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# Correlated aggregation operators for simplified neutrosophic set and their application in multi-attribute group decision making

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**Abstract**. The simplified neutrosophic set (SNS) is a generalization of the fuzzy set that is designed for some incomplete, uncertain and inconsistent situations in which each element has different truth membership, indeterminacy membership and falsity membership functions. In this paper, we propose the simplified neutrosophic correlated averaging (SNCA) operator and the simplified neutrosophic correlated geometric (SNCG) operator, and further study the properties of the operators. Then, an approach to multi-attribute group decision making (MAGDM) within the framework of SNS is developed by the proposed aggregation operators. Finally, a practical application of the developed approach to the problem of investment is given, and the result shows that our approach is reasonable and effective in dealing with uncertain decision making problems.

Keywords: Multi-attribute group decision making (MAGDM), simplified neutrosophic set (SNS), correlated aggregation operators (CAO)

## 1. Introduction

Fuzzy set was introduced by Zadeh, which has been widely used in decision making, artificial intelligence, pattern recognition, information fusion, etc. [1, 2, 6]. On the basis of Zadeh's work, interval-valued fuzzy set, type-2 fuzzy set, type-*n* fuzzy set, soft set, rough set, intuitionistic fuzzy set, interval-valued intuitionistic fuzzy set, hesitant fuzzy set and neutrosophic set (NS) [2–5] have been proposed and successfully utilized in dealing with different uncertain problems, such as decision making [7], pattern recognition [8], artificial intelligence [9], etc. Multi-attribute group decision making (MAGDM) is a common method to modelling in the social science, economics, management and decision making. Aggregating data using various techniques belongs to key operations in decision making or information fusion process [10, 11]. The aggregation operators are one of effective tools to deal with the decision making problems. Xu and Yager [12] developed some geometric aggregation operators and applied them to multi-attribute decision making (MADM) based on IFS. Later Xu [13] developed some weighted averaging aggregation operator, ordered weighted averaging aggregation operator and hybrid aggregation operator for the intuitionistic fuzzy sets. As a generalization of fuzzy sets, NS was proposed by Smarandache [5] not only to deal with the decision information which is often incomplete, indeterminate and inconsistent but also include the truth membership degree,

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the falsity membership degree and the indeterminacy membership degree. Since NS contains both non-standard and standard intervals in its theory and related operations which restricts its application in many fields. For simplicity and practical application, Wang proposed the interval NS (INS) and the single valued NS (SVNS) which are the instances of NS and gave some operations on these sets [9, 14]. Under the single valued neutrosophic environment, Broumi proposed the single valued neutrosophic trapezoid linguistic weighted arithmetic averaging aggregation (SVNTrLWAA) operator and the single valued neutrosophic trapezoid linguistic weighted geometric aggregation (SVNTrLWGA) operator [15]. Furthermore, Ye proposed the simplified NS (SNS) which includes the SVNS and the INS, then discussed its basic operations and aggregation operators [16]. Peng defined the novel operations and proposed some aggregation operators for SNSs, then developed a method to MAGDM [17]. The existing aggregation operators for IFS or SNS only consider situations where all the elements are independent, and cannot deal with the situations where all of the elements are correlative. In order to overcome these limitations, Xu used the Choquet integral to propose the correlated aggregation operators for aggregating intuitionistic fuzzy values or interval-valued intuitionistic fuzzy values with correlative weights and applied them to MADM [18]. Based on Xu's work, Wei proposed some induced correlated aggregating operators for intuitionistic fuzzy values or interval-valued intuitionistic fuzzy values with correlative weights and applied them to MAGDM [19]. The prominent characteristic of the operators is that they not only consider the importance of the elements and the ordered positions, but also reflect the correlations among the elements and their ordered positions.

Constructing aggregation operators and ranking alternatives expressed with SNSs belong to two key open problems for MAGDM within the framework of SNSs. Motivated by the pioneers' work, we propose the simplified neutrosophic correlated averaging (SNCA) operator and the simplified neutrosophic correlated geometric (SNCG) operator, and further study the properties of the operators. Depending on the proposed operators, we investigate the multi-attribute group decision making problems and present some decision making methods. Furthermore, we utilize a numerical example to validate the proposed decision making methods, particular emphasis is put on addressing aggregation operators on SNSs. The result shows that our approach is reasonable and effective in dealing with uncertain decision making problems.

The rest of this paper is organized as follows. In Section 2, we recall the concept of SNSs and correlated aggregation operators for intuitionistic fuzzy values. In Section 3, we propose simplified neutrosophic correlated aggregation operators, including simplified neutrosophic correlated averaging (SNCA) operator and simplified neutrosophic correlated geometric (SNCG) operator. Meanwhile, we present some useful properties of the operators. In Section 4, a series of multi-attribute group decision making (MAGDM) methods are developed based on the proposed operators defined in Section 3. Section 5 utilizes an example to validate the proposed decision making methods introduced in Section 4. Finally, a conclusion is given in Section 6.

## 2. Preliminaries

### 2.1. SNSs

**Definition 2.1.** [16] Assume $X$ be a space of points with a generic element in $X$ denoted by $x$. A simplified neutrosophic set (SNS) $A$ on $X$ is defined by a truth membership function $T_A(x)$, an indeterminacy membership function $I_A(x)$ and a falsity membership function $F_A(x)$. $T_A(x)$, $I_A(x)$ and $F_A(x)$ are defined by

$$T_A(x) : X \to [0, 1] \tag{1}$$

$$I_A(x) : X \to [0, 1] \tag{2}$$

$$F_A(x) : X \to [0, 1] \tag{3}$$

For similarity, we utilize $A(x) = \{< x, T_A(x), I_A(x), F_A(x) > | x \in X\}$ to denote a SNS $A$ in the following part, and call the ordered pair $\{T_A(x), I_A(x), F_A(x)\}$ the simplified neutrosophic value (SNV) and give some useful operations on SNVs as follows.

**Definition 2.2.** [17] Let $A = \{T_A(x), I_A(x), F_A(x)\}$ and $B = \{T_B(x), I_B(x), F_B(x)\}$ be two SNSs on $X$, $\lambda > 0$, the operations on $A$ and $B$ are defined by

$$A \oplus B = \{T_A(x) + T_B(x) - T_A(x)T_B(x), \\ I_A(x)I_B(x), F_A(x)F_B(x)\} \tag{4}$$

$$A \otimes B = \{T_A(x)T_B(x), I_A(x) + I_B(x) - I_A(x)I_B(x), F_A(x) + F_B(x) - F_A(x)F_B(x)\} \tag{5}$$

$$\lambda A = \{1 - (1 - T_A(x))^\lambda, (I_A(x))^\lambda, (F_A(x))^\lambda\} \tag{6}$$

$$A^\lambda = \{(T_A(x))^\lambda, 1 - (1 - I_A(x))^\lambda, 1 - (1 - F_A(x))^\lambda\} \tag{7}$$

**Definition 2.3.** [17] Let $A = \{T_A(x), I_A(x), F_A(x)\}$ be a SNS, then the score function $s(A)$, accuracy function $a(A)$ and certainty function $c(A)$ is defined by

$$s(A) = \frac{T_A(x) + 2 - I_A(x) - F_A(x)}{3} \tag{8}$$

$$a(A) = T_A(x) - F_A(x) \tag{9}$$

$$c(A) = T_A(x) \tag{10}$$

Depending on the concept of score function, accuracy function and certainty function on SNS, the method for ranking alternatives expressed with SNSs as below.

**Definition 2.4.** [17] Let $A$ and $B$ be two simplified neutrosophic values (SNVs), the ranking method is as follows:

(1) if $s(A) > s(B)$, then $A \succ B$;
(2) if $s(A) = s(B)$ and $a(A) > a(B)$, then $A$ is greater than $B$, that is, $A$ is superior to $B$, denoted by $A \succ B$;
(3) if $s(A) = s(B)$, $a(A) = a(B)$ and $c(A) > c(B)$, then $A$ is greater than $B$, that is, $A$ is superior to $B$, denoted by $A \succ B$;
(4) if $s(A) = s(B)$, $a(A) = a(B)$ and $c(A) = c(B)$, then $A$ is equal to $B$, that is, $A$ is indifferent to $B$, denoted by $A \sim B$.

### 2.2. *Review of correlated aggregation operators for intuitionistic fuzzy value*

Let $\mu(\{x_i\})$ $(i = 1, 2, \ldots, n)$ be the weight of the elements, where $\mu$ is a fuzzy measure defined as follows.

**Definition 2.5.** [20] A fuzzy measure $\mu$ on the set $X$ is a set function $\mu : \theta \to [0, 1]$ satisfying the following axioms:

(1) $\mu(\varnothing) = 0$, $\mu(X) = 1$;
(2) $A \subset B$, implies $\mu(A) \leq \mu(B)$;
(3) $\mu(A \cup B) = \mu(A) + \mu(B) + \rho\mu(A)\mu(B)$, for all $A, B \subseteq X$ and $A \cap B = \varnothing$, where $\rho \in (-1, \infty)$.

Especially, if $\rho = 0$, then the condition (3) reduces to the axiom of additive measure:

$\mu(A \cup B) = \mu(A) + \mu(B)$, for all $A, B \subseteq X$ and $A \cap B = \varnothing$.

If all the elements in $X$ are independent, we have $\mu(A) = \sum_{x_i \in A} \mu(\{x_i\})$, for all $A \subseteq X$.

**Definition 2.6.** [18] Let $\mu$ be a fuzzy measure on $X$ and $\alpha(x_i) = (t_\alpha(x_i), f_\alpha(x_i))$ $(i = 1, 2, \ldots, n)$ be a collection of intuitionistic fuzzy values (IFVs), then we call

$$(C_1)\int \alpha d\mu = \mathrm{IFCA}(\alpha(x_1), \alpha(x_2), \ldots, \alpha(x_n)) = \oplus_{i=1}^n (\mu(B_{\sigma(i)}) - \mu(B_{\sigma(i-1)}))\alpha(x_i) \tag{11}$$

an intuitionistic fuzzy correlated averaging (IFCA) operator, where $(C_1)\int \alpha d\mu$ denote the Choquet integral, $\sigma(1), \sigma(2), \ldots, \sigma(n)$ is a permutation of $(1, 2, \ldots, n)$ such that $\alpha(x_{\sigma(1)}) \geq \alpha(x_{\sigma(2)}) \geq \cdots \geq \alpha(x_{\sigma(n)})$, $B_{\sigma(k)} = \{x_{\sigma(j)} | j \leq k\}$ for $k \geq 1$ and $B_{\sigma(0)} = \varnothing$.

With the operations of IFVs, by induction on $n$ we obtain the IFCA operator whose aggregated value is also an IFV as follows.

$$(C_1)\int \alpha d\mu = \mathrm{IFCA}(\alpha(x_1), \alpha(x_2), \ldots, \alpha(x_n)) = \left(1 - \prod_{i=1}^n (1 - t_\alpha(x_i))^{\mu(B_{\sigma(i)}) - \mu(B_{\sigma(i-1)})}, \prod_{i=1}^n (f_\alpha(x_i))^{\mu(B_{\sigma(i)}) - \mu(B_{\sigma(i-1)})}\right) \tag{12}$$

**Definition 2.7.** [18] Let $\mu$ be a fuzzy measure on $X$ and $\alpha(x_i) = (t_\alpha(x_i), f_\alpha(x_i))$ $(i = 1, 2, \ldots, n)$ be a collection of intuitionistic fuzzy values (IFVs), then we call

$$\begin{aligned} &\mathrm{IFCG}(\alpha(x_1), \alpha(x_2), \ldots, \alpha(x_n)) \\ &= \otimes_{i=1}^n (\mu(B_{\sigma(i)}) - \mu(B_{\sigma(i-1)}))\alpha(x_i) \\ &= \left(\prod_{i=1}^n (t_\alpha(x_i))^{\mu(B_{\sigma(i)}) - \mu(B_{\sigma(i-1)})}, 1 - \prod_{i=1}^n (1 - f_\alpha(x_i))^{\mu(B_{\sigma(i)}) - \mu(B_{\sigma(i-1)})}\right) \end{aligned} \tag{13}$$

an intuitionistic fuzzy correlated geometric (IFCG) operator whose aggregated value is also an IFV, where $\sigma(1), \sigma(2), \ldots, \sigma(n)$ is a permutation of $(1, 2, \ldots, n)$

such that $\alpha(x_{\sigma(1)}) \geq \alpha(x_{\sigma(2)}) \geq \cdots \geq \alpha(x_{\sigma(n)})$, $B_{\sigma(k)} = \{x_{\sigma(j)} | j \leq k\}$ for $k \geq 1$ and $B_{\sigma(0)} = \varnothing$.

## 3. Correlated aggregation operators for SNVs

Based on the existing correlated averaging operator for intuitionistic fuzzy values, we present simplified neutrosophic correlated aggregation operator in this section.

### 3.1. SNCA operator

**Definition 3.1.** Let $A_i = \{T_A(x_i), I_A(x_i), F_A(x_i)\}$ $(i = 1, 2, \ldots, n)$ be a collection of SNVs, for simplicity we denote $A_i = \{T_{A_i}, I_{A_i}, F_{A_i}\}$ in the following part, and $\mu$ be a fuzzy measure on $X$, then the simplified neutrosophic correlated averaging (SNCA) operator is also a SNV, and

$$\mathrm{SNCA}(A_1, A_2, \ldots, A_n) = \oplus_{i=1}^{n} A_{\sigma(i)}(\mu(B_{\sigma(i)}) - \mu(B_{\sigma(i-1)})) \quad (14)$$

where $\sigma(1), \sigma(2), \ldots, \sigma(n)$ is a permutation of $1, 2, \ldots, n$, such that $A_{\sigma(1)} \geq A_{\sigma(2)} \geq \cdots \geq A_{\sigma(n)}$, $B_{\sigma(k)} = \{x_{\sigma(j)} | j \leq k\}$ for $k \geq 1$ and $B_{\sigma(0)} = \varnothing$.

With the operations of SNVs, by induction on $n$ we obtain the SNCA operator as follows.

$$\mathrm{SNCA}(A_1, A_2, \ldots, A_n) = \left(1 - \prod_{i=1}^{n}(1 - T_{A_{\sigma(i)}})^{\mu(B_{\sigma(i)}) - \mu(B_{\sigma(i-1)})}, \prod_{i=1}^{n}(I_{A_{\sigma(i)}})^{\mu(B_{\sigma(i)}) - \mu(B_{\sigma(i-1)})}, \prod_{i=1}^{n}(F_{A_{\sigma(i)}})^{\mu(B_{\sigma(i)}) - \mu(B_{\sigma(i-1)})}\right) \quad (15)$$

It can be easily proved that the SNCA operator has the following properties.

**Theorem 3.1.** (Idempotency) Let $A_i = \{T_{A_i}, I_{A_i}, F_{A_i}\}$ $(i = 1, 2, \ldots, n)$ be a collection of SNVs, and all $A_i$ $(i = 1, 2, \ldots, n)$ are equal, i.e., $A_i = A$ for all $(i = 1, 2, \ldots, n)$, then

$$\mathrm{SNCA}(A_1, A_2, \ldots, A_n) = A \quad (16)$$

**Theorem 3.2.** (Commutativity) Let $A_i = \{T_{A_i}, I_{A_i}, F_{A_i}\}$ $(i = 1, 2, \ldots, n)$ be a collection of SNVs, and $\acute{A}_1, \acute{A}_2, \ldots, \acute{A}_n$ be a permutation of $A_1, A_2, \ldots, A_n$, then

$$\mathrm{SNCA}(A_1, A_2, \ldots, A_n) = \mathrm{SNCA}(\acute{A}_1, \acute{A}_2, \ldots, \acute{A}_n) \quad (17)$$

**Theorem 3.3.** (Boundedness) Let $A_i = \{T_{A_i}, I_{A_i}, F_{A_i}\}$ $(i = 1, 2, \ldots, n)$ be a collection of SNVs, and let $A_{\min} = \{\min_i T_{A_i}, \max_i I_{A_i}, \max_i F_{A_i}\}$, $A_{\max} = \{\max_i T_{A_i}, \min_i I_{A_i}, \min_i F_{A_i}\}$, then

$$A_{\min} \leq \mathrm{SNCA}(A_1, A_2, \ldots, A_n) \leq A_{\max} \quad (18)$$

**Example 3.1.** Let $A_1 = \{0.4, 0.2, 0.3\}$, $A_2 = \{0.5, 0.2, 0.2\}$, $A_3 = \{0.2, 0.1, 0.5\}$ be a set of SNVs, according to (8), (9), (10), we rank the SNVs in a decreasing order as follows:

$$A_{\sigma(1)} = A_2, A_{\sigma(2)} = A_1, A_{\sigma(3)} = A_3.$$

Suppose that the fuzzy measure of attribute of $x_i$ $(i = 1, 2, 3)$ as follows.

$\mu(\varnothing) = 0$, $\mu(x_1) = 0.4$, $\mu(x_2) = 0.3$, $\mu(x_3) = 0.35$, $\mu(x_1, x_2) = 0.75$, $\mu(x_1, x_3) = 0.80$, $\mu(x_2, x_3) = 0.65$, $\mu(x_1, x_2, x_3) = 1$.

Then by (15), we obtain $\mathrm{SNCA}(\mathrm{A}_1, \mathrm{A}_2, \mathrm{A}_3) = (0.3896, 0.1682, 0.3018)$.

### 3.2. SNCG operator

Based on the existing correlated geometric operator for intuitionistic fuzzy values, we present simplified neutrosophic correlated geometric (SNCG) operator in this section.

**Definition 3.2.** Let $A_i = \{T_{A_i}, I_{A_i}, F_{A_i}\}$ $(i = 1, 2, \ldots, n)$ be a collection of SNVs, and $\mu$ be a fuzzy measure on $X$, then the simplified neutrosophic correlated geometric (SNCG) operator is also a SNV, and

$$\mathrm{SNCG}(A_1, A_2, \ldots, A_n) = \otimes_{i=1}^{n} A_{\sigma(i)}(\mu(B_{\sigma(i)}) - \mu(B_{\sigma(i-1)})) \quad (19)$$

where $\sigma(1), \sigma(2), \ldots, \sigma(n)$ is a permutation of $1, 2, \ldots, n$ such that $A_{\sigma(1)} \geq A_{\sigma(2)} \geq \cdots \geq A_{\sigma(n)}$, $B_{\sigma(k)} = \{x_{\sigma(j)} | j \leq k\}$ for $k \geq 1$ and $B_{\sigma(0)} = \varnothing$.

With the operations of SNVs, by induction on $n$ we obtain the SNCG operator as follows.

$$\mathrm{SNCG}(A_1, A_2, \ldots, A_n) = \left(\prod_{i=1}^{n}(T_{A_{\sigma(i)}})^{\mu(B_{\sigma(i)})-\mu(B_{\sigma(i-1)})}, 1-\prod_{i=1}^{n}(1-I_{A_{\sigma(i)}})^{\mu(B_{\sigma(i)})-\mu(B_{\sigma(i-1)})}, 1-\prod_{i=1}^{n}(1-F_{A_{\sigma(i)}})^{\mu(B_{\sigma(i)})-\mu(B_{\sigma(i-1)})}\right) \quad (20)$$

**Remark 3.1.** The prosposed operators that aggregating the SNVs with correlative weights not only consider the importance of the elements or their ordered positions but also reflect the correlations among the elements or their ordered positions, the rank of the SNVs is in a decreasing order according to Definition 2.3.

## 4. Multi-attribute group decision making method

SNSs provide an effective way to solve uncertain multi-attribute group decision making (MAGDM) problems in which the alternatives on attributes have uncertain information can be classified by truth membership, indeterminacy membership and falsity membership. In this section, we present a MAGDM method based on correlated aggregation operators on SNSs.

For a MAGDM problem within the framework of SNSs, let $A = \{A_1, A_2, \ldots, A_m\}$ be a set of alternatives, $G = \{G_1, G_2, \ldots, G_n\}$ be a set of attributes and there are $s$ decision makers denoted by $D = \{D_1, D_2, \ldots, D_s\}$, The simplified neutrosophic decision matrix by $D_k$ of $X$ on $G$ provided is $R^k = [\alpha^k_{ij}]_{m\times n}$, $\alpha^k_{ij}$ is a SNV denoted by $\{T_{\alpha^k_{ij}}, I_{\alpha^k_{ij}}, F_{\alpha^k_{ij}}\}$.

Then, we utilize the proposed SNCA operator on SNVs to develop a method to deal with MAGDM problem within the framework of SNSs, which can be described as follows:

**Step 1.** Confirm the fuzzy measures of weighted vector of decision makers $D_k$ $(k = 1, 2, \ldots, s)$ and sets of decision makers $D$.

**Step 2.** Aggregate the decision making matrices $R^k$ $(k = 1, 2, \ldots, s)$ using SNCA operator (15) on SNVs and obtain a collective matrix denoted by $R = [r_{ij}]_{m\times n}$.

**Step 3.** Confirm the fuzzy measures of attribute $G_j$ $(j = 1, 2, \ldots, n)$ and attribute sets of $G$.

**Step 4.** By (15), obtain the SNCA operator $r_i = \mathrm{SNCA}(r_{i1}, r_{i2}, \ldots, r_{in})$, $i = 1, 2, \ldots, m$.

**Step 5.** Calculate the score function $s(r_i)$ $(i = 1, 2, \ldots, m)$ by (8) of the collective overall SNV $r_i$ to rank all the alternatives $A_i$ $(i = 1, 2, \ldots, m)$ and then to choose the best one.

**Step 6.** Rank all the alternatives and select the most desirable one depending on the obtained values of $s(r_i)$ $(i = 1, 2, \ldots, m)$.

**Step 7.** End.

## 5. Numerical example and analysis

### 5.1. Numerical example

In this section, an example adapted from [21] is utilized to illustrate the applicability and validity of the proposed MAGDM method. There is an invest problem concerning a financial company with the following four potential alternatives: (1) $A_1$ car company; (2) $A_2$ food company; (3) $A_3$ computer company; (4) $A_4$ arms company. The invest problem must take a decision making according to the following three attributes: $C_1$ risk analysis; $C_2$ growth analysis; $C_3$ environmental impact analysis. Under the three aforementioned attributes, all the simplified neutrosophic decision making matrices are listed as follows:

$$R^1 = \begin{bmatrix} \{0.4, 0.2, 0.3\} & \{0.4, 0.2, 0.3\} & \{0.2, 0.2, 0.5\} \\ \{0.6, 0.1, 0.2\} & \{0.6, 0.1, 0.2\} & \{0.5, 0.2, 0.2\} \\ \{0.3, 0.2, 0.3\} & \{0.5, 0.2, 0.3\} & \{0.5, 0.3, 0.2\} \\ \{0.7, 0, 0.1\} & \{0.6, 0.1, 0.2\} & \{0.4, 0.3, 0.2\} \end{bmatrix} \quad (21)$$

$$R^2 = \begin{bmatrix} \{0.5, 0.2, 0.2\} & \{0.6, 0.2, 0.3\} & \{0.3, 0.2, 0.4\} \\ \{0.6, 0.1, 0.2\} & \{0.7, 0.2, 0.3\} & \{0.5, 0.2, 0.3\} \\ \{0.4, 0.1, 0.3\} & \{0.5, 0.3, 0.3\} & \{0.6, 0.2, 0.2\} \\ \{0.7, 0.3, 0.1\} & \{0.6, 0.3, 0.2\} & \{0.5, 0.1, 0.2\} \end{bmatrix} \quad (22)$$

$$R^3 = \begin{bmatrix} \{0.5, 0.1, 0.2\} & \{0.5, 0.2, 0.2\} & \{0.3, 0.1, 0.3\} \\ \{0.5, 0.3, 0.2\} & \{0.7, 0.1, 0.3\} & \{0.5, 0.3, 0.3\} \\ \{0.6, 0.2, 0.3\} & \{0.5, 0.1, 0.3\} & \{0.5, 0.1, 0.2\} \\ \{0.5, 0.3, 0.2\} & \{0.7, 0.2, 0.2\} & \{0.7, 0.2, 0.2\} \end{bmatrix} \quad (23)$$

The decision making process is as follows.

**Step 1.** Suppose the fuzzy measures of weight vector of decision makers $D_k$ $(k = 1, 2, 3)$ and sets of decision makers $D$ as follows:
$\mu(\varnothing) = 0$, $\mu(D_1) = 0.25$, $\mu(D_2) = 0.35$, $\mu(D_3) = 0.30$,
$\mu(D_1, D_2) = 0.70$, $\mu(D_1, D_3) = 0.65$, $\mu(D_2, D_3) = 0.50$, $\mu(D_1, D_2, D_3) = 1$.

**Step 2.** Based on SNCA operator, we get

$$R = \begin{bmatrix} \{0.4523, 0.1625, 0.2449\} & \{0.4934, 0.2000, 0.2823\} & \{0.2212, 0.1625, 0.4102\} \\ \{0.5723, 0.1390, 0.2000\} & \{0.6682, 0.1275, 0.2602\} & \{0.5, 0.2258, 0.2710\} \\ \{0.4261, 0.1741, 0.3000\} & \{0.5000, 0.1872, 0.3000\} & \{0.5376, 0.2207, 0.2000\} \\ \{0.6503, 0, 0.1231\} & \{0.6330, 0.1712, 0.2000\} & \{0.5301, 0.2132, 0.2000\} \end{bmatrix} \quad (24)$$

**Step 3.** Suppose the fuzzy measures of attribute of $G_j$ $(j = 1, 2, 3)$ and attribute set of $G$ as follows. $\mu(\varnothing) = 0$, $\mu(G_1) = 0.30$, $\mu(G_2) = 0.35$, $\mu(G_3) = 0.30$, $\mu(G_1, G_2) = 0.70$, $\mu(G_1, G_3) = 0.60$, $\mu(G_2, G_3) = 0.50$, $\mu(G_1, G_2, G_3) = 1$.

**Step 4.** Using the decision information given in matrix $R$ and the SCNA operator, we obtain the collective overall preference values $r_i$ of the alternative $A_i$ $(i = 1, 2, 3, 4)$.

$$r_1 = \{0.4120, 0.1784, 0.3050\} \quad (25)$$

$$r_2 = \{0.4101, 0.1566, 0.2402\} \quad (26)$$

$$r_3 = \{0.4767, 0.1896, 0.2656\} \quad (27)$$

$$r_4 = \{0.6104, 0, 0.1729\} \quad (28)$$

**Step 5.** Based on the score functions of SNVs, we get $s(r_1) = 0.6429$, $s(r_2) = 0.6711$, $s(r_3) = 0.6738$ and $s(r_4) = 0.8125$.

**Step 6.** Since $s(r_4) > s(r_3) > s(r_2) > s(r_1)$, the ranking order of all the alternatives is $A_4 \succ A_3 \succ A_2 \succ A_1$ and the most desirable one is $A_4$.

By applying the methods of [16, 17] to the example, the ranking order of all the alternatives is $A_4 \succ A_3 \succ A_2 \succ A_1$ and the most desirable one is $A_4$.

### 5.2. *Analysis*

In this section, we have proposed a method to solve the MAGDM problem expressed with SNSs. From the above example and comparison with the method in [16, 17], we can see that the main advantages of the proposed correlated aggregation operators provide a more wider perspective for addressing decision making situations which expressed by the correlated element in SNSs.

## 6. Conclusion

We have proposed SNCA and SNCG operators based on the related research on the IFVs. Moreover, we have developed a method for addressing the MAGDM problem expressed with SNSs. The prominent characteristic of the proposed aggregation operators is that they take into account the correlations among the elements and the ordered positions. Finally, a practical numerical example is given to verify the developed MAGDM method and to demonstrate its capacity in dealing with practical and uncertain decision making problems.

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## Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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