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Real Life Decision Optimization Model

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Abstract: In real life scientific and engineering problems decision making is common practice. Decision making include single decision maker or group of decision makers. Decision maker's expressions consists imprecise, inconsistent and indeterminate information. Also, the decision maker cannot select the best solution in unidirectional (single goal) way. Therefore, proposed model adopts decision makers' opinions in Neutrosophic Values (SVNS/INV) which effectively deals imprecise, inconsistent and indeterminate information, Multi goal (criteria) decision making and creditability (due to partial knowledge of decision maker) associated decision makers' expressions. Then partially known or unknown priorities (weights) of Multi Criteria Group Decision Making (MCGDM) problem is determined by establishing Correlation Coefficient (CC) established from improved cross entropy linear programming technique. The Multi Goal Linear equation was solved using a Novel Self Adaptive Harmonic Search Algorithm. The (NSAH) alternate solutions were ranked by weighted correlation coefficients of each alternative (lower the CC higher will be the rank). The validation of proposed method was demonstrated with an illustrative examples and compare with recent advancements. Hence, the proposed method was effective, flexible and accurate.

Keywords: MCGDM, Creditability, Improved Cross Entropy, Correlational Coefficient, and NSAH.

1 Introduction

In process of decision making real life scientific and engineering problems includes conflicting, non-commensurable, multi criteria and innumerable alternatives. The input information of decision making problem may involve decision maker's qualitative information and actual quantitative information. Hence, Multi Criteria Decision Making **(MCDM)** is a strategy of evaluating practical complex problems based on various qualitative or quantitative criteria in certain or uncertain environments to recommend best choice among various alternatives. Several comparative studies **[1]** have been taken to demonstrate its vast applicability **[2, 3, 4].** Briefing MCDM methods **[5]** will give clear understanding over techniques available **[6]** and benefits **[1].** More than one decision maker comprise in decision making process stated as Multi Criteria Group Decision Making **(MCGDM).**

In evaluation process MCDM had undergone quantification of decision makers' subjective information. Fundamental stages MCDM uses crisp information to represent decision makers' opinions. Crisp values can induce imprecision and confusion to the decision makers resulting inaccurate results. Real world decision making conflicting, inconsistent, indeterminate information cannot be expressed in terms of crisp values. To reduce fuzziness and vagueness of subjective information Zadeh **[7]** proposed Fuzzy Set **(FS)** theory and the decision making methods have developed by Bellman and Zadeh **[8]** using fuzzy theory. Subsequent research had been conducted to reduce uncertainty in decision maker's opinion under fuzzy environment.

F. Smarandache **[8]** represents truth function which describes decision maker acceptance value to alternative categorized by an attribute. But the constraint lies, it doesn't represent false (rejection value) function. Therefore, Atanassov introduce Intuitionistic Fuzzy Sets **(IFS)** **[9, 10]** which can represent truth membership function T(x) as well as falsity membership function F(x), they satisfy the condition $T(x), F(x) \in [0,1]$ and $0 \le T(x) + F(x) \le 1$. In IFS the indeterminate function is rest of truth and false functions $1-T(x) - F(x)$, here indeterminate and inconsistence functions are not clearly defined.

Smarandache [11] generalized FS, IFS, and Interval Valued Intuitionistic Fuzzy Set **(IVIFS)** **[10]** so on as Neutrosophic Set **(NS)** by adding indeterminate information. In NS the truth membership, indeterminacy membership, false membership functions are completely independent. Recently, NS became interesting area for researcher in decision making which can express supporting, nondeterministic, rejection values in terms of NS Values. Wang **[13]** propose Single Valued Neutrosophic Sets (SVNS) and Ye **[14]** gives correlation coefficient and weighted correlation coefficient in SVNS similar to IVIFS. Wang **[15]** proposed Interval Neutrosophic Sets (INS) in which the truth memberships, indeterminacy membership, false membership functions were extended to interval values. Ye **[16]** given similarity measures between INSs based on hamming and Euclidean distances and demonstrate with a MCDM problem.

Ye [18] developed a simplified neutrosophic weighted arithmetic averaging (SNWAA) operator, a simplified neutrosophic weighted geometric averaging (SNWGA) operator and applied to multiple attribute decision making under simplified neutrosophic environment. **Tian et al (2015) [19]** proposed a simplified neutrosophic linguistic normalized weighted Bonferroni mean operator (SNNWB) and constructed a multi criteria decision-making model based on SNNWB. But, the current aggregation operators for SVNNs and INNs ignore the knowledge background of the decision maker and his corresponding credibility on every evaluation value of SVNNs/INNs for each attributes.

Inspired by this idea **Jun Ye (2015) [20]** put forward a concept of Credibility-Induced Interval Neutrosophic Weighted Arithmetic Averaging (CIINWAA) operator and a Credibility-Induced Interval Neutrosophic Weighted Geometric Averaging (CIINWGA) operator by taking the importance of attribute weights and the credibility of the evaluation values of attributes into account. He also applied CIINWAA and CIINWGA to MCGDM problem; ranking of alternatives are based on INNs projection measures under creditability information.

Ye [22] reviewed evolution of cross entropy and its applicability in scientific and engineering applications. He proposed Improved cross entropy measures for SVNS and INS by overcome drawbacks (fail to fulfill the symmetric property) of cross entropy measures proposed by **Ye [21]**. Also he developed MCDM model based on improved cross entropy measures for SVNS and INS by taking advantage of ability of producing accurate results and minimizing information loss.

Jun Ye [23] presents correlational coefficients and weighted correlational coefficients of SVNS. He also introduced cosine similarity measure for SVNS. **Surapati et al [24]** proposed TOPSIS for single valued neutrosophic sets to solve multi criteria decision making problem which has unknown attribute weights and group of decision makers. The unknown weights of attributes derived from maximizing deviation method and rating of alternatives based on TOPSIS with imprecise and indeterminate information. **Said Broumi et al [25]** proposed extended TOPSIS using interval neutrosophic linguistic information for multi attribute decision making problems in which attribute weights are unknown.

Pranab Biswas et al (2016) [26] defined Triangular Fuzzy Number Neutrosophic Sets (TFNNS) by combining Triangular Fuzzy Numbers (TFN) and Single Valued Neutrosophic Sets (SVNS). He also proposed its operational rules based on TFN, SVNS and aggregation operators for TFNNS by extending Single Valued Neutrosophic Weighted Arithmetic (SVNWA) and Single Valued Neutrosophic Weighted Geometric (SVNWG) operators. Then, he developed MADM model based on TFNNS aggregation operators, score and accuracy functions. He also **[27]** introduced Single Valued Trapezoidal Neutrosophic Numbers (SVTrNN) and their operational rules, cut sets. The neutrosophic trapezoidal numbers express the truth function (T), indeterminate function (I) and false function (F) independently. He presents cosine similarity measures based multi criteria decision making method using trapezoidal fuzzy nutrosophic sets (TFNS). The ranking method is proposed after defining value and ambiguity indices of truth, false, indeterminate membership functions. The validity and applicability is shown by illustrative tablet selection problem. He also **[28]** proposed cosine similarity measures between two trapezoidal neutrosophic sets and its properties.

Jun Ye [29] introduced simplified neutrosophic harmonic averaging projection measures for multi criteria decision making problems. Projection measures are very suitable tool for dealing MCDM problems because it considers not only distance between alternatives but also its direction. The projection measures have extended flexibility of handling various types of information for instance **[30, 31]** uncertain and fuzzy based projection measures applied in multi attribute decision making. Ye observed drawbacks of general projection measures and proposed bidirectional projection measures **[32]** by overcoming shortcomings of general projection measures. He extends the applications of bidirectional projection measures in complex group decision making under neutrosophic environment.

Surapati and Kalyan [33] defined Accumulated Arithmetic Operator (AAO) to transform interval neutrosophic set to single valued neutrosophic sets. He also extended single valued Gray Relation Analysis (GRA) to interval valued numbers in multi criteria decision making. Then he proposed entropy based GRA for unknown attributes in MCDM problems under INN environment. **Rıdvan Şahin [34]** proposed two transformation methods for interval neutrosophic values to fuzzy sets and single valued neutrosophic sets. He developed two methodologies based on extended cross entropy to MCDM problems using interval valued numbers. But the transformation of INN to SVNS may results inaccurate outcomes.

Kalyan and Surapati [35] present quality bricks selection based on multi criteria decision making with single valued neutrosophic grey relational analysis. The weights of attributes are determined using experts opinions. Ranking is based on gray relation coefficient that derived from hamming distance between alternative to ideal neutrosophic estimate reliable solution and ideal neutrosophic estimates unreliable solution then neutrosophic relational degree used to select the quality brick. **Jun Ye [36]** proposed exponential similarity measures between two neutrosophic numbers. The advantages of exponential measures are that indicates stronger discrimination and higher sensitivity with respect than cosine similarity measure of neutrosophic numbers. He applied exponential similarity measures to the vibration fault diagnosis of steam turbine under indeterminate information. The proposed method not only analysis fault type but also predicts fault trends based on relation indices.

Tian et al (2016) [37] extends uncertain linguistic variable and simplified neutrosophic sets to simplified neutrosophic uncertain linguistic sets which integrates qualitative as well as quantitative evaluation. It reflects decision maker's expressions having inconsistence, incompleteness, indeterminate information. After reviewing relevant literature he developed Generalized Simplified Neutrosophic Uncertain Linguistic Prioritized Weighted Aggregation (GSNULPWA) operators and applied to solving MCDM problems.

Bipolarity refers to the propensity of the human mind to reason and make decisions on the basis of positive and negative effects**. Irfan Deli et al [38]** introduced bipolar sets which is the extension of fuzzy sets, bipolar fuzzy sets, intuitionistic fuzzy sets, neutrosophic sets. He also developed the Bipolar Neutrosophic Weighted Average (BNWA) Operators and Bipolar Neutrosophic Weighted Geometric (BNWG) operators to aggregate the bipolar neutrosophic information. Then he proposed multi criteria decision making model using bipolar neutrosophic sets and its operators of certainty, score and accuracy functions.

Roy and Dos [39] developed neutrosophic based linear goal programming and lexicographic goal programming for multi objective linear programming (MOLP) problem. He describes evolution of neutrosophic theory and its operations in linear programming models. He also proposed two models for MOLP, applied to bank there investment problem by varying the weights. **Feng Li (2011) [40]** reduced process complexity and computation time after developing the closeness coefficient based non-linear programming model for MCDM problem. The nonlinear equation based on closeness coefficient applied to searching algorithm to obtain attribute weights and the ranking of alternatives estimated based on optimal membership degrees. The proposed methodology validated with real example and demonstrates its applicability.

Tian et al (2015) [41] put forward the concept of multi criteria decision making based on cross entropy under interval neutrosophic sets. The INS values are transformed to SVNS for ease of calculations and formulated a linear equation for deriving weights of attributes. These two linear equations are constructed from decision maker's indeterminate and inconsistent information.

Then the linear programming techniques are used to determine weights of attributes here constraints established by partially known indeterminate weights. After obtaining attribute weights possibility degree method ranked the alternatives.

After rigorous investigation on literature and research gap analysis the proposed model considered performance factors such as it should adopt practical/ real world problems, flexible to operate, accurate in results and effective. Real life decision making includes group of decision makers, their limited knowledge about specific attributes (creditability) and unknown priorities of multi objectives (attributes) to choose best out of existing alternatives.

Therefore considering shortcomings of recent methods we proposed new Multi criteria Group Decision Making Model for unknown attribute weights in continuous space and finite set of alternatives in discrete space in Neutrosophic environment.

The rest of the paper is organized as follows. Section 2 briefly describes some basic concepts of neutrosophic numbers and its operational functions. Section 3 proposes new approaches to solve real world decision making problems under neutrosophic environment. In Section 5, illustrative examples are presented to demonstrate the application of the proposed method, and then the effectiveness and advantages of the proposed methods are demonstrated by the comparative analysis with existing relative methods in sections 6. Finally, Section 7 contains conclusions and applications of present work.

2 Preliminaries

2.1 Single Valued Neutrosophic Sets (SVNS)

Let X be a universe of discourse. A single valued neutrosophic set A over X is an object having the form $A=\{\langle x,\ u_A(x),\ w_A(x),\ v_A(x)\rangle : x\in X\}$where $u_A(x)$: $X\rightarrow[0,1]$, $w_A(x)$:$X\rightarrow[0,1]$ and $v_A(x)$:$X\rightarrow[0,1]$ with $0 \leq u_A(x) + w_A(x) + v_A(x) \leq 3$ for all $x\in X$. The intervals (x), w_A (x) and (x) denote the truth membership degree, the indeterminacy membership degree and the falsity membership degree of x to A, respectively.

2.2 Geometric Weighted Average Operator (GWA) for SVNC

Let A_k (k=1, 2,…, n) ∈ SVNS (X). The single valued neutrosophic weighted geometric average operator is defined by $G_\omega = (A_1, A_2,\ldots, A_n) = \prod_{k=1}^{n} A_k^{w_k}$

$$= \left(\prod_{k=1}^{n}\left(u_{A_k}(x)\right)^{w_k},\quad 1-\prod_{k=1}^{n}\left(1-w_{A_k}(x)\right)^{w_k}, 1-\prod_{k=1}^{n}\left(1-v_{A_k}(x)\right)^{w_k}\right) \quad (2)$$

Where ω_k is the weight of A_k (k=1, 2,…,n), ω_k∈[0,1] and $\sum_{k=1}^{n} w_k = 1$. Principally, assume ω_k=1/n (k=1, 2,…, n), then G_ω is called a geometric average for SVNSs.

2.3 Compliment of SVNS

The complement of an SVNS A is denoted by Ac and is defined as uAc (x) = v (x), wAc (x) = 1−(x), and $vAc(x)$ = uA (x) for all $x \in X$. That is, $Ac = \{\langle x,\ vA\ (x),\ 1-wA\ (x),\ uA\ (x)\ \rangle : x\in X\}$.

2.4 Improved Cross Entropy Measures of SVNS

For any two SVNSs A and B in a universe of discourse X = $\{x_1, x_2,\ldots, x_n\}$. Let weight of each element is w_i, $\omega_i \in [0,1]$ and $\sum_{i=1}^{n} w_i = 1$ then the weighted cross entropy between SVNSs A from B is defined as follows:

$$N_w(A,B)=\sum_{i=1}^{n} w_i \left[\begin{array}{c} \sqrt{\left[\frac{T_A^2(x_i)+T_B^2(x_i)}{2}\right]} - \left(\frac{\sqrt{T_A(x_i)}+\sqrt{T_B(x_i)}}{2}\right)^2 \\ +\sqrt{\left[\frac{I_A^2(x_i)+I_B^2(x_i)}{2}\right]} - \left(\frac{\sqrt{I_A(x_i)}+\sqrt{I_B(x_i)}}{2}\right)^2 \\ +\sqrt{\frac{[1-I_A(x_i)]^2+[1-I_B(x_i)]^2}{2}} \\ -\left(\frac{\sqrt{[1-I_A(x_i)]}+\sqrt{[1-I_B(x_i)]}}{2}\right)^2 \\ +\sqrt{\left[\frac{F_A^2(x_i)+F_B^2(x_i)}{2}\right]} \\ -\left(\frac{\sqrt{F_A(x_i)}+\sqrt{F_B(x_i)}}{2}\right)^2 \end{array}\right]$$

2.5 Interval Valued Neutrosophic Sets (INS)

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]. 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, $0\leq \sup u\tilde{A}(x)+\sup w\tilde{A}(x)+\sup v\tilde{A}\ (x)\leq 3$ for all $x\in X$. Here, we only consider the sub-unitary interval of [0, 1]. Therefore, an INS is clearly neutrosophic set.

2.6 Compliment of INS

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, $\tilde{A}c=\{\langle x,\ [v\tilde{A}-(x),v\tilde{A}+(x)],\ [1-w\tilde{A}+(x),1-w\tilde{A}-(x)],\ [u\tilde{A}-(x),u\tilde{A}+(x)]\rangle : x\in X\}$.

2.7 Geometric Aggregation Operator for INS

Let $\tilde{A}k$ (k=1,2,…,n) ∈ INS(X). The interval neutrosophic weighted geometric average operator is defined by $G\omega=(\tilde{A}1,\tilde{A}2,\ldots,\tilde{A}n) = \prod_{k=1}^{n} A_k^{w_k}$

$$\left(\begin{array}{c} \left[\prod_{k=1}^{n}\left(u^-{}_{\tilde{A}_k}(x)\right)^{w_k}, \prod_{k=1}^{n}\left(u^+{}_{\tilde{A}_k}(x)\right)^{w_k}\right], \\ \left[1-\prod_{k=1}^{n}\left(1-w^-{}_{A_k}(x)\right)^{w_k}, 1-\prod_{k=1}^{n}\left(1-w^+{}_{A_k}(x)\right)^{w_k}\right], \\ \left[1-\prod_{k=1}^{n}\left(1-v^-{}_{A_k}(x)\right)^{w_k},\quad \left(1-\prod_{k=1}^{n}\left(1-v^+{}_{A_k}(x)\right)^{w_k}\right)\right] \end{array}\right) \quad (4)$$

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 ωk=1/n (k=1,2,…,n), then $G\omega$ is called a geometric average for INSs.

2.8 Improved Cross Entropy Measures of INS

For any two SVNSs A and B in a universe of discourse X = {x1, x2,⋯, xn}. Let weight of each element is wi, $\omega i \in [0,1]$ and Σ_(i=1)^n w_i =1 then the weighted cross entropy between SVNSs A from B is defined as follows:

$$M(A,B)= \frac{1}{2}\left\{\sum_{i=1}^{n} w_i \left[\sqrt{\left[\frac{infT_A^2(x_i)+infT_B^2(x_i)}{2}\right]} - \left(\frac{\sqrt{infT_A(x_i)}+\sqrt{infT_B(x_i)}}{2}\right)^2 + \sqrt{\left[\frac{infI_A^2(x_i)+infI_B^2(x_i)}{2}\right]} - \left(\frac{\sqrt{infI_A(x_i)}+\sqrt{infI_B(x_i)}}{2}\right)^2 + \sqrt{\frac{[1-infI_A(x_i)]^2+[1-infI_B(x_i)]^2}{2}} - \left(\frac{\sqrt{[1-infI_A(x_i)]}+\sqrt{[1-infI_B(x_i)]}}{2}\right)^2 + \sqrt{\left[\frac{infF_A^2(x_i)+infF_B^2(x_i)}{2}\right]} - \left(\frac{\sqrt{infF_A(x_i)}+\sqrt{infF_B(x_i)}}{2}\right)^2\right] + \sum_{i=1}^{n} w_i \left[\sqrt{\left[\frac{supT_A^2(x_i)+supT_B^2(x_i)}{2}\right]} - \left(\frac{\sqrt{supT_A(x_i)}+\sqrt{supT_B(x_i)}}{2}\right)^2 + \sqrt{\left[\frac{supI_A^2(x_i)+supI_B^2(x_i)}{2}\right]} - \left(\frac{\sqrt{supI_A(x_i)}+\sqrt{supI_B(x_i)}}{2}\right)^2 + \sqrt{\frac{[1-supI_A(x_i)]^2+[1-supI_B(x_i)]^2}{2}} - \left(\frac{\sqrt{[1-supI_A(x_i)]}+\sqrt{[1-supI_B(x_i)]}}{2}\right)^2 + \sqrt{\left[\frac{supF_A^2(x_i)+supF_B^2(x_i)}{2}\right]} - \left(\frac{\sqrt{supF_A(x_i)}+\sqrt{supF_B(x_i)}}{2}\right)^2\right]\right\}$$

3 Proposed Methodology

In real life problems decision makers' expressions are inconsistence, indeterminate, incomplete. The Neutrosophic sets are most popular in dealing with such a vague and imprecise decision makers' opinions. The decision maker is not always aware of all the attributes in complex decision making problems. So, the results tend to unreasonable or incredible if the evaluations of the decision maker for all the attributes imply the same credibility.

Therefore, the credibility of the attribute evaluations given by the decision maker in the aggregation process of the attribute values should consider to avoiding the unreasonable or incredible judgments in decision making. In reality, decision making is multi-dimensional (Multi Goal) and prioritized goals are considered for evaluations.

The unknown priorities (weights) of goals (attributes) are determined by constructing Multi Goal Linear Programming (MGLP). While construction MGLP [46, 47] adopts maximizing deviation method and weighted distance methods. Some limitations observed as complexity in calculations, improper results due to distance measures which are not effective for discriminating any two NS and MGLP is solved using trade off/ heuristic techniques these focused on local optima implies inaccurate results. Then ranking of alternatives using score and accuracy or distance measures from PIS may loss valid information or produces indefinite outcomes.

Therefore the proposed method is developed by overcoming shortcomings of recent models and designed for real world problems focused on performance factors such as accuracy, flexibility and effectiveness. The proposed MCGDM problem solving procedure described as follows.

In a multiple attribute group decision-making problem with neutrosophic numbers, let S = {S1, S2… Sm} be a set of alternatives, Ai = {A1, A2… Am} be a set of attributes, and Dk = {D1, D2… Ds} be a set of decision makers or experts. The weight vector of attributes is Wj = (w1, w2,…, wn) with $wj \in [0, 1]$ and ∑_(j=1)^n 〖w_j=1〗 the creditability weight vector of Decision makers is λ = {λ1, λ2, . . . , λs}.with with λ k∈ [0, 1] and ∑_(k=1)^s 〖λ_k=1〗 .

Step: 1 Obtain decision matrices D_s from each decision maker. Decision makers' expressions of each alternative to corresponding attributes represented in SVNS/INS.

Step: 2 Establish grouped decision matrix D_ij by aggregating individual decision matrices using Equation 2 in case of SVNS or Equation 7 in case of INS values.

Step: 3 Normalize group decision matrix (r_ij) if required (contains cost & benefit attributes) using Equation 3 for SVNS or Equation 6 for INS values.

Step: 4 Construct Multi Goal Linear Programming using min ∑_(i=1)^m∑_(j=1)^n 〖(d^+ (r_ij,r^+))/(d^+ (r_ij, r^+)+d^- (r_ij,r^-)) w_j 〗 where d^+ (r_ij, r^+) ,d^- (r_ij, r^-) are symmetric discrimination measures of r_ij to r^+ and r^- respectively. Here r^+ is PIS assumed as (1,0,0) and r^- is NIS assumed as (0,1,1)

Step: 5 Determine priorities of goal by solving MGLP applying Novel Self Adaptive Harmonic Search algorithm [46].

Step: 6 Rank the alternatives based on weighted correlational coefficient derived from improved cross entropy i.e.

$$A_i=\sum_{j=1}^{n} \frac{d^+(r_{ij},r^+)}{d^+(r_{ij},r^+)+d^-(r_{ij},r^-)} w_j$$

lower the Ai value higher will be the rank.

4 Illustrative Examples

Example: 1 here, we choose the decision making problem adapted from [47]. An automotive company is desired to select the most appropriate supplier for one of the key elements in its manufacturing process. After preevaluation, four suppliers have remained as alternatives for further evaluation. In order to evaluate alternative suppliers, a committee composed of four decision makers has been formed. The committee selects four attributes to evaluate the alternatives: (1) $C1$: product quality, (2) $C2$: relationship closeness, (3) $C3$: delivery performance and (4) $C4$: price. Suppose that there are four decision makers, denoted by D1, D2, D3, D4, whose corresponding weight vector is λ = (0.25, 0.25, 0.25, 0.25).

Step: 1 Decision matrices of each decision maker

$$D1=\begin{bmatrix} \{0.4,0.2,0.3\} & \{0.4,0.2,0.3\} & \{0.2,0.2,0.5\} & \{0.7,0.2,0.3\} \\ \{0.6,0.1,0.2\} & \{0.6,0.1,0.2\} & \{0.5,0.2,0.3\} & \{0.5,0.1,0.2\} \\ \{0.3,0.2,0.3\} & \{0.5,0.2,0.3\} & \{0.1,0.5,0.2\} & \{0.1,0.4,0.5\} \\ \{0.7,0.2,0.1\} & \{0.6,0.1,0.2\} & \{0.4,0.3,0.2\} & \{0.4,0.5,0.1\} \end{bmatrix}$$

$$D2=\begin{bmatrix} \{0.1,0.3,0.5\} & \{0.5,0.1,0.5\} & \{0.3,0.1,0.6\} & \{0.4,0.1,0.4\} \\ \{0.2,0.5,0.4\} & \{0.3,0.4,0.3\} & \{0.2,0.3,0.1\} & \{0.2,0.3,0.5\} \\ \{0.5,0.2,0.6\} & \{0.2,0.4,0.3\} & \{0.5,0.2,0.5\} & \{0.1,0.5,0.3\} \\ \{0.2,0.4,0.2\} & \{0.1,0.1,0.3\} & \{0.1,0.5,0.4\} & \{0.5,0.3,0.1\} \end{bmatrix}$$

$$D3=\begin{bmatrix} \{0.3,0.2,0.1\} & \{0.3,0.1,0.3\} & \{0.1,0.4,0.5\} & \{0.2,0.3,0.5\} \\ \{0.6,0.1,0.4\} & \{0.6,0.4,0.2\} & \{0.5,0.4,0.1\} & \{0.5,0.2,0.4\} \\ \{0.3,0.3,0.6\} & \{0.4,0.2,0.4\} & \{0.2,0.3,0.2\} & \{0.3,0.5,0.1\} \\ \{0.3,0.6,0.1\} & \{0.5,0.3,0.2\} & \{0.3,0.3,0.6\} & \{0.4,0.3,0.2\} \end{bmatrix}$$

$$D4=\begin{bmatrix} \{0.2,0.2,0.3\} & \{0.3,0.2,0.3\} & \{0.2,0.3,0.5\} & \{0.4,0.2,0.5\} \\ \{0.4,0.1,0.2\} & \{0.6,0.3,0.5\} & \{0.1,0.2,0.2\} & \{0.5,0.1,0.2\} \\ \{0.3,0.5,0.1\} & \{0.2,0.2,0.3\} & \{0.5,0.4,0.3\} & \{0.5,0.3,0.2\} \\ \{0.3,0.1,0.1\} & \{0.2,0.1,0.4\} & \{0.2,0.3,0.2\} & \{0.3,0.1,0.6\} \end{bmatrix}$$

Step: 2 Group Decision Matrix after aggregation with decision maker's creditability

$$\begin{bmatrix} \{0.2213,0.9906,0.9953\} & \{0.3663,0.9790,0.9972\} & \{0.1861,0.9923,0.9995\} & \{0.3869,0.9875,0.9987\} \\ \{0.4120,0.9867,0.9954\} & \{0.5045,0.9952,0.9955\} & \{0.2659,0.9942,0.9835\} & \{0.3976,0.9835,0.9964\} \\ \{0.3409,0.9955,0.9984\} & \{0.2991,0.9926,0.9964\} & \{0.2659,0.9972,0.9955\} & \{0.1968,0.9987,0.9940\} \\ \{0.3350,0.9964,0.9722\} & \{0.2783,0.9782,0.9942\} & \{0.2213,0.9972,0.9973\} & \{0.3936,0.9953,0.9924\} \end{bmatrix}$$

Step: 3 Normalized group decision matrix (criteria 4 is cost type attribute) apply Equation: 3 to step 2 to normalize so that all attributes are in benefit type.

$$\begin{bmatrix} \{0.2213,0.9906,0.9953\} & \{0.3663,0.9790,0.9972\} & \{0.1861,0.9923,0.9995\} & \{0.9987,0.0125,0.3869\} \\ \{0.4120,0.9867,0.9954\} & \{0.5045,0.9952,0.9955\} & \{0.2659,0.9942,0.9835\} & \{0.9964,0.0165,0.3976\} \\ \{0.3409,0.9955,0.9984\} & \{0.2991,0.9926,0.9964\} & \{0.2659,0.9972,0.9955\} & \{0.9964,0.0013,0.1968\} \\ \{0.3350,0.9964,0.9722\} & \{0.2783,0.9782,0.9942\} & \{0.2213,0.9972,0.9973\} & \{0.9924,0.0047,0.3936\} \end{bmatrix}$$

Step: 4 Multi Goal Linear Equation formed as

$\min\ 3.6171\acute{\omega}_1 + 3.5687\acute{\omega}_2 + 3.7290\acute{\omega}_3 + 0.4031\acute{\omega}_4$

Subjected to

Case: 1 completely unknown weights $\sum_{i=1}^{n} w_i = 1$ and $w_j \in [0, 1]$ here j=1, 2, 3, 4

Step: 5 Priorities of attributes obtain after solving MGLP with unknown weights using NSAH are

$w_1 = 0.1996, w_2 = 0.2126, w_3 = 0.3278, w_4 = 0.3587$

Step: 6 Ranking based on weighted correlation coefficients of each alternatives

$$A_i = \sum_{j=1}^{n} \frac{d^+(r_{ij}, r^+)}{d^+(r_{ij}, r^+) + d^-(r_{ij}, r^-)} w_j$$

A1=0.9029

A2=0.8950

A3=0.9337

A4=0.1080

Therefore the ranking of alternative A4 > A2 > A1 > A3 (lower the Ai value higher the rank)

Case: 2 partially known weights from decision makers'

$$0.18 \le w_1 \le 0.20$$
$$0.15 \le w_2 \le 0.25$$
$$0.30 \le w_3 \le 0.35$$
$$0.30 \le w_4 \le 0.40$$
$$\sum_{j=1}^{n} w_j = 1$$

Step: 5 Priorities of attributes obtain after solving MGLP with unknown weights using NSAH are

$w_1 = 0.2291, w_2 = 0.2126, w_3 = 0.1996, w_4 = 0.3587$

Step: 6 Ranking based on weighted correlation coefficients of each alternatives

A1=0.9047

A2=0.8948

A3=0.9333

A4=0.1034

Therefore the ranking of alternative A4 > A2 > A1 > A3 (lower the Ai value higher the rank)

Example: 2 The decision making problem is adapted from [47]. Suppose that an organization plans to implement ERP system. The first step is to format project team that consists of CIO and two senior representatives from user departments. By collecting all information about ERP vendors and systems, project team chooses four potential ERP systems Ai (i = 1, 2, 3, 4) as candidates. The company employs some external professional organizations (experts) to aid this decision making. The project team selects four attributes to evaluate the alternatives: (1) $C1$: function and technology, (2) $C2$: strategic fitness, (3) $C3$: vendors' ability, and (4) $C4$: vendor's reputation. Suppose that there are three decision makers, denoted by $D1$, $D2$, $D3$, whose corresponding weight vector is λ = (1/3, 1/3, 1/3). The four possible alternatives are to be evaluated under these four attributes and are in the form of IVNNs for each decision maker, as shown in the following:

Interval valued neutrosophic decision matrix:

D1=

$$\begin{bmatrix} \{\{[0.4,0.5],[0.2,0.3],[0.3,0.5]\} & \{[0.3,0.4],[0.3,0.6],[0.2,0.4]\} & \{[0.2,0.5],[0.2,0.6],[0.3,0.5]\} & \{[0.5,0.6],[0.3,0.5],[0.2,0.5]\}\} \\ \{\{[0.6,0.7],[0.1,0.2],[0.2,0.3]\} & \{[0.1,0.3],[0.1,0.4],[0.2,0.5]\} & \{[0.4,0.5],[0.2,0.5],[0.3,0.7]\} & \{[0.2,0.4],[0.1,0.4],[0.3,0.3]\}\} \\ \{\{[0.3,0.4],[0.2,0.3],[0.3,0.4]\} & \{[0.3,0.6],[0.2,0.3],[0.2,0.5]\} & \{[0.2,0.7],[0.2,0.4],[0.3,0.6]\} & \{[0.2,0.6],[0.4,0.7],[0.2,0.7]\}\} \\ \{\{[0.2,0.6],[0.1,0.2],[0.1,0.2]\} & \{[0.2,0.5],[0.4,0.5],[0.1,0.6]\} & \{[0.3,0.5],[0.1,0.3],[0.2,0.2]\} & \{[0.4,0.4],[0.1,0.6],[0.1,0.5]\}\} \end{bmatrix}$$

D2=

$$\begin{bmatrix} \{\{[0.4,0.6],[0.1,0.3],[0.2,0.4]\} & \{[0.3,0.5],[0.1,0.4],[0.3,0.4]\} & \{[0.4,0.5],[0.2,0.4],[0.1,0.3]\} & \{[0.3,0.6],[0.3,0.6],[0.3,0.6]\}\} \\ \{\{[0.3,0.5],[0.1,0.2],[0.2,0.3]\} & \{[0.3,0.4],[0.2,0.2],[0.1,0.3]\} & \{[0.2,0.7],[0.3,0.5],[0.3,0.6]\} & \{[0.2,0.5],[0.2,0.7],[0.1,0.2]\}\} \\ \{\{[0.5,0.6],[0.2,0.3],[0.3,0.4]\} & \{[0.1,0.4],[0.1,0.3],[0.3,0.5]\} & \{[0.5,0.5],[0.4,0.6],[0.3,0.4]\} & \{[0.1,0.2],[0.1,0.4],[0.5,0.6]\}\} \\ \{\{[0.3,0.4],[0.1,0.2],[0.1,0.3]\} & \{[0.3,0.3],[0.1,0.5],[0.2,0.4]\} & \{[0.2,0.3],[0.4,0.5],[0.5,0.6]\} & \{[0.3,0.3],[0.2,0.3],[0.1,0.4]\}\} \end{bmatrix}$$

D3=

$$\begin{bmatrix} \{\{[0.1,0.3],[0.2,0.3],[0.4,0.5]\} & \{[0.3,0.3],[0.1,0.3],[0.3,0.4]\} & \{[0.2,0.6],[0.3,0.5],[0.3,0.5]\} & \{[0.4,0.6],[0.3,0.4],[0.2,0.3]\}\} \\ \{\{[0.3,0.6],[0.3,0.5],[0.3,0.5]\} & \{[0.3,0.4],[0.3,0.4],[0.3,0.5]\} & \{[0.3,0.5],[0.2,0.4],[0.1,0.5]\} & \{[0.1,0.2],[0.3,0.5],[0.3,0.4]\}\} \\ \{\{[0.4,0.5],[0.2,0.4],[0.2,0.4]\} & \{[0.2,0.3],[0.1,0.1],[0.3,0.4]\} & \{[0.1,0.4],[0.2,0.6],[0.3,0.6]\} & \{[0.4,0.5],[0.2,0.6],[0.1,0.3]\}\} \\ \{\{[0.2,0.4],[0.3,0.4],[0.1,0.3]\} & \{[0.1,0.4],[0.2,0.5],[0.1,0.5]\} & \{[0.3,0.6],[0.2,0.4],[0.2,0.2]\} & \{[0.2,0.4],[0.3,0.3],[0.2,0.6]\}\} \end{bmatrix}$$

Step: 2 Group Decision Matrix after aggregation with decision maker's creditability

{0.2213, 0.9906, 0.9953}	{0.3663, 0.9790, 0.9972}	{0.1861, 0.9923, 0.9995}	{0.3869, 0.9875, 0.9987}
{ 0.4120, 0.9867, 0.9954}	{0.5045, 0.9952, 0.9955}	{0.2659, 0.9942, 0.9835}	{0.3976, 0.9835, 0.9964}
{0.3409, 0.9955, 0.9984}	{0.2991, 0.9926, 0.9964}	{0.2659, 0.9972, 0.9955}	{0.1968, 0.9987, 0.9940}
{0.3350, 0.9964,0.9722}	{0.2783, 0.9782, 0.9942}	{0.2213, 0.9972, 0.9973}	{0.3936, 0.9953, 0.9924

Step: 3 Normalized group decision matrix (criteria 4 is cost type attribute) apply Equation: 3 to step 2 to normalize so that all attributes are in benefit type.

{0.2520 0.4481] [0.1680 0.3000] [0.3048 0.4687]}	{[0.3000 0.3915][0.1723 0.4482][0.2681 0.4000]}	{[0.2520 0.5313] [0.2348 0.5068] [0.2388 0.4407]}	{[0.3915 0.6000] [0.3000 0.5068] [0.2348 0.4808]}
{0.3780 0.5944] [0.1723 0.3160] [0.2348 0.3743]}	{[0.2080 0.3634 [0.2042 0.3396] [0.2042 0.4407]}	{[0.2884 0.5593] [0.2348 0.4687] [0.2388 0.6085]}	{[0.1587 0.3420] [0.2042 0.5519] [0.2388 0.3048]}
[{0.3915 0.4932][0.2000 0.3351][0.2681 0.4000]}	{[0.1817 0.4160][0.1347 0.2388][0.2681 0.4687]}	{[0.2154 0.5192] [0.2732 0.5421] [0.3000 0.5421]}	{[0.2000 0.3915] [0.2440 0.5840] [0.2886 0.5620]}
[{0.2289 0.4579][0.1723 0.2732][0.1000 0.2681]}	{[0.1817 0.4160][0.1347 0.2388][0.2681 0.4687]}	{[0.2621 0.4481] [0.2440 0.4056] [0.3160 0.3650]}	{[0.2884 0.3634] [0.2042 0.4191] [0.1347 0.5068]}

Step: 4 Multi Goal Linear Equation formed as

$$\min 1.19451\acute{\omega}_1 + 1.4945\acute{\omega}_2 + 1.6462\acute{\omega}_3 + 1.6798\acute{\omega}_4$$

Subjected to

Case: 1 completely unknown weights $\sum_{i=1}^{n} w_i = 1$ and $w_j \in [0, 1]$ here j=1, 2, 3, 4

Step: 5 Priorities of attributes obtain after solving MGLP with unknown weights using NSAH are

$$w_1 = 0.18, w_2 = 0.1211, w_3 = 0.4378, w_4 = 0.2611$$

Step: 6 Ranking based on weighted correlation coefficients of each alternatives

A1=0.3831
A2=0.3830
A3=0.4238
A4=0.3623

Therefore the ranking of alternative A4 > A2 > A1 > A3 (lower the Ai value higher the rank)

Case: 2 partially known weights from decision makers'

$$0.18 \leq w_1 \leq 0.20$$
$$0.15 \leq w_2 \leq 0.25$$
$$0.30 \leq w_3 \leq 0.35$$
$$0.30 \leq w_4 \leq 0.40$$

$$\sum_{j=1}^{n} w_j = 1$$

Step: 5 Priorities of attributes obtain after solving MGLP with unknown weights using NSAH are

$$w_1 = 0.1856, w_2 = 0.1939, w_3 = 0.3138, w_4 = 0.3067$$

Step: 6 Ranking based on weighted correlation coefficients of each alternatives

A1=0.3803
A2=0.3811
A3=0.4177
A4=0.3641

Therefore the ranking of alternative A4 > A1 > A2 > A3 (lower the Ai value higher the rank)

6. Comparative Analysis and Discussion

The results obtain from two examples with partially known and completely unknown weights are compared to Sahin and Liu [44] and Liu and Luo [45] methods.

1. Sahin and Liu [44] developed score and accuracy discrimination functions for MCGDM problem after proposing two aggregation operators. The unknown weights of attributes are determined by constructing linear equation based on maximizing deviation method. The attribute weights are obtained by solving linear equation using Lagrange technique. Then individual decision matrixes are grouped with aid of geometric weighted aggregation operator. For each alternative weighted aggregated neutrosophic values are calculated using obtained attribute weights to aggregated group decision matrix. Therefore the ranking of each alternative is based on score and accuracy functions applied to alternative weighted aggregated neutrosophic values.

2. Liu and Luo [45] proposed weighted distance from positive ideal solution to each alternative based linear equation for determining unknown weights of attributes after observing some drawback in [27] for MAGDM under SVNS. The linear function aims to minimize overall weighted distance from PIS where attribute weights are unknown. The partially known or unknown conditions are subjected to proposed linear equation and solved using any linear programming technique results weights of attributes. Then ranking of alternatives given based on weighted hamming distance from PIS. The proposed model also extended to IVNS.

3. Proposed method aimed to enhance results accuracy, flexible to operate and effectiveness. In table 2 two examples are evaluated with two cases. Then the proposed method given similar results to [44] and [45] except for example 2 case 2. Liu method and proposed method ranked first as A4 but sachin method ranks A2 as first. The successive ranks for Liu are A2, A1 and A3 but in case of present method A1, A2, and A3 respectively because present method considers weighted positive and negative symmetric deviation from PIS and NIS. Therefore the proposed method is accurate, flexible and effective.

Table: 2 Comparisons of Methods

Type of Problem	Sachin and Liu [44]		Liu and Luo [45]		Proposed Method	
	Example 1	**Example 2**	**Example 1**	**Example 2**	**Example 1**	**Example 2**
Completely Unknown weights **(case 1)**	$A2 \succ A4 \succ A1 \succ A3$	$A2 \succ A4 \succ A1 \succ A3$	$A2 \succ A4 \succ A1 \succ A3$	$A2 \succ A4 \succ A1 \succ A3$	$A4 \succ A2 \succ A1 \succ A3$	$A4 \succ A2 \succ A1 \succ A3$
Partially Unknown Weights **(case 2)**	$A2 \succ A4 \succ A1 \succ A3$	$A2 \succ A4 \succ A1 \succ A3$	$A2 \succ A4 \succ A1 \succ A3$	$A4 \succ A2 \succ A1 \succ A3$	$A4 \succ A2 \succ A1 \succ A3$	$A4 \succ A1 \succ A2 \succ A3$

7. Conclusion

Real world problems involved inconsistent, indeterminate and imprecise information therefore present method represents decision makers' expression in Neutrosophic Sets (SVNS/INS). Group Decision makers' creditability weights are considered to aggregate their expressions to overcome partial or incomplete knowledge of decision makers in the respective attributes to alternatives. Partially known or completely unknown priorities of MCGDM problem is solved by establishing MGLP based on symmetric discrimination measure from each alternative to PIS and NIS then solved using NSAH algorithm. Ranks of alternatives are given based on weighted correlation coefficients of each alternative lower the value higher the rank. Illustrative examples are demonstrated its effectiveness, accuracy and flexibility by compared with two recent methods. The proposed technique can be applied to scientific and engineering problems such as project evaluation, supplier selection, manufacturing system, data mining, and medical diagnosis and management decisions.

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