematic. Scholars in [12] argued that I4.0 is a new tier of value chain management across the product lifecycle and a collective word for value chain technology and concepts. Integrating this innovation within supplier strategies transforms classical suppliers into intelligent/innovative/digital suppliers. Subsequently, the supplier becomes more sustainable, whereas the technologies of I4.0 are employed to achieve three pillars for the supplier's Sustainability as mentioned in the introduction section.

2.3 Sustainable Supplier Selection Evaluation

Many researchers have used various evaluation models or approaches. This subsection will illustrate these methods. [15] introduced MCDM methods for evaluating SS, as Decision making trial and evaluation laboratory (DEMATEL) is used for obtaining the weight of criteria for the dimensions of resilience. Also, Grey Simple Additive Weighting (GSAW) utilized to calculate each supplier's ranking rating based on each dimension. Other scholars in [28] represented the process of decision-making as hierarchical architecture through Analytic Hierarchy Process (AHP) for evaluating alternatives and multi-criteria. Technique for order preference by similarity to an ideal solution (TOPSIS) is developed by [29] to obtain an ideal solution. This solution should be the one that is closest to the Positive Ideal Solution and the furthest away from the Negative Ideal Solution. [30] adopted TOPSIS in Iran Auto SC for SS. Others attempted to strengthen the process of evaluating suppliers as in [31] through integrating TOPSIS with AHP.

To address the uncertainty problem that MCDM suffers from during the decision-making process, the fuzzy technique was proposed [15]. Fuzzy Best Worst Method (FBWM) is applied in [32] to get decision makers' weight and rank alternatives of supplier-based TOPSIS. Even though this hybridization attempts to strengthen MCDM, fuzzy take into consideration the degree of membership and ignores non-membership and independence [33].

Consequently, we will address such flaws by utilizing MCDM techniques under a neutrosophic environment to generalize a novel hybrid methodology. This methodology is employed in developing our DSF, which will be explained in the next section.

2.4 Research Gaps

We performed a systematic analysis of two titles (TI). TI_1 ("sustainable SS") and TI_2 ("sustainable SS based I4.0") on two large databases are Web of Science (WoS) and Scopus. The TI_2 is less attention than TI_1 has been extensively researched. Hence, this paper tackles the gap in the existing literature by developing an integrated decision framework to assess the Sustainability of suppliers and select the most sustainable one based on I4.0 criteria

3 MCDM Neutrosophic Sets

Definition of the term "bipolar trapezoidal neutrosophic set" (BTNS). In addition, we develop some elementary procedures for working with BTNSs.

A point P in the grand narrative If and only if the set R defined by r is a bipolar trapezoidal neutrosophic set (BTNS), as shown by the notation

$$P = \left\{ \left\langle r, \begin{pmatrix} x^+(r) \\ y^+(r) \\ z^+(r) \end{pmatrix}, \begin{pmatrix} x^-(r) \\ y^-(r) \\ z^-(r) \end{pmatrix} \right\rangle : r \in P \right\}$$

Where the following parameters refer to the trapezoidal degrees of truth, indeterminacy and falsity for positive information.

$$\begin{aligned} x^+(r) &= (a^+(r), b^+(r), c^+(r), d^+(r)) \\ y^+(r) &= (e^+(r), f^+(r), g^+(r), h^+(r)) \end{aligned}$$

$$z^+(r) = (l^+(r), m^+(r), n^+(r), o^+(r))$$

Where the following parameters refer to the trapezoidal degrees of truth, indeterminacy and falsity for negative information.

$$x^-(r) = (a^-(r), b^-(r), c^-(r), d^-(r))$$

$$y^-(r) = (e^-(r), f^-(r), g^-(r), h^-(r))$$

$$z^-(r) = (l^-(r), m^-(r), n^-(r), o^-(r))$$

Let

$$P_1 = \left\{ \begin{array}{l} < r, \left(\begin{array}{l} a_1^+(r), b_1^+(r), c_1^+(r), d_1^+(r) \\ e_1^+(r), f_1^+(r), g_1^+(r), h_1^+(r) \\ l_1^+(r), m_1^+(r), n_1^+(r), o_1^+(r) \end{array} \right), \\ \left(\begin{array}{l} a_1^-(r), b_1^-(r), c_1^-(r), d_1^-(r) \\ e_1^-(r), f_1^-(r), g_1^-(r), h_1^-(r) \\ l_1^-(r), m_1^-(r), n_1^-(r), o_1^-(r) \end{array} \right) \\ >: r \in P \end{array} \right\}$$

$$P_2 = \left\{ \begin{array}{l} < r, \left(\begin{array}{l} a_2^+(r), b_2^+(r), c_2^+(r), d_2^+(r) \\ e_2^+(r), f_2^+(r), g_2^+(r), h_2^+(r) \\ l_2^+(r), m_2^+(r), n_2^+(r), o_2^+(r) \end{array} \right), \\ \left(\begin{array}{l} a_2^-(r), b_2^-(r), c_2^-(r), d_2^-(r) \\ e_2^-(r), f_2^-(r), g_2^-(r), h_2^-(r) \\ l_2^-(r), m_2^-(r), n_2^-(r), o_2^-(r) \end{array} \right) \\ >: r \in P \end{array} \right\}$$

$$P_1 \sqsubseteq P_2 \text{ if}$$

$$a_1^+(r) \leq a_2^+(r), b_1^+(r) \leq b_2^+(r), c_1^+(r) \leq c_2^+(r), d_1^+(r) \leq d_2^+(r)$$

$$e_1^+(r) \geq e_2^+(r), f_1^+(r) \geq f_2^+(r), g_1^+(r) \geq g_2^+(r), h_1^+(r) \geq h_2^+(r)$$

$$l_1^+(r) \geq l_2^+(r), m_1^+(r) \geq m_2^+(r), n_1^+(r) \geq n_2^+(r), o_1^+(r) \geq o_2^+$$

$$a_1^-(r) \geq a_2^-(r), b_1^-(r) \geq b_2^-(r), c_1^-(r) \geq c_2^-(r), d_1^-(r) \geq d_2^-(r)$$

$$e_1^-(r) \leq e_2^-(r), f_1^-(r) \leq f_2^-(r), g_1^-(r) \leq g_2^-(r), h_1^-(r) \leq h_2^-(r)$$

$$l_1^-(r) \leq l_2^-(r), m_1^-(r) \leq m_2^-(r), n_1^-(r) \leq n_2^-(r), o_1^-(r) \leq o_2^-$$

$$P_1 \cap P_2 =$$

$$\begin{aligned} & \min\{a_1^+(r), a_2^+(r)\}, \min\{b_1^+(r), b_2^+(r)\}, \min\{c_1^+(r), c_2^+(r)\}, \min\{d_1^+(r), d_2^+(r)\} \\ & \max\{e_1^+(r), e_2^+(r)\}, \max\{f_1^+(r), f_2^+(r)\}, \max\{g_1^+(r), g_2^+(r)\}, \max\{h_1^+(r), h_2^+(r)\} \\ & \max\{l_1^+(r), l_2^+(r)\}, \max\{m_1^+(r), m_2^+(r)\}, \max\{n_1^+(r), n_2^+(r)\}, \max\{o_1^+(r), o_2^+(r)\} \\ & \max\{a_1^-(r), a_2^-(r)\}, \max\{b_1^-(r), b_2^-(r)\}, \max\{c_1^-(r), c_2^-(r)\}, \max\{d_1^-(r), d_2^-(r)\} \\ & \min\{e_1^-(r), e_2^-(r)\}, \min\{f_1^-(r), f_2^-(r)\}, \min\{g_1^-(r), g_2^-(r)\}, \min\{h_1^-(r), h_2^-(r)\} \\ & \min\{l_1^-(r), l_2^-(r)\}, \min\{m_1^-(r), m_2^-(r)\}, \min\{n_1^-(r), n_2^-(r)\}, \min\{o_1^-(r), o_2^-(r)\} \end{aligned}$$

$$P_1 \cup P_2 =$$

$$\begin{aligned} & \max\{a_1^+(r), a_2^+(r)\}, \max\{b_1^+(r), b_2^+(r)\}, \max\{c_1^+(r), c_2^+(r)\}, \max\{d_1^+(r), d_2^+(r)\} \\ & \min\{e_1^+(r), e_2^+(r)\}, \min\{f_1^+(r), f_2^+(r)\}, \min\{g_1^+(r), g_2^+(r)\}, \min\{h_1^+(r), h_2^+(r)\} \\ & \min\{l_1^+(r), l_2^+(r)\}, \min\{m_1^+(r), m_2^+(r)\}, \min\{n_1^+(r), n_2^+(r)\}, \min\{o_1^+(r), o_2^+(r)\} \\ & \min\{a_1^-(r), a_2^-(r)\}, \min\{b_1^-(r), b_2^-(r)\}, \min\{c_1^-(r), c_2^-(r)\}, \min\{d_1^-(r), d_2^-(r)\} \\ & \max\{e_1^-(r), e_2^-(r)\}, \max\{f_1^-(r), f_2^-(r)\}, \max\{g_1^-(r), g_2^-(r)\}, \max\{h_1^-(r), h_2^-(r)\} \\ & \max\{l_1^-(r), l_2^-(r)\}, \max\{m_1^-(r), m_2^-(r)\}, \max\{n_1^-(r), n_2^-(r)\}, \max\{o_1^-(r), o_2^-(r)\} \end{aligned}$$

Our proposed framework employs various MCDM techniques under a neutrosophic environment to contribute to fulfilling the following points as in Figure 1:

- Determine the most influential criteria of I4.0 on the Sustainability of suppliers.
- Generation criteria's weight also, alternatives which participate in the evaluation process via employing entropy under neutrosophic to generalize N-entropy.
- Ranking the alternatives of suppliers who adopt I4.0 technologies via VIKOR and EDAS-based neutrosophic environment to select the most sustainable supplier who achieves three pillars based on I4.0.

Criteria Selection and Evaluation

Step 1. Collect criteria and alternatives

In this paper, we select the best supplier selection under sets of criteria, where a refers to the criteria ($a = 1, 2, 3, \dots, b$) and b indicates the number of criteria. Then determine suppliers (Alternatives), where c indicates suppliers ($c = 1, 2, 3, \dots, d$) and d indicates the number of suppliers.

Step 2. Let experts evaluate criteria and alternatives.

Build the decision matrix between criteria and alternatives by using Single-Valued Neutrosophic Sets (SVNSs) as mentioned [34]. Then apply the score function by Eq. (1). Then aggregate the opinions of experts into one matrix.

$$S(A) = \frac{2 + T - I - F}{3} \quad (1)$$

Estimation Criteria Weights

Apply entropy weight integrated with neutrosophic to compute the weights of criteria.

Step 3. Normalize the decision matrix as Eq. (2)

$$Nor_{bd} = \frac{g_{bd}}{\sum_{d=1}^c g_{bd}} \quad (2)$$

where g_{bd} refers to the aggregated decision matrix value.

Step 4. Compute entropy as Eq. (3)

$$EO_b = -LO \sum_{d=1}^c Nor_{bd} \ln Nor_{bd} \quad (3)$$

Where $LO = 1/\ln(d)$

Step 5. The weights of criteria are computed as Eq. (4)

$$W_b = \frac{1 - EO_b}{\sum_{d=1}^a (1 - EO_b)} \quad (4)$$

Ranking Suppliers based on N-VIKOR

VIKOR method is used to rank alternatives bipolar neutrosophic.

Step 6. Compute the positive and cost ideal solution as Eqs. (5 and 6)

$$N_b^+ = \max_b g_{bd} \text{ for Positive criteria and } N_b^+ = \min_b g_{bd} \text{ for cost criteria} \quad (5)$$

$$N_b^- = \min_b g_{bd} \text{ for Positive criteria and } N_b^- = \max_b g_{bd} \text{ for cost criteria} \quad (6)$$

Step 7. compute the E_b and F_b values as Eqs. (7 and 8)

$$E_b = \sum_{d=1}^a (W_d * \frac{N_b^+ - g_{bd}}{N_b^+ - N_b^-}) \quad (7)$$

$$F_b = \max_d (W_y * \frac{N_b^+ - g_{bd}}{N_b^+ - N_b^-}) \quad (8)$$

Step 8. Compute the O_b value as Eq. (9)

$$Q_x = K \left(\frac{E_b - \min_b E_b}{\max_b E_b - \min_b E_b} \right) + (1 - K) \left(\frac{F_b - \min_b F_b}{\max_b F_b - \min_b F_b} \right) \quad (9)$$

Where K refers to utility degrees and has values in the range 0 to 1.

Step 9. Rank alternatives according to the lowest value of O_b .



Figure 1: The framework of Decision Support for the selection of sustainable supplier.

Ranking Suppliers based N-EDAS: Comparative ranking method

We consolidate the EDAS method with the neutrosophic to rank alternatives as:

Step 10. Calculate the average solution as Eq. (10):

$$AS_d = \frac{\sum_{b=1}^d g_{bd}}{b} \tag{10}$$

Step 11. Compute the positive and negative distance for beneficial and non-beneficial criteria as Eqs. (11,12,13 and 14):

$$DisP_{bd}^+ = \frac{\max(0, (g_{bd} - AS_d))}{AS_d} \quad \text{For beneficial criteria} \tag{11}$$

$$DisP_{bd}^- = \frac{\max(0, (AS_d - g_{bd}))}{AS_d} \quad \text{For non-beneficial} \tag{12}$$

$$DisN_{bd}^+ = \frac{\max(0, (AS_d - g_{bd}))}{AS_d} \quad \text{For beneficial criteria} \tag{13}$$

$$DisN_{bd}^- = \frac{\max(0, (g_{bd} - AS_d))}{AS_d} \quad \text{For non-beneficial criteria} \tag{14}$$

Step 12. From positive distance compute the weighted sum as Eqs. (15 and 16)

$$WP_b = \sum_{d=1}^c W_d DisP_{bd} \tag{15}$$

$$WN_b = \sum_{d=1}^c W_d DisN_{bd} \tag{16}$$

Step 13. Normalize the WP_b and WN_b values as Eqs. (17 and 18)

$$NWP_b = \frac{WP_b}{\max(WP_b)} \tag{17}$$

$$NWN_b = 1 - \frac{WN_b}{\max(WN_b)} \tag{18}$$

Step 14. Normalize the NWP_b and NWN_b values as Eq. (19);

$$NW_b = \frac{NWP_b + NWN_b}{2} \tag{19}$$

Step 15. Rank alternatives based on the highest value of NW_b

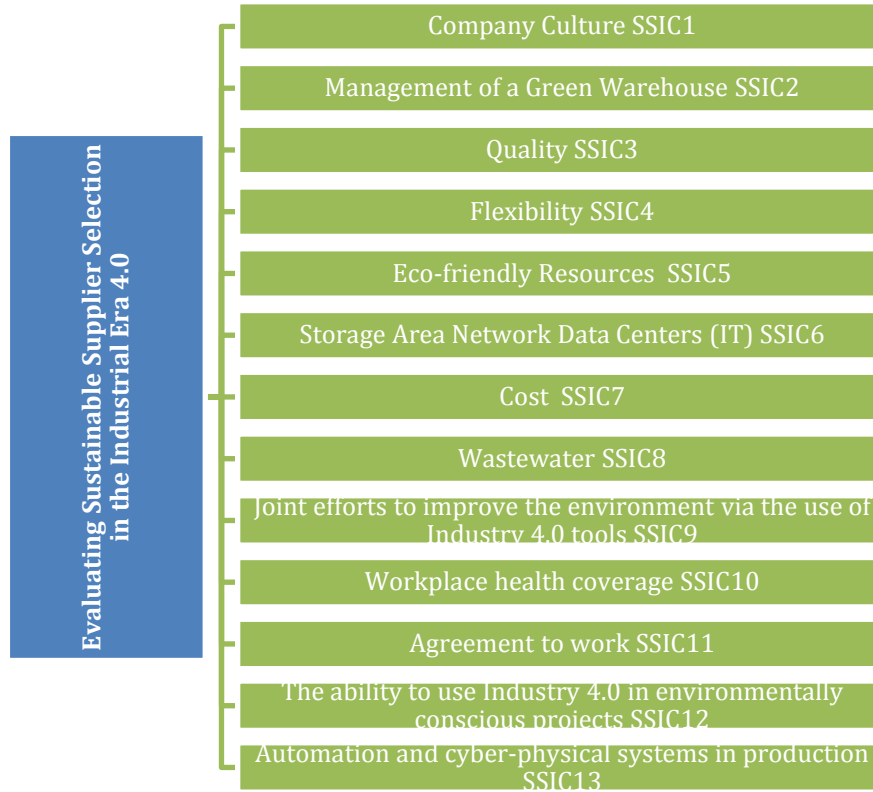


Figure 2: Criteria are used in this paper.

4. Results

An actual case study is carried out at textile firm to see how the suggested method works in practice. Using data in the moment and green standards, this firm plans to strengthen its partnerships with its suppliers. This firm is certain that combining the features of Industry 4.0 with SSS would help it better compete with other firms in Iran.

Step 1. We used three experts to evaluate thirteen criteria with four decision matrices from the previous research that collected SSS industry 4.0. The criteria and alternatives are shown in Figure 2.

Step 2. Using linguistic terms, experts evaluate the criteria and alternatives to build three decision matrices. Then convert the linguistics terms to the SVN numbers. Then convert these three numbers into one number by using Eq. (1). Then aggregate the opinions of experts into one matrix by using the average method in Table 1.

Step 3. By using Eq. (2), the aggregated decision matrix is normalized in Table 2.

Step 4. Eq. (3) is used to compute the entropy.

Step 5. Eq. (4) is used to compute the weights of the criteria. $W_1 = 0.010531, W_2 = 0.012978, W_3 = 0.0333, W_4 = 0.051, W_5 = 0.076144, W_6 = 0.083402, W_7 = 0.395452, W_8 = 0.076142, W_9 = 0.054237, W_{10} = 0.077782, W_{11} = 0.039903, W_{12} = 0.025723, W_{13} = 0.063407$. Figure 3 shows the weights of the criteria.

Table 1: The aggregated decision matrix.

| | SSIC ₁ | SSIC ₂ | SSIC ₃ | SSIC ₄ | SSIC ₅ | SSIC ₆ | SSIC ₇ | SSIC ₈ | SSIC ₉ | SSIC ₁₀ | SSIC ₁₁ | SSIC ₁₂ | SSIC ₁₃ |
|------------------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|--------------------|--------------------|--------------------|--------------------|
| SSI A₁ | 0.75 | 0.5388 89 | 0.4944 22 | 0.7166 67 | 0.4944 22 | 0.7833 33 | 0.7166 67 | 0.7166 67 | 0.5388 89 | 0.5388 89 | 0.5722 22 | 0.5055 56 | 0.6833 33 |
| SSI A₂ | 0.7833 33 | 0.6388 78 | 0.4944 22 | 0.5722 11 | 0.6055 44 | 0.75 | 0.3833 | 0.4944 22 | 0.6833 33 | 0.6833 33 | 0.6388 78 | 0.6055 44 | 0.4610 89 |
| SSI A₃ | 0.7833 33 | 0.6388 78 | 0.5722 22 | 0.5722 22 | 0.6055 44 | 0.6388 78 | 0.2499 89 | 0.5388 89 | 0.6055 44 | 0.7833 33 | 0.4611 | 0.6055 44 | 0.6722 11 |
| SSI A₄ | 0.6722 11 | 0.6055 44 | 0.6388 78 | 0.4944 22 | 0.7833 33 | 0.4944 22 | 0.4277 67 | 0.7166 67 | 0.7833 33 | 0.5277 56 | 0.6055 44 | 0.4944 22 | 0.6388 78 |

Table 2: The normalized aggregated decision matrix.

| | SSIC ₁ | SSIC ₂ | SSIC ₃ | SSIC ₄ | SSIC ₅ | SSIC ₆ | SSIC ₇ | SSIC ₈ | SSIC ₉ | SSIC ₁₀ | SSIC ₁₁ | SSIC ₁₂ | SSIC ₁₃ |
|------------------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|--------------------|--------------------|--------------------|--------------------|
| SSI A₁ | 0.2509 3 | 0.2224 8 | 0.2247 43 | 0.3042 5 | 0.1986 55 | 0.2937 54 | 0.4031 38 | 0.2905 43 | 0.2063 84 | 0.2127 21 | 0.2512 23 | 0.2286 48 | 0.2782 86 |
| SSI A₂ | 0.2620 83 | 0.2637 61 | 0.2247 43 | 0.2429 23 | 0.2433 03 | 0.2812 54 | 0.2156 13 | 0.2004 43 | 0.2617 03 | 0.2697 39 | 0.2804 87 | 0.2738 7 | 0.1877 77 |
| SSI A₃ | 0.2620 83 | 0.2637 61 | 0.2601 08 | 0.2429 28 | 0.2433 03 | 0.2395 82 | 0.1406 23 | 0.2184 7 | 0.2319 12 | 0.3092 13 | 0.2024 37 | 0.2738 7 | 0.2737 56 |
| SSI A₄ | 0.2249 04 | 0.2499 99 | 0.2904 06 | 0.2098 99 | 0.3147 38 | 0.1854 11 | 0.2406 26 | 0.2905 43 | 0.3000 01 | 0.2083 26 | 0.2658 53 | 0.2236 13 | 0.2601 81 |

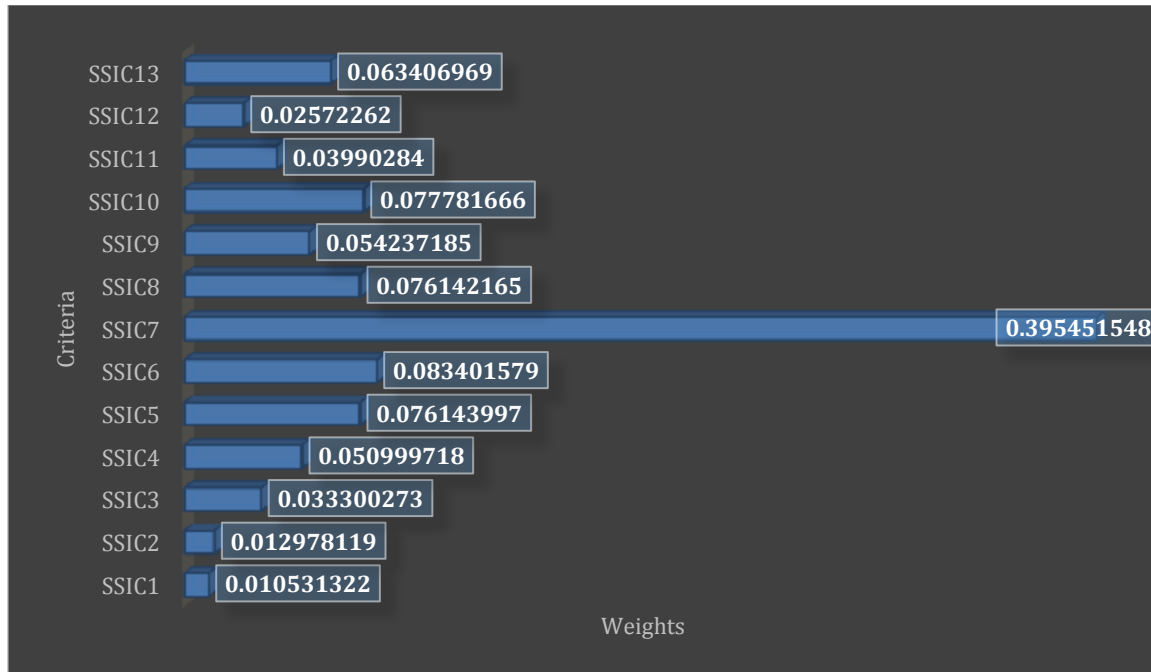


Figure 3: The weights of the criteria

The rank of alternatives by the VIKOR method.

Step 6. Start with the aggregated decision matrix. Then compute the positive and cost ideal solution by using Eq. (5,6) in Table 3.

Step 7. The values of E_b and F_b is computed by using Eq. (7,8)

Step 8. The value of O_b is computed by using Eq. (9).

Step 9. Rank alternatives according to the lowest value of O_b in Figure 4.

Table 3: The positive and cost ideal solution.

| | SSIC ₁ | SSIC ₂ | SSIC ₃ | SSIC ₄ | SSIC ₅ | SSIC ₆ | SSIC ₇ | SSIC ₈ | SSIC ₉ | SSIC ₁₀ | SSIC ₁₁ | SSIC ₁₂ | SSIC ₁₃ |
|-----------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|--------------------|--------------------|--------------------|--------------------|
| SSI A ₁ | 0.0031 59 | 0.0129 78 | 0.0333 | 0 | 0.0761 44 | 0 | 0 | 0 | 0.0542 37 | 0.0743 93 | 0.0149 61 | 0.0231 45 | 0 |
| SSI A ₂ | 0 | 0 | 0.0333 | 0.0331 49 | 0.0468 57 | 0.0096 23 | 0.2824 87 | 0.0761 42 | 0.0221 88 | 0.0304 34 | 0 | 0 | 0.0634 07 |
| SSI A ₃ | 1.05E- 17 | 0 | 0.0153 66 | 0.0331 47 | 0.0468 57 | 0.0417 01 | 0.3954 52 | 0.0609 08 | 0.0394 48 | 0 | 0.0399 03 | 0 | 0.0031 73 |

| | | | | | | | | | | | | | |
|----------------|--------|--------|---|-------|---|--------|--------|---|---|--------|--------|--------|--------|
| SSI | 0.0105 | 0.0043 | 0 | 0.051 | 0 | 0.0834 | 0.2448 | 0 | 0 | 0.0777 | 0.0074 | 0.0257 | 0.0126 |
| A ₄ | 31 | 27 | 0 | 0.051 | 0 | 02 | 07 | 0 | 0 | 82 | 82 | 23 | 83 |

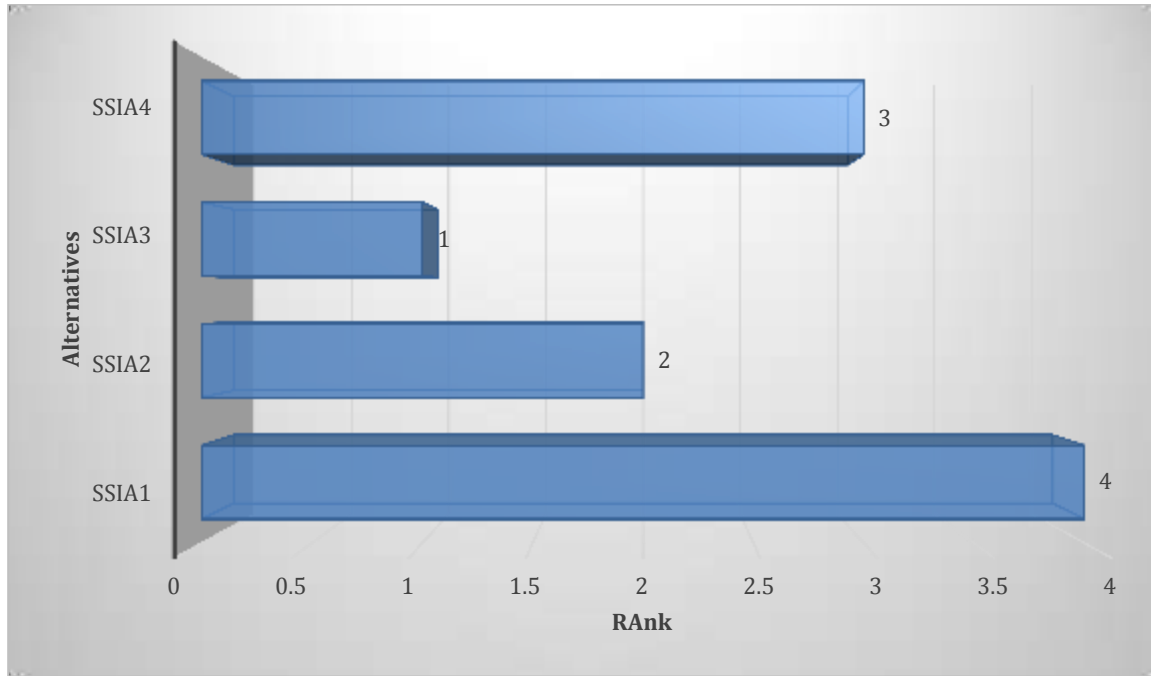


Figure 4: The rank of alternatives by the VIKOR method.

Rank alternatives by the EDAS method.

- Step 10.** Start with the aggregated decision matrix. Then the average solution is computed by using Eq. (10)
- Step 11.** By using Eqs. (11,12,13 and 14) positive and negative distances for beneficial and non-beneficial criteria are computed in Tables 4 and 5.
- Step 12.** By using Eqs. (15,16) the weighted sum is computed. The weight sum matrix.
- Step 13.** By using Eqs. (17,18) the normalized values of WP_b and WN_b is computed.
- Step 14.** Normalize the NWP_b and NWN_b values by using Eq. (19);
- Step 15.** Figure 5. Shows the rank of alternatives by the EDAS method.

Table 4: The positive distance for beneficial and non-beneficial criteria.

| | SSIC ₁ | SSIC ₂ | SSIC ₃ | SSIC ₄ | SSIC ₅ | SSIC ₆ | SSIC ₇ | SSIC ₈ | SSIC ₉ | SSIC ₁₀ | SSIC ₁₁ | SSIC ₁₂ | SSIC ₁₃ |
|----------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|--------------------|--------------------|--------------------|--------------------|
| SSI | | | | | | | | | | | | | |
| A ₁ | 0.0037 | | | 0.2169 | | 0.1750 | | 0.1621 | | | 0.0048 | 0.0854 | |
| | 21 | 0 | 0 | 98 | 0 | 15 | 0 | 73 | 0 | 0 | 93 | 09 | 0 |

| | | | | | | | | | | | | | |
|----------------------|--------|--------|--------|---|--------|--------|----------|--------|--------|--------|--------|--------|--------|
| SSI | | | | | | | | | | | | | |
| A₂ | 0.0483 | 0.0550 | | | | 0.1250 | 0.137548 | | 0.0468 | 0.0789 | 0.1219 | | 0.2488 |
| | 31 | 42 | 0 | 0 | 0 | 14 | 048 | 0 | 13 | 57 | 48 | 0 | 91 |
| SSI | | | | | | | | | | | | | |
| A₃ | 0.0483 | 0.0550 | 0.0404 | | | | 0.437507 | | | 0.2368 | | | |
| | 31 | 42 | 3 | 0 | 0 | 0 | 423 | 0 | 0 | 53 | 0 | 0 | 0 |
| SSI | | | | | | | | | | | | | |
| A₄ | | | 0.1616 | | 0.2589 | | 0.037494 | 0.1621 | 0.2000 | | 0.0634 | 0.1055 | |
| | 0 | 0 | 25 | 0 | 51 | 0 | 922 | 73 | 05 | 0 | 11 | 5 | 0 |

Table 5: The negative distance for beneficial and non-beneficial criteria.

| SSI | C₁ | SSIC₂ | SSIC₃ | SSIC₄ | SSIC₅ | SSIC₆ | SSIC₇ | SSIC₈ | SSIC₉ | SSIC₁₀ | SSIC₁₁ | SSIC₁₂ | SSIC₁₃ |
|----------------------|----------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| SSI | 0 | 0.1100 | 0.1010 | 0 | 0.2053 | 0 | 0.6125503 | 0 | 0.1744 | 0.1491 | 0 | 0 | 0.1131 |
| A₁ | | 79 | 28 | | 79 | | 93 | | 65 | 15 | | | 42 |
| SSI | 0 | 0 | 0.1010 | 0.0283 | 0.0267 | 0 | 0 | 0.1982 | 0 | 0 | 0 | 0.0954 | 0 |
| A₂ | | | 28 | 07 | 86 | | | 27 | | | | 79 | |
| SSI | 0 | 0 | 0 | 0.0282 | 0.0267 | 0.0416 | 0 | 0.1261 | 0.0723 | 0 | 0.1902 | 0.0954 | 0.0950 |
| A₃ | | | | 88 | 86 | 71 | | 18 | 53 | | 52 | 79 | 24 |
| SSI | 0 | 4.59E- | 0 | 0.1604 | 0 | 0.2583 | 0 | 0 | 0 | 0.1666 | 0 | 0 | 0.0407 |
| A₄ | | 06 | | 03 | | 57 | | | | 94 | | | 25 |

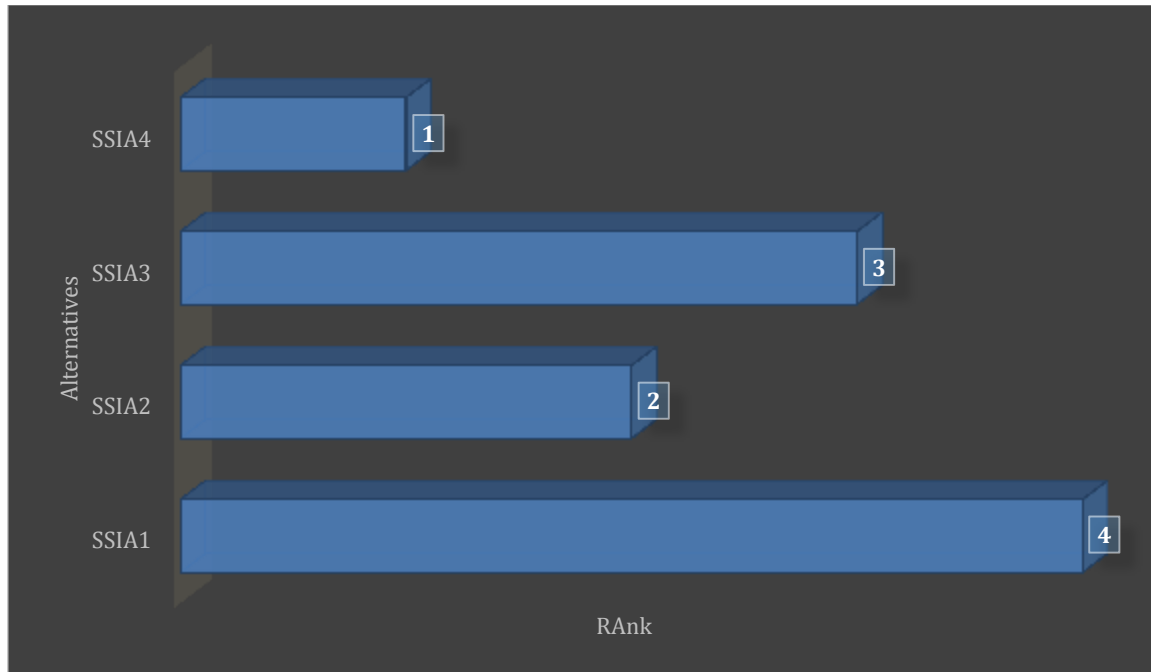


Figure 5: The rank of alternatives by the EDAS method.

5. Comparative Analysis

A thorough comparison with the available SVN-based MCDM methods can shed light on the dependability of the obtained ranking results. Therefore, the emphasized issue of selecting a suitable supplier based on industry 4.0 is resolved using all available SVNSs-based MCDM approaches, i.e., crisp VIKOR, crisp WSM between SVN-VIKOR and SVN-EDAS. The ranking results of the examined SVN-based MCDM approaches are shown in Table 6. The suggested SVN-VIKOR and crisp WSM, crisp VIKOR algorithms are in perfect agreement with one another, as they both provided the identical ranking of suitability suppliers based on industry 4.0 possibilities.

Table 6 shows that SSIA₁ is the best alternative in all MCDM methods. SSIA₃ is the worst alternative in SVN-VIKOR, crisp VIKOR, and crisp WSM. However, in the SVN-EDAS, the SSIA₄ is the worst alternative. SSIA₄ is the second rank in three MCDM methods (SVN-VIKOR, crisp-VIKOR, crisp WSM), but in SVN-EDAS, the SSIA₃ is the second rank. SSIA₂ is the third rank in all MCDM methods.

Table 6: The comparison of different SVN-based MCDM techniques.

| Method | Ranking |
|-------------|---|
| SVN-VIKOR | SSIA ₁ > SSIA ₄ > SSIA ₂ > SSIA ₃ |
| SVN-EDAS | SSIA ₁ > SSIA ₃ > SSIA ₂ > SSIA ₄ |
| Crisp VIKOR | SSIA ₁ > SSIA ₄ > SSIA ₂ > SSIA ₃ |
| Crisp WSM | SSIA ₁ > SSIA ₄ > SSIA ₂ > SSIA ₃ |

6. Conclusion

There is a dearth of research examining the effects of Industry 4.0 on SSCM. There is a dearth of research that combines Industry 4.0 characteristics with sustainability standards for SSS. For SSS, the majority of existing assessment models primarily provide data on how different providers compare to one another. To assess the suppliers with Industry 4.0 and sustainability standards, this study has designed a hybridized neutrosophic entropy weights with the EDAS and VIKOR methods. We used neutrosophic entropy weight to arrive at the criterion weights and EDAS and VIKOR methods to calculate the efficacy of each supplier. In a nutshell, the proposed methodology allows decision-makers to evaluate suppliers independently and choose the best one, even in a hazy setting. The

Metaheuristics algorithms can be used to solve this problem. Also, the proposed methodology can be used in many fields of MCDM problems.

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