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Lean Supplier Selection based on Hybrid MCGDM Approach using Interval Valued Neutrosophic Sets: A Case Study

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Abstract:
In any manufacturing industry 60% - 70% of total cost of product pertains raw materials cost. Therefore selection of raw material supplier is very significant factor to improve quality of product as well as reducing total cost. Supplier selection considers various factors and numerous alternatives. However it is conflicting multi criteria decision making problem having various choices. The proposed multi criteria group decision making problem paves selection of best supplier among available. Linguistic variable associate with Interval Valued Neutrosophic Sets (IVNS) are used to derive criteria weights with aid of Analytical Hierarchy Process (AHP). Technique for Order Preference Similar to Ideal Solution (TOPSIS) ranks best supplier, Functions of IVNS distances and similarity measures performed in the present work.

Keywords: *AHP, Interval Neutrosophic Values, MCGDM, Supplier, TOPSIS.*

1. Introduction

Recent competitive global markets are customers centered. Customer oriented products need to be more customized, higher quality subsequently lower in cost. The final product must satisfy customer needs as well as achieve organizational goals like profitability and market expansion etc., Based on raw material and production process quality of product can be improved consequently reduce cost of product. In process of acquiring raw material several suppliers are evaluated to find best lean supplier. Evaluation process includes multiple criteria and innumerable alternatives. Hence, supplier selection is conflicting multi criteria problem [1, 2]. Multi criteria decision making (MCDM) methods have been chosen for accurate results comparatively [1, 2]. Group of decision makers involved in selection of supplier can term as Multi Criteria Group Decision Making (MCGDM) process. Here, Decision Makers has platform for evaluating lean supplier through experiences, reviews and feedbacks.

In process of evaluating MCDM problem decision maker's subjective information interpreted into quantitative data. Crisp values can induce imprecision and confusion to the decision makers resulting inaccurate results. To reduce fuzziness and vagueness of subjective information Zadeh proposed Fuzzy Set (FS) theory [3] and the decision making methods have developed by Bellman and Zadeh using fuzzy theory [4]. Subsequent research had been conducted to reduce uncertainty in decision maker's opinion under fuzzy environment. Different types of MCDM approaches are used to evaluate best supplier using fuzzy information for instance Fuzzy AHP [4a, 4b, 4c], Fuzzy TOPSIS[5], Fuzzy PROMTHEE, Fuzzy VIKOR [6], Fuzzy ANP [7] and some of integrated techniques were proposed [8, 9,10].Fuzzy set theory was more supportive when supplier selection involves uncertain and imprecise human judgments.

However, the fuzzy set theory can't define false function which is rejection mapping value of corresponding alternative characterized by criteria [11]it only expresses truth value of decision maker's. Later, Atanassov [12] proposed Intuition Single Value Fuzzy Numbers (ISVFN) which can represent truth function as well as false function of decision maker's expression. Atanassov and Gargove extend intuition single value set to Interval Valued Intuition Fuzzy Numbers (IVIFN) [13] in terms of truth and false membership functions. But it is unable to define indeterminate function expressively; the indeterminate value is rest of truth and false functions value. The ISVFN and IVIFN are unable to represent indeterminate and inconsistence data of decision maker's information clearly. Samaranache [14, 15] generalizes FS, ISVFN and IVIFN so on, proposed a Neutrosophic Set (NS) which can represent truth function, false function and indeterminate functions which are independent.

In recent days NS grasped researcher's attention. From scientific or engineering point of view Wang [16] develop Single Valued Neutrosophic Sets (SVNS). Ye [17] gave some basic correlation operators and cross entropy for SVNS to solve MCDM problems. Wang [18] extends SVNS to Interval Valued Neutrosophic Sets (IVNS) which represents truth membership, indeterminacy membership, and false membership functions in terms of interval values and gave some basic operators and comparing methods. Ye [19] develops MCDM problem based on similarity measures, Hamming distances and Euclidean distances for IVN numbers.
The proposed work carried out by hybridizing MCDM techniques such as Analytical Hierarchy Process (AHP) best suited for deriving weights based on relative prioritizing criteria and Technique for Order Preference Similar to Ideal Solution (TOPSIS) recommended approach for ranking the alternatives [24] and group of decision makers. AHP used to derive criteria weights by applying Geometric aggregation operators which is more sensitive towards individual opinions [20] and score function [21], TOPSIS gives ranks of supplier using Euclidean distances and similarity measures[22].
The remaining paper is arranged as follows. Section 2 gives basic theories of INVS. In Section 3 propose methodology is discussed. Section 4 defines MCDM Lean Supplier problem and evaluation of problem by proposed method as a case study. Conclusion is given in Section 5.

2. Briefing Interval Valued Neutrosophic Set Theories

2.1. Interval Neutrosophic Sets (INS) [18]
The real scientific and engineering applications can be expressed as INS values.
Let X be a space of points (objects) and Int [0,1] be the set of all closed subsets of [0,1]. An INS $\tilde{A}$ in X is defined with the form $\tilde{A}=\{\langle x, u_{\tilde{A}}(x), w_{\tilde{A}}(x), v_{\tilde{A}}(x)\rangle : x\in X\}$
Where $u_{\tilde{A}}(x):X\to\text{int}[0,1]$, $w_{\tilde{A}}(x):X\to\text{int}[0,1]$ and $v_{\tilde{A}}(x):X\to\text{int}[0,1]$ with $0\le\sup u_{\tilde{A}}(x)+\sup w_{\tilde{A}}(x)+\sup v_{\tilde{A}}(x)\le 3$ for all $x\in X$. The intervals $u_{\tilde{A}}(x)$, $w_{\tilde{A}}(x)$ and $v_{\tilde{A}}(x)$ denote the truth membership degree, the indeterminacy membership degree and the falsity membership degree of x to $\tilde{A}$, respectively.
For convenience, if let $u_{\tilde{A}}(x) = [u_{\tilde{A}}^-(x), u_{\tilde{A}}^{+(}x)]$, $w_{\tilde{A}}(x) = [w_{\tilde{A}}^-(x), w_{\tilde{A}}+(x)]$ and $v_{\tilde{A}}(x) = [v_{\tilde{A}}-(x), v_{\tilde{A}}+(x)]$, then $\tilde{A}=\{\langle x, [u_{\tilde{A}}-(x),u_{\tilde{A}}+(x)], [w_{\tilde{A}}-(x),w_{\tilde{A}}+(x)], [v_{\tilde{A}}-(x),v_{\tilde{A}}+(x)]\rangle : x\in X\}$ with the condition, $0\le\sup u_{\tilde{A}}+(x)+\sup w_{\tilde{A}}+(x)+\sup v_{\tilde{A}}+(x)\le 3$ for all $x\in X$. Here, we only consider the sub-unitary interval of [0,1]. Therefore, an INS is clearly neutrosophic set.

2.2. Compliment of INS [19]
The complement of an INS $\tilde{A}$ is denoted by $\tilde{A}^c$ and is defined as $u_{\tilde{A}}{}^c(x) = v(x)$, $(w_{\tilde{A}}-)^c(x)=1-w_{\tilde{A}}^+(x)$, $(w_{\tilde{A}}^+)^c(x)=1-w_{\tilde{A}}^-(x)$ and $v_{\tilde{A}}{}^c(x)=u(x)$ for all $x\in X$. That is, $\tilde{A}^c=\{\langle x,[v_{\tilde{A}}^-(x),v_{\tilde{A}}^+(x)],[1-w_{\tilde{A}}^+(x),1-w_{\tilde{A}}^-(x)],[u_{\tilde{A}}^-(x),u_{\tilde{A}}^+(x)]\rangle : x\in X\}$.

2.3. INS Subsets [19]
An interval neutrosophic set $\tilde{A}$ is contained in the other INS $\tilde{B}$, $\tilde{A}\subseteq\tilde{B}$, if $u_{\tilde{A}}-(x)\le u_B-(x)$,
$u_{\tilde{A}}+(x)\le u_B+(x)$, $w_{\tilde{A}}-(x)\ge w_B-(x)$, $w_{\tilde{A}}+(x)\ge w_B+(x)$ and $v_{\tilde{A}}-(x)\ge v_B-(x)$, $v_{\tilde{A}}+(x)\ge v_B+(x)$ for all $x\in X$.

2.4. INS Equality [19]
Two INSs $\tilde{A}$ and B are equal, can be written as $\tilde{A}=\tilde{B}$, if $\tilde{A}\subseteq\tilde{B}$ and $\tilde{B}\subseteq\tilde{A}$.

2.5. Arithmetic Weighted Average Operator for INS [20]
Let $\tilde{A}_k$ (k=1,2,…,n) ∈ INS(X). The interval neutrosophic weighted average operator is defined by $F_\omega=(\tilde{A}_1,\tilde{}_2,\dots,\tilde{A}_n)=\sum_{k=1}^{n} w_k\, A_k=1$

$$=\begin{pmatrix} \left[1-\prod_{k=1}^{n}\left(1-u^-{}_{\tilde{A}_k}(x)\right)^{w_k}, 1-\prod_{k=1}^{n}\left(1-u^+{}_{\tilde{A}_k}(x)\right)^{w_k}\right], \\ \left[\prod_{k=1}^{n}\left(w^-{}_{A_k}(x)\right)^{w_k}, \prod_{k=1}^{n}\left(w^+{}_{A_k}(x)\right)^{w_k}\right], \\ \left[\prod_{k=1}^{n}\left(v^-{}_{A_k}(x)\right)^{w_k}, \prod_{k=1}^{n}\left(v^+{}_{A_k}(x)\right)^{w_k}\right] \end{pmatrix} \quad \text{(Equation: 1)}$$

Where ω_k is the weight of $\tilde{A}_k$ (k=1,2,…,n), $\omega_k\in[0,1]$ and $\sum_{k=1}^{n} w_k = 1$. Principally, assume $\omega_k=1/n$ (k=1,2,…,n), then F_ω is called an arithmetic average operator for INSs.

2.6. Geometric Weighted Average Operator for INS [20]
Let $\tilde{A}_k$ (k=1,2,…,n) ∈ INS(X). The interval neutrosophic weighted geometric average operator is defined by $G_\omega=(\tilde{A}1,\tilde{A}2,\dots,\tilde{}n)=\prod_{k=1}^{n} A_k^{w_k}$

$$=\begin{pmatrix} \left[\prod_{k=1}^{n}\left(u^-{}_{\tilde{A}_k}(x)\right)^{w_k}, \prod_{k=1}^{n}\left(u^+{}_{\tilde{A}_k}(x)\right)^{w_k}\right], \\ \left[1-\prod_{k=1}^{n}\left(1-w^-{}_{A_k}(x)\right)^{w_k}, 1-\prod_{k=1}^{n}\left(1-w^+{}_{A_k}(x)\right)^{w_k}\right], \\ \left[1-\prod_{k=1}^{n}\left(1-v^-{}_{A_k}(x)\right)^{w_k}, \left(1-\prod_{k=1}^{n}\left(1-v^+{}_{A_k}(x)\right)^{w_k}\right)\right] \end{pmatrix} \quad \text{(Equation: 2)}$$

Where ωk is the weight of $\tilde{A}_k$ (k=1,2,…,n), $\omega_k\in[0,1]$ and $\sum_{k=1}^{n} w_k = 1$. Principally, assume $\omega_k=1/n$ (k=1,2,…,n), then G_ω is called a geometric average for INSs.

The above aggregation operators remain INS values. The emphasis on above definitions 2.5 and 2.6 can be defined as the arithmetic weighted average operator gives group influence and geometric weighted average operator gives individual influence. So, the geometric weighted average (GWA) operator more sensitive comparatively. For this reason the current work is carried out with GWA.

2.7. INS Score Function [21]
Let $\tilde{A}$ = ([a, b], [c, d], [e, f]) be an interval valued neutrosophic number, a score function L of an interval valued neutrosophic value, based on the truth-membership degree, indeterminacy membership degree and falsity membership degree is defined by

$$(\tilde{A}) = \frac{2+a+b-2c-2d-e-f}{4} \quad \text{(Equation: 3)}$$

where $L(\tilde{A}) \in [-1,1]$.

2.8. INS Accuracy Function [21]
Let A = ([a, b], [c, d], [e, f]) be an interval valued neutrosophic number. Then an accuracy function N of an interval neutrosophic value, based on the truth membership degree, indeterminacy membership degree and falsity membership degree is defined by

$$(\tilde{A})=1/2(a+b-(1-b)-c(1-a)-f(1-c)-e(1-d)) \quad \text{(Equation: 4)}$$

where $L(\tilde{A}) \in [-1,1]$.

2.9. INS Ranking [21]
Suppose that $\tilde{A}_1$ = ([a_1, b_1], [c_1, d_1], [e_1, f_1]) and $\tilde{A}_2$ = ([a_2, b_2], [c_2, d_2], [e_2, f_2]) are two interval valued neutrosophic sets Then we define the ranking method as follows:
(i) If L ($\tilde{A}_1$) > L ($\tilde{A}_2$), then $\tilde{A}_1$>$\tilde{A}_2$.
(ii) If L ($\tilde{A}_1$) = L ($\tilde{A}_2$) and N ($\tilde{A}1$) > N ($\tilde{A}2$), then $\tilde{A}_1$>$\tilde{A}_2$.

2.10. INS Distance Measuring Functions[23]
Let $x = ([T_1^L, T_1^U], [I_1^L, I_1^U], [F_1^L, F_1^U])$, and
$y = ([T_2^L, T_2^U], [I_2^L, I_2^U], [F_2^L, F_2^U])$ be two INVs, then
(1) The Hamming distance between x and y is defined as follows

$$d_H(x,y) = \frac{1}{6}(|T_1^L - T_2^L| + |T_1^U - T_2^U| + |I_1^L - I_2^L| + |I_1^U - I_2^U| + |F_1^L - F_2^L| + |F_1^U - F_2^U|) \quad \text{(Equation: 5)}$$

(2) The Euclidian distance between x and is defined as follows.

$$d_E(x,y) = \sqrt{\frac{1}{6}\begin{pmatrix}(T_1^L - T_2^L)^2 + (T_1^U - T_2^U)^2 + (I_1^L - I_2^L)^2 + \\ (I_1^U - I_2^U)^2 + (F_1^L - F_2^L)^2 + (F_1^U - F_2^U)^2\end{pmatrix}} \quad \text{(Equation: 6)}$$

3. Proposed Methodology
- Step 1: Define a Multi Criteria Group Decision Making Lean supplier selection problem.
- Step 2: Obtain relative prioritized Criteria matrix from each decision maker.
- Step 3: Use IVNS GWA (Equation: 2) operator to aggregate each decision matrix from all decision maker into an aggregate decision matrix
- Step 4: Derive weights of criteria aid of score function (Equation:3) after row aggregation.
- Step 5: Establish Criteria-Alternative group decision matrix using predefined attributes of IVNS values
- Step 6: Find the relative Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS) for each criterion column.
- Step 7: Measure Euclidean distances (Equation: 6) of each alternative deviated from PIS and NIS.
- Step 8: Rank the alternatives based on Closeness Coefficient (CC) values. Lower the CC value higher will be the rank

4. Case Study
- Step: 1

In order to reduce cost, improve quality of final product and eradicate rejections, the raw material procurement and production process plays a key role in any manufacturing firm. Raw material procurement can takes plays in several stages such as identify, evaluate and contract with supplier. Frequent procurement of raw material reflects financial stability of the firm. Moreover it takes additional time to process and receiving the material. Therefore selection of lean supplier is a critical task for manufacturing industry. Lean supplier is one who should promise material quality and lowest cost products which are input material to manufacturing firm by continuous improvement of material value and offer services over appropriate period. As well asLean supplier should able to meet dynamic demands of customer. Selection of Lean supplier is a complex multi criterion decision making problem to choose among various suppliers.
After reviewing the literature and considering practical exposure in current manufacturing industry.
The criteria for selecting Lean Supplier is: {C1, C2, C3, C4, C5}
→ C1. Quality

→ C2. Cost
→ C3. Lead time
→ C4. Serviceability
→ C5. Payment Terms

Decision Maker involved in selection process includes {DM1, DM2, and DM3}

→ DM1. Material Department Head
→ DM2. Finance and Commercial Head
→ DM3. Operational Head

The choices are taken after screening and given as generalized way as follows: {A1, A2, A3, A4, A5}

→ A1. Imports
→ A2. Original Equipment Manufacturers (OEM)
→ A3. Dealers
→ A4. Developers
→ A5. E-Commerce

Very Low (VL)	([0.1,0.2], [0.4,0.5], [0.5,0.6])
Low (L)	([0.3,0.4], [0.3,0.4], [0.2,0.3])
Below Average(BA)	([0.3,0.4], [0.2,0.3], [0.3,0.4])
Average (A)	([0.4,0.5], [0.2,0.3], [0.2,0.3])
Above Average (AA)	([0.4,0.5], [0.1,0.2], [0.2,0.3])
Good (G)	([0.5,0.6], [0.1,0.2], [0.1,0.2])
Very Good (VG)	([0.6,0.7], [0.1,0.2], [0.0,0.1])
Excellent (E)	([0.7,0.8], [0.0,0.1], [0.0,0.1])

Table 1: Predefined Linguistic Variables associated with Interval Valued Neutorsophic Sets

Note: The case study evaluated by proposed methodology is simulated using **MATLAB** software

- Step: 2

Criteria	DM1	DM2	DM3
Quality	G	G	E
Cost	VG	E	G
Lead Time	E	E	AA
Serviceability	VG	AA	G
Payment Terms	E	G	VG

Table 2: Relative prioritized criteria matrix of decision makers

- Step: 3

Quality	([0.5944 0.6952] [0.0678 0.1680] [0.0345 0.1347])
Cost	([0.5518 0.6542] [0.0678 0.1680] [0.0717 0.1723])
Lead Time	([0.5518 0.6542] [0.1037 0.2042] [0.0717 0.1723])
Serviceability	([0.4579 0.5593] [0.1347 0.2348] [0.1382 0.2388])
Payment Terms	([0.5518 0.6542] [0.1037 0.2042] [0.0717 0.1723])

Table 3: Aggregated Criteria matrix

- Step: 4

Criteria	Score	Weights
Quality	0.7042	0.2216
Cost	0.6646	0.2091
Lead Time	0.6376	0.2006
Serviceability	0.534	0.168
Payment Terms	0.6376	0.2006

Table 4: Score and Weights of each criterion

- Step: 5

Alternatives	Quality			Cost			Lead Time			Serviceability			Payment Terms		
DM's	**DM1**	**DM2**	**DM3**	**DM1**	**DM2**	**DM3**	**DM1**	**DM2**	**DM3**	**DM1**	**DM2**	**DM3**	**DM1**	**DM2**	**DM3**
Imports	VG	G	E	VG	A	L	L	A	BA	A	BA	G	L	A	L
OEMS	E	E	E	L	G	A	A	G	E	E	E	E	BA	G	AA
Dealers	G	L	A	AA	VG	AA	VG	G	VG	VL	G	BA	VG	E	G
Developers	A	VL	A	VG	E	E	G	AA	G	BA	VG	VG	E	L	VG
E-Commerce	AA	AA	BA	G	G	VG	E	VG	VG	VL	A	L	G	VG	G

Table 5: Criteria-Alternative group decision matrix

- Step: 6

For instance first column Positive and Negative Ideal solutions are given.
Positive Ideal Solution (PIS): For all j $\{[\max(a_{ij})\ \max(b_{ij})]\ [\min(c_{ij})\ \min(d_{ij})]\ [\min(e_{ij})\ \min(f_{ij})]\}$
([0.2342 0.3000] [0 0.6004] [0 0.6004])
Negative Ideal Solution (NIS): For all j $\{[\min(a_{ij})\ \min(b_{ij})]\ [\max(c_{ij})\ \max(d_{ij})]\ [\max(e_{ij})\ \max(f_{ij})]\}$
([0.0623 0.0968] [0.7501 0.7848] [0.7747 0.8247])

- Step: 7: Euclidean distances: Derived from Equation 6 (First column only)

S1	0.3008
S2	0
S3	0.4151
S4	0.4687
S5	0.4154

Table 6: Euclidean Distance from PIS

S1	0.1863
S2	0.4687
S3	0.0626
S4	0
S5	0.0599

Table 7: Euclidean Distance from NIS

- Step: 8 Ranking of alternatives is based on ratio of closeness coefficient $Rcc_i = d_i^+ / d_i^+ - d_i^-$ (Equation: 7)

Rank order	RCCI
S1	0.8568
S3	0.7767
S4	0.6957
S5	0.6773
S2	0.3889

Table 8

5. Conclusion

To select a suitable supplier is critical and key strategy for organization to accomplish goals as well as withstand global competition. Evaluation of appropriate supplier is a multi-criteria group decision making process that involves various alternatives. Therefore, this paper proposed a new hybrid method which combines AHP and TOPSIS to find best supplier suited for present practical scenario. IVNS associate with Linguistic Variables are used to derive criteria weights with AHP. Here decision maker has own choice of prioritizing criteria instead of deviational weights and TOPSIS ranks the alternatives with aid of aggregation operator and similarity measures.

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