An Integrated Model with Interval Valued Neutrosophic Sets for the Selection of Lean and Sustainable Suppliers

Ahmet Selcuk Yalcin[1(✉)], Huseyin Selcuk Kilic[2], and Nadide Caglayan[3]

[1] Department of Industrial Engineering, Okan University, 34959 Istanbul, Turkey
ahmetselcukyalcin@gmail.com

[2] Department of Industrial Engineering, Marmara University, 34722 Istanbul, Turkey

[3] Department of Industrial Engineering, Istanbul Technical University, 34367 Istanbul, Turkey

Abstract. Suppliers have a very important role in the supply chain (SC) and accordingly the evaluation and selection of the supplier is quite significant. The aim of this study is to develop a hybrid methodology for the determination of the best supplier considering lean and sustainable factors. However, the selection of sustainable suppliers often includes indeterminate, inconsistent and vague information due to the subjective nature of individual decisions. Interval-valued neutrosophic sets (IVNSs) have a considerable capability to deal with indeterminacy and vagueness in the decision-making process. To this end, we integrated two strong decision making tools, ANP and TODIM, under interval valued neutrosophic sets environment. Firstly, IVN-ANP was employed to calculate the criteria weights. Further, obtained weights are utilized in the IVN-TODIM method as an input for the best sorting of the alternatives. A numerical example was introduced to illustrate the applicability and efficacy of the proposed approach.

Keywords: Lean and sustainable supplier · IVN-ANP · IVN-TODIM

1 Introduction

Supply chain management (SCM) includes all the activities related to the flow of goods and services from source to consumer. [1]. In this system, strategic and tactical decisions are taken; the choice of locations, technologies and suppliers are strategic decisions, while tactical decisions involve various decisions on planning, production, storage and delivery of end products to customers [2]. Sustainable SCM, which is a different approach in SCM, intends to join the system by considering the economic, environmental and social factors [3]. When lean and sustainable approaches are regarded, it is aimed to remove non-value added process throughout the SC in order to create a sustainable system in SCM [4]. However, the performance of the process is closely related to choices of suppliers. Selection of suppliers based on lean and

C. Kahraman et al. (Eds.): INFUS 2019, AISC 1029, pp. 693–701, 2020.
https://doi.org/10.1007/978-3-030-23756-1_83

sustainable factors helps producers improve their green performance and competitive advantage.

Evaluation and selection of suppliers can be regarded as a multi-criteria decision making problem (MCDM) which includes both qualitative and quantitative criteria concurrently [5]. While eco-environmental and social elements are crucial for sustainability, zero defects, frequent deliveries, long-term relationships, the closest sources and reasonable prices are the key factors of lean supply [6]. The lean approach concentrates on eliminating any activity and waste non-value added throughout the process as sustainability is particularly concerned with its environmental impact [7]. However, the common philosophy of a lean and sustainable approach is to avoid waste.

It is difficult for decision-makers (DMs) to choose the best alternative based on several elements, when there is incomplete and inexact data. In this case, it is quite normal for DMs to be unstable and timid in the evaluation process. They can also be specialized in different fields. DMs' subjective decisions can cause a great uncertainty in the process [8]. Neutrosophic sets (NSs) are robust and effective to handle the vagueness and indeterminacy. They can demonstrate the positive, negative and indeterminate data efficaciously and are more resilient than fuzzy and intuitionistic fuzzy sets [9]. Moreover, IVNSs can better reflect vague, incomplete and inconsistent knowledge emerging in the real world [10]. Thus, we combined INVSs with ANP and TODIM respectively to select the most appropriate supplier considering lean and sustainable criteria. To the best of our knowledge, this is the first research in which these integrated methods was used in the literature. Firstly, IVN-ANP is used to compute the criteria weights. Then, IVN TODIM is employed to rank the alternatives considering obtained weights. The organization of this paper is as follows: Sect. 2 illustrates the steps the proposed model. Section 3 presents an application to prove the applicability of the proposed approach. The last section shows the conclusion.

2 IVN-ANP and IVN-TODIM

In this section, the steps of proposed methodology are demonstrated. Before that, the necessary equations and operations of IVNSs are given [11].

2.1 INVSs and Their Operations

Definition 1. There are a truth- membership function $T_A(x)$, an indeterminacy-membership function $I_A(x)$ and a falsity-membership function $F_A(x)$ in any neutrosophic set A in X. There is no restriction on the summation of $T_A(x)$, $I_A(x)$ and $F_A(x)$, therefore $0^- \leq \sup T_A(x) + \sup I_A(x) + \sup F_A(x) \leq 3^+$.

Definition 2. An interval valued number (INN) can be shown as $\widetilde{A} = (T_{\widetilde{A}}, I_{\widetilde{A}}, F_{\widetilde{A}}) = \left(\left[T^L_{\widetilde{A}}, T^U_{\widetilde{A}}\right], \left[I^L_{\widetilde{A}}, I^U_{\widetilde{A}}\right], \left[F^L_{\widetilde{A}}, F^U_{\widetilde{A}}\right]\right)$, where $\left[T^L_{\widetilde{A}}, T^U_{\widetilde{A}}\right] \subseteq [0,1]$, $\left[I^L_{\widetilde{A}}, I^U_{\widetilde{A}}\right] \subseteq [0,1]$, $\left[F^L_{\widetilde{A}}, F^U_{\widetilde{A}}\right] \subseteq [0,1]$ and $0 \leq T^U_{\widetilde{A}} + I^U_{\widetilde{A}} + F^U_{\widetilde{A}} \leq 3$.

Definition 3. Let $\widetilde{A}=\left([a^L,a^U],\left[b^L,b^U\right],[c^L,c^U]\right)$ be an INN, score function of it is shown below.

$$S(\widetilde{A}) = \left(2+a^L-b^L-c^L\right)+\left(2+a^U-b^U-c^U\right)/6, \quad S\left(\widetilde{A}\right)\in[0,1] \tag{1}$$

Definition 4. Let $\widetilde{A}=\left([a^L,a^U],\left[b^L,b^U\right],[c^L,c^U]\right)$ be an INN, an accuracy function is defined.

$$H(\widetilde{A}) = \left(a^L+a^U\right)-\left(c^L+c^U\right)/2, \quad H(\widetilde{A})\in[-1,1] \tag{2}$$

Definition 5. Let $\widetilde{A}_1=\left(\left[a_1^L,a_1^U\right],\left[b_1^L,b_1^U\right],\left[c_1^L,c_1^U\right]\right)$ and $\widetilde{A}_2=\left(\left[a_2^L,a_2^U\right],\left[b_2^L,b_2^U\right],\left[c_2^L,c_2^U\right]\right)$ be two different INNs, $S(\widetilde{A}_1)$ and $S(\widetilde{A}_2)$ be score functions, $H(\widetilde{A}_1)$ and $H(\widetilde{A}_2)$ be accuracy functions. If $S(\widetilde{A}_1)<S(\widetilde{A}_2)$, then $\widetilde{A}<\widetilde{B}$; if $S(\widetilde{A}_1)=S(\widetilde{A}_2)$, then if $H(\widetilde{A}_1)=H(\widetilde{A}_2)$, then $\widetilde{A}=\widetilde{B}$ and if $H(\widetilde{A}_1)<H(\widetilde{A}_2)$, then $\widetilde{A}<\widetilde{B}$.

Definition 6. Let $\widetilde{A}_1=\left(\left[a_1^L,a_1^U\right],\left[b_1^L,b_1^U\right],\left[c_1^L,c_1^U\right]\right)$ and $\widetilde{A}_2=\left(\left[a_2^L,a_2^U\right],\left[b_2^L,b_2^U\right],\left[c_2^L,c_2^U\right]\right)$ be two different INNs, then the calculation of normalized Hamming distance between them is presented below.

$$d(\widetilde{A}_1,\widetilde{A}_2) = 1/6\left(\left|a_1^L-a_2^L\right|+\left|a_1^U-a_2^U\right|+\left|b_1^L-b_2^L\right|+\left|b_1^U-b_2^U\right|+\left|c_1^L-c_2^L\right|+\left|c_1^U-c_2^U\right|\right) \tag{3}$$

Definition 7. Let $\widetilde{A}=\left([a^L,a^U],\left[b^L,b^U\right],[c^L,c^U]\right)$ be an INN. A novel deneutrosophication function of an INN is proposed by [12] below.

$$D = \left(\left(a^L+a^U\right)/2+\left(1-\left(b^L+b^U\right)/2\right)\cdot\left(b^U\right)-\left(c^L+c^U/2\right)\cdot\left(1-c^U\right)\right) \tag{4}$$

2.2 IVN-ANP

The ANP method is an evaluation method that detects the relationships between the criteria and shows them in the form of networks. In order to cope with uncertainty and indeterminacy, it is used with IVNSs. Within the interval valued neutrosophic analytic network process (IVN-ANP), firstly, the interaction between the criteria is determined.

After determining the interaction between the criteria, the eigenvalues of the criteria with respect to the affecting criteria are obtained. In order to calculate weights of the criteria, the steps of the neutrosophic AHP proposed by [12] are used as follows:

(1) Detect the interval-valued neutrosophic assessment scale as shown Table 1.
(2) Create the pairwise comparison matrices by utilizing IVNSs.
(3) In the measurement of consistency of the pairwise comparison matrices deneutrosophication formula given in Eq. (4) is used. If the consistently ratio of deneutrosophicated pairwise comparison matrix is smaller than 0.10, the neutrosophic pairwise comparison matrix is regarded as consistent.

Table 1. Linguistic terms and neutrosophicated importance weights.

Linguistic term	T_L	T_U	I_L	I_U	F_L	F_U
Equal Importance (EqI)	0.5	0.5	0.5	0.5	0.5	0.5
Weakly more importance (WEI)	0.5	0.6	0.35	0.45	0.4	0.5
Moderate importance (MI)	0.55	0.65	0.3	0.4	0.35	0.45
Moderately more importance (MMI)	0.6	0.7	0.25	0.35	0.3	0.4
Strong importance (SI)	0.65	0.75	0.2	0.3	0.25	0.35
Strongly more importance (SMI)	0.7	0.8	0.15	0.25	0.2	0.3
Very strong importance (VSI)	0.75	0.85	0.1	0.2	0.15	0.25
Very strongly more importance (VSMI)	0.8	0.9	0.05	0.1	0.1	0.2
Extreme importance (ExI)	0.9	0.95	0	0.05	0.05	0.15
Extremely high importance (EHI)	0.95	1	0	0	0	0.1
Absolutely more importance (AMI)	1	1	0	0	0	0

(4) Compute the weights of criteria by using the interval-valued neutrosophic assessment scale in Table 1 proposed by [12].

- Firstly, the values in each column are summed
- Secondly, upper value for each parameter is opted and each term is divided by its corresponding factor. Therefore, normalized values are obtained.
- Lastly, the criteria weights are computed by averaging the elements in the normalized rows. Then, deneutrosophication formula given in Eq. (4) is implemented to achieve the crisp value of criteria weights.

The obtained eigenvalues are used in the unweighted super matrix and sequentially weighted and limit super matrixes are constructed by obeying the similar steps as in the usual ANP [13]. Finally, the importance weights of the criteria are determined.

2.3 IVN-TODIM

TODIM method is one of MCDM methods based on prospect theory. The steps of IVN-TODIM are shown as follows [11]:

1. Determine the interval neutrosophic matrix $\widetilde{R} = (\widetilde{r}_{ij})_{m \times n}$, $\widetilde{r}_{ij}$ is an INN.
2. Compute the relative weight of w_{jr} by using the Eq. (5). $w_r = \max\{w_j | j = 1, 2, \ldots, n\}$ and $0 \leq w_{jr} \leq 1$.

$$w_{jr} = w_j / w_r \tag{5}$$

3. Compute the dominance degree $\phi_j(X_k, X_l)$ of X_k over each X_l under w_{jr} using Eq.

$$\phi_j(X_i, X_t) = \begin{cases} \sqrt{\frac{w_{jr} d(\tilde{r}_{ij}, \tilde{r}_{tj})}{\sum_{j=1}^{n} w_{jr}}}, & \text{if } \tilde{r}_{ij} > \tilde{r}_{tj} \\ 0, & \text{if } \tilde{r}_{ij} = \tilde{r}_{ti} \\ -\frac{1}{\theta}\sqrt{\left(\sum_{j=1}^{n} w_{jr}\right) d(\tilde{r}_{ij}, \tilde{r}_{tj})/w_{jr}}, & \text{if } \tilde{r}_{ij} < \tilde{r}_{ti} \end{cases} \tag{6}$$

4. Compute the overall dominance degree $\delta(X_k, X_l)$ of X_k over each candidate X_l by utilizing Eq. (7).

$$\delta(X_i, X_t) = \sum_{j=1}^{n} \phi_j(X_i, X_t),\ (i, t = 1, 2, \ldots m) \tag{7}$$

5. Calculate the final value $\delta(X_i)$ of each candidate X_t by using Eq. (8).

$$\delta(X_i) = \frac{\sum_{t=1}^{m} \delta(X_i, X_l) - \min\left\{\sum_{t=1}^{m} \delta(X_k, X_l)\right\}}{\max\left\{\sum_{t=1}^{m} \delta(X_k, X_l)\right\} - \min\left\{\sum_{t=1}^{m} \delta(X_k, X_l)\right\}} \tag{8}$$

6. Detect the ranking of the candidates taking into account the values of $\delta(X_i)$.

3 Application

A company manufacturing filters desires to select a supplier considering sustainable and lean factors. The suppliers are called as A1, A2, A3, A4 and A5. A detailed literature review on the selection criteria of lean and sustainable suppliers and the suggestions of the experts and academic scientists, the relevant criteria were detected. Frequent delivery capacity (C1), timely delivery capacity (C2), product quality (C3), information systems compatibility (C4), energy consumption (C5), material recycling (C6), worker health and safety (C7) and price (C8).

3.1 IVN-ANP for Calculating the Weights of the Criteria

After determining the related criteria, the interactions between the criteria are detected by the DMs. Considering the network relation model, it is seen that criterion 1 affects the criteria 2, 5 and 8 and affected by the criterion 2. Similarly, the relations between the other criteria are represented in the network model as shown in Fig. 1.

Considering the interactions between the criteria, the pairwise comparisons are constructed as indicated in Table 2.

After utilizing the required operations of neutrosophic AHP, the weights with respect to the affecting criterion are obtained as shown in Table 3.

Afterwards, the unweighted, weighted and limit super matrices are obtained. Due to the limitation of space, all the matrices are not provided. However, the criteria importance weights extracted from the limit super matrix are provided in Table 4.

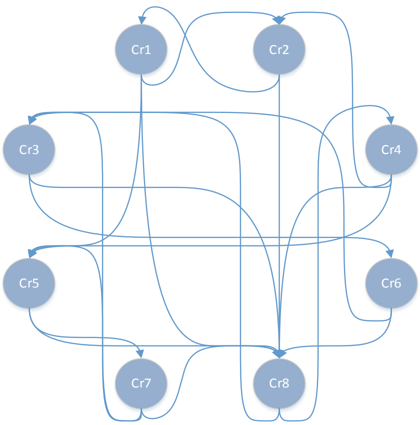

Fig. 1. Network relation model of the criteria.

Table 2. The pairwise comparisons of the criteria with respect to each criterion.

With respect to C1	C2	C5	C8	With respect to C2	C1	C8
C2	EqI	SMI	SI	C1	EqI	MMI
C5	inv SMI	EqI	inv WEI	C8	inv MMI	EqI
C8	inv SI	WEI	EqI			
…	…	…	…	…	…	…
With respect to C7	C3	C5	C8	With respect to C8	C3	C4
C3	EqI	inv MMI	SMI	C3	EqI	MI
C5	MMI	EqI	ExI	C4	inv MI	EqI
C8	inv SMI	inv ExI	EqI			

Table 3. The pairwise comparisons of the criteria with respect to each criterion.

With respect to C1	C2	C5	C8	With respect to C2	C1	C8
Weights	0.461	0.246	0.293	Weights	0.575	0.425
…	…	…	…	…	…	…
With respect to C7	C3	C5	C8	With respect to C8	C3	C4
Weights	0.372	0.497	0.131	Weights	0.550	0.450

Table 4. The criteria importance weights.

Criteria	Cr1	Cr2	Cr3	Cr4	Cr5	Cr6	Cr7	Cr8
Importance weight	0.047	0.082	0.247	0.110	0.066	0.162	0.041	0.244

3.2 Ranking Suppliers with IVN-TODIM

Five possible candidates (A1, A2, A3, A4, A5) are assessed by employing IVNSs under eight criteria (whose weights are 0.0474, 0.0824, 0.2469, 0.1199, 0.0659, 0.1617, 0.0413, 0.2443). They are rated with respect to the criteria in Table 5.

Table 5. Ratings of alternatives with respect to the criteria.

	C1						C2					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
A1	0.4	0.5	0.1	0.2	0.6	0.7	0.7	0.8	0.4	0.5	0.3	0.4
A2	0.3	0.4	0.5	0.6	0.1	0.2	0.8	0.9	0.5	0.6	0.4	0.5
A3	0.3	0.4	0.5	0.6	0.6	0.7	0.6	0.7	0.5	0.6	0.3	0.4
A4	0.8	0.9	0.2	0.3	0.6	0.7	0.5	0.6	0.4	0.5	0.4	0.5
A5	0.5	0.6	0.5	0.6	0.6	0.7	0.8	0.9	0.6	0.7	0.8	0.9
…	…	…	…	…	…	…	…	…	…	…	…	…

Initially, since w_3 is the highest value amongs criteria it is determined as the reference criterion. We can compute relative weights of the criteria by using Eq. (5) as $w_{1r} = 0.192$, $w_{2r} = 0.334$, $w_{3r} = 1.00$, $w_{4r} = 0.445$, $w_{5r} = 0.267$, $w_{6r} = 0.655$, $w_{7r} = 0.168$ and $w_{8r} = 0.989$. Let $\theta = 2.5$, dominance degree matrices of the criteria are determined by Eq. (6) as shown in Table 6. In this step, score function in Eq. (1), accuracy function in Eq. (2), distance measure in Eq. (3) and Definition 5 are used.

Table 6. Dominance degree matrices of alternatives with respect to each criterion.

	ϕ_1					ϕ_2					
	A1	A2	A3	A4	A5		A1	A2	A3	A4	A5
A1	0	–1.061	…	…	0.089	A1	0	0.091	…	…	0.148
A2	0.126	0	…	…	0.105	A2	–0.44	0	…	…	0.117
A3	–0.751	–0.751	…	…	–0.472	A3	–0.358	–0.44	…	…	0.148
A4	0.089	0.143	…	…	0.097	A4	–0.44	–0.508	…	…	0.157
A5	–0.751	–0.887	…	…	0	A5	–0.718	–0.568	…	…	0
…	…	…	…	…	…	…	…	…	…	…	…

The overall dominance degree $\delta(A_i, A_t)$ of alternative A_i over each alternative A_t can be calculated by using Eq. (7). The results are demonstrated in Table 7. Lastly, we obtained the overall value using Eq. (8). Then, the best one is A4 followed by A1, A3, A2, and A5 considering the values obtained in the last step of IVN-TODIM.

Table 7. Overall dominance degree matrices of alternatives.

	A1	A2	A3	A4	A5
A1	0	–1.075	–0.793	–2.508	–0.348
…	…	…	…	…	…
A5	–2.953	–2.032	–1.647	–3.563	0

4 Conclusion

Supplier selection problem is a MCDM problem because of involving conflicting qualitative and quantitative criteria. However, MCDM problems have ambiguity and indeterminacy because of human judgments and subjectivity. Therefore, IVNSs are preferred in a number of researches to deal with the uncertainty and indeterminacy of evaluations. This paper proposes an integrated model for lean and sustainable supplier selection. IVN-ANP is regarded as a suitable method to weight the criteria because of its flexibility. Initially, IVN-ANP is applied to determine the criteria weights. Afterwards, IVN-TODIM is applied to rank the alternative suppliers. Eventually, an application is presented for the validation and detailed analysis of the proposed method. In further studies, Neutrosophic DEMATEL can be used to show the relationship between criteria and to eliminate the non-effective ones.

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