Correlation Coefficients of Linguistic Neutrosophic Sets and their Mul- ticriteria Group Decision Making Strategy for Medical Treatment Options

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RESEARCH ARTICLE

Correlation Coefficients of Linguistic Neutrosophic Sets and their Multicriteria Group Decision Making Strategy for Medical Treatment Options

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Abstract: ***Background***: Owing to Linguistic Neutrosophic Numbers (LNNs) depicted independently by the truth, indeterminacy, and falsity linguistic variables, they fit in with human thinking and expressing habits to judgments of complicated objects, such as medical diagnosis and Medical Treatment Options (MTOs) for patients in clinical medicine. Unfortunately, existing linguistic neutrosophic Decision Making (DM) approaches have not been applied in medical DM problems so far.

Objective: Then, the LNN multicriteria group DM method especially suits medical DM problems with LNN information since medical DM problems commonly imply inconsistent, incomplete, and indeterminate linguistic information due to the medical DM complexity.

Method: Therefore, this study proposes two correlation coefficients of linguistic neutrosophic sets (LNSs) and their multicriteria group DM method to deal with the DM problem of MTOs as a new complementary in linguistic medical DM problems. Then, an actual example regarding the DM problem of MTOs is provided to illustrate the applicability of the developed group DM method.

Result: By comparative analysis with existing relative methods in LNN setting, the best MTO for the patient with verruca plantaris is feasible.

Conclusion: The developed DM method is effective in the DM problem of MTOs with LNN information and provides a new way for linguistic medical DM problems.

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1. INTRODUCTION

In inconsistent and indeterminate situations, Smarandache [1] originally gave the definition of the Neutrosophic Set (NS) that is described independently by truth, falsity, indeterminacy degrees. Then, Ye [2] introduced the simplified NS containing single-valued and interval-valued NSs for the convenience of real applications. Recently, some researchers presented new methods and applications of simplified NSs, such as shortest path problems in interval-valued neutrosophic setting [3, 4], energy and spectrum analysis of interval-valued neutrosophic graph using MATLAB [5], and a generalized ordered weighted simplified neutrosophic cosine similarity measure for Decision Making (DM) [6]. Linguistic DM is an important research topic in the DM theory and applications. Since human thinking complicated objects usually imply subjectivity and vagueness, they are difficult to give accurate assessment values of complicated/ill-defined problems regarding the expression of qualitative information, then linguistic variables/term values can effectively depict qualitative information and customarily accord with human thinking and expressing habits. Since the language variable concept was first proposed in 1975 by Zadeh [7], linguistic information has been used for language DM problems [8-14]. Then, uncertain linguistic information [15] was applied to uncertain linguistic DM problems [15-18]. Regarding the hybrid form of an interval/uncertain language variable and a single-valued/certain language variable, linguistic cubic information [19] was utilized for linguistic cubic DM problems [19-20]. To depict the truth, falsity, indeterminacy linguistic values independently in real-life situations, Linguistic Neutrosophic Numbers (LNNs) [21], Linguistic Refined Neutrosophic Sets (LRNSs) [22], and Linguistic Neutrosophic Cubic Numbers (LNCNs) [23] were proposed as the generalization of the neutrosophic set theory [24] and used for DM problems with LNN/LRNS/LNCN information. Since then, cosine measures, bidirectional projection measures, and correlation coefficients of Linguistic Neutrosophic Sets (LNSs)

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have been used for multicriteria group DM problems with LNN information [25-28]. Unfortunately, existing linguistic neutrosophic DM approaches have not been applied in medical DM problems so far. Then, the LNN multicriteria group DM method especially suits medical DM problems with LNN information since medical DM problems commonly imply inconsistent, incomplete, and indeterminate linguistic information due to the medical DM complexity. Therefore, this study proposes two correlation coefficients of LNSs and their multicriteria group DM method to deal with the DM problem of medical treatment options (MTOs) as a new complement in linguistic medical DM problems.

This study is structured as the following framework. Section 2 introduces some preliminaries of LNNs. Section 3 proposes two correlation coefficients of LNSs. Section 4 establishes a multicriteria group DM method by using the proposed correlation coefficients in the LNN setting. In Section 5, an illustrative example regarding the DM problem of MTOs is provided to show the applicability of the proposed DM method in the LNN setting. Section 6 contains conclusions and further work.

2. SOME PRELIMINARIES OF LNNS

An LNN concept [21] was proposed based on of the truth, indeterminacy, and falsity linguistic term values g_t, g_u, g_v, which are obtained independently from a specified linguistic term set $L = \{g_0, g_1, \ldots, g_p\}$ with odd cardinality p+1, and represented as $g = \langle g_t, g_u, g_v \rangle$ for $g_t, g_u, g_v \in L$.

For three LNNs $g = \langle g_t, g_u, g_v \rangle$, $g_1 = \langle g_{t_1}, g_{u_1}, g_{v_1} \rangle$, and $g_2 = \langle g_{t_2}, g_{u_2}, g_{v_2} \rangle$ in L, Fang and Ye [21] introduced their operational laws:

(a)

$$g_1 \oplus g_2 = \langle g_{t_1}, g_{u_1}, g_{v_1} \rangle \oplus \langle g_{t_2}, g_{u_2}, g_{v_2} \rangle = \left\langle g_{t_1+t_2-\frac{t_1t_2}{p}}, g_{\frac{u_1u_2}{p}}, g_{\frac{v_1v_2}{p}} \right\rangle;$$

(b)

$$g_1 \otimes g_2 = \langle g_{t_1}, g_{u_1}, g_{v_1} \rangle \otimes \langle g_{t_2}, g_{u_2}, g_{v_2} \rangle = \left\langle g_{\frac{t_1t_2}{p}}, g_{u_1+u_2-\frac{u_1u_2}{p}}, g_{v_1+v_2-\frac{v_1v_2}{p}} \right\rangle;$$

(c) $\gamma g = \gamma \langle g_t, g_u, g_v \rangle = \left\langle g_{p-p\left(1-\frac{t}{p}\right)^{\gamma}}, g_{p\left(\frac{u}{p}\right)^{\gamma}}, g_{p\left(\frac{v}{p}\right)^{\gamma}} \right\rangle$ for $\gamma > 0$;

(d) $g^{\gamma} = \langle g_t, g_u, g_v \rangle^{\gamma} = \left\langle g_{p\left(\frac{t}{p}\right)^{\gamma}}, g_{p-p\left(1-\frac{u}{p}\right)^{\gamma}}, g_{p-p\left(1-\frac{v}{p}\right)^{\gamma}} \right\rangle$ for $\gamma > 0$.

Set $g_k = \langle g_{t_k}, g_{u_k}, g_{v_k} \rangle$ (k = 1, 2, …, d) as a group of LNNs in L, then Fang and Ye [21] introduced the weighted arithmetic averaging operator of LNNs:

$$LNN-WAA(g_1, g_2, \ldots, g_q) = \sum_{i=1}^{q} \beta_i g_i = \left\langle g_{p-p\prod_{i=1}^{q}\left(1-\frac{t_i}{p}\right)^{\beta_i}}, g_{p\prod_{i=1}^{q}\left(\frac{u_i}{p}\right)^{\beta_i}}, g_{p\prod_{i=1}^{q}\left(\frac{v_i}{p}\right)^{\beta_i}} \right\rangle, \quad (1)$$

where $\beta_i \in [0, 1]$ is the weight of g_i (i =1, 2, …, q) for $\sum_{i=1}^{q} \beta_i = 1$.

3. CORRELATION COEFFICIENTS BETWEEN LNSS

This section presents two correlation coefficients of LNSs.

Definition 1. Set two LNSs as $G_1 = \{g_{11}, g_{12}, \ldots, g_{1n}\}$ and $G_2 = \{g_{21}, g_{22}, \ldots, g_{2n}\}$, where $g_{1j} = \langle g_{t_{1j}}, g_{u_{1j}}, g_{v_{1j}} \rangle$ and $g_{2j} = \langle g_{t_{2j}}, g_{u_{2j}}, g_{v_{2j}} \rangle$ for $g_{t_{1j}}, g_{u_{1j}}, g_{v_{1j}} \in L$ and $g_{t_{2j}}, g_{u_{2j}}, g_{v_{2j}} \in L$ (j = 1, 2, …, n) are two groups of LNNs. Set $f(g_{kj}) = \langle t_{kj}, u_{kj}, v_{kj} \rangle$ (k = 1, 2; j = 1, 2, …, n) as a specified linguistic scale function (transformation function), which is considered as a vector composed of the three components. Then we can propose the two correlation coefficients between two LNSs G_1 and G_2:

$$C_1(G_1, G_2) = \frac{1}{n}\sum_{j=1}^{n}\left(1 - \frac{\|f(g_{1j}) - f(g_{2j})\|}{\|f(g_{1j})\| + \|f(g_{2j})\|}\right) = \frac{1}{n}\sum_{j=1}^{n}\left(1 - \frac{\sqrt{(t_{1j}-t_{2j})^2 + (u_{1j}-u_{2j})^2 + (v_{1j}-v_{2j})^2}}{\sqrt{t_{1j}^2 + u_{1j}^2 + v_{1j}^2} + \sqrt{t_{2j}^2 + u_{2j}^2 + v_{2j}^2}}\right), \quad (2)$$

$$C_2(G_1, G_2) = \frac{1}{n}\sum_{j=1}^{n}\left(1 - \frac{\|f(g_{1j}) - f(g_{2j})\|}{\max\left(\|f(g_{1j})\|, \|f(g_{2j})\|\right)}\right) = \frac{1}{n}\sum_{j=1}^{n}\left(1 - \frac{\sqrt{(t_{1j}-t_{2j})^2 + (u_{1j}-u_{2j})^2 + (v_{1j}-v_{2j})^2}}{\max\left(\sqrt{t_{1j}^2 + u_{1j}^2 + v_{1j}^2}, \sqrt{t_{2j}^2 + u_{2j}^2 + v_{2j}^2}\right)}\right). \quad (3)$$

Regarding the properties of the correlation coefficient of LNSs [28], it is obvious that the proposed correlation coefficients $C_1(G_1, G_2)$ and $C_2(G_1, G_2)$ also contains the following properties:

(a) $C_1(G_1, G_2) = C_1(G_2, G_1)$ and $C_2(G_1, G_2) = C_2(G_2, G_1)$;

(b) $C_1(G_1, G_2) \in [0, 1]$ and $C_2(G_1, G_2) \in [0, 1]$;

(c) $C_1(G_1, G_2) = C_2(G_1, G_2) = 1$ for $G_1 = G_2$.

Proof: The properties (a) and (c) can hold obviously based on (2) and (3). Hence, we only verify the property (b).

(b) Since $\frac{\sqrt{(t_{1j}-t_{2j})^2 + (u_{1j}-u_{2j})^2 + (v_{1j}-v_{2j})^2}}{\sqrt{t_{1j}^2 + u_{1j}^2 + v_{1j}^2} + \sqrt{t_{2j}^2 + u_{2j}^2 + v_{2j}^2}}$ is a normalized Euclidean distance, there is the following inequality:

$$0 \le \frac{\sqrt{(t_{1j}-t_{2j})^2 + (u_{1j}-u_{2j})^2 + (v_{1j}-v_{2j})^2}}{\sqrt{t_{1j}^2 + u_{1j}^2 + v_{1j}^2} + \sqrt{t_{2j}^2 + u_{2j}^2 + v_{2j}^2}} \le 1.$$

Then, there also exists the following inequality:

$$0 \le \frac{\sqrt{(t_{1j}-t_{2j})^2 + (u_{1j}-u_{2j})^2 + (v_{1j}-v_{2j})^2}}{\max\left(\sqrt{t_{1j}^2 + u_{1j}^2 + v_{1j}^2}, \sqrt{t_{2j}^2 + u_{2j}^2 + v_{2j}^2}\right)} \le 1.$$

Hence, there are $C_1(G_1, G_2) \in [0, 1]$ and $C_2(G_1, G_2) \in [0, 1]$ based on the above inequalities and Eqs. (2) and (3).

Thus, we complete the proof. □

When the importance of each LNN g_{kj} (k = 1, 2; j = 1, 2, …, n) in G_1 and G_2 is specified by its weight value $\alpha_j \in [0, 1]$ for

$\sum_{j=1}^{n}\alpha_j = 1$, the two weighted correlation coefficients between two LNSs G_1 and G_2 can be presented as follows:

$$C_{w1}\left(G_1, G_2\right) = \sum_{j=1}^{n}\alpha_j\left(1 - \frac{\left\|f(g_{1j}) - f(g_{2j})\right\|}{\left\|f(g_{1j})\right\| + \left\|f(g_{2j})\right\|}\right) = \sum_{j=1}^{n}\alpha_j\left(1 - \frac{\sqrt{(t_{1j}-t_{2j})^2 + (u_{1j}-u_{2j})^2 + (v_{1j}-v_{2j})^2}}{\sqrt{t_{1j}^2 + u_{1j}^2 + v_{1j}^2} + \sqrt{t_{2j}^2 + u_{2j}^2 + v_{2j}^2}}\right), \quad (4)$$

$$C_{w2}\left(G_1, G_2\right) = \sum_{j=1}^{n}\alpha_j\left(1 - \frac{\left\|f(g_{1j}) - f(g_{2j})\right\|}{\max\left(\left\|f(g_{1j})\right\|, \left\|f(g_{2j})\right\|\right)}\right) = \sum_{j=1}^{n}\alpha_j\left(1 - \frac{\sqrt{(t_{1j}-t_{2j})^2 + (u_{1j}-u_{2j})^2 + (v_{1j}-v_{2j})^2}}{\max\left(\sqrt{t_{1j}^2 + u_{1j}^2 + v_{1j}^2}, \sqrt{t_{2j}^2 + u_{2j}^2 + v_{2j}^2}\right)}\right). \quad (5)$$

Obviously, the two weighted correlation coefficients $C_{w1}(G_1, G_2)$ and $C_{w2}(G_1, G_2)$ also contain the following properties:

(a) $C_{w1}(G_1, G_2) = C_{w1}(G_2, G_1)$ and $C_{w2}(G_1, G_2) = C_{w2}(G_2, G_1)$;

(b) $C_{w1}(G_1, G_2) \in [0, 1]$ and $C_{w2}(G_1, G_2) \in [0, 1]$;

(c) $C_{w1}(G_1, G_2) = C_{w2}(G_1, G_2) = 1$ for $G_1 = G_2$.

4. MULTICRITERIA GROUP DM METHOD REGARDING THE WEIGHTED CORRELATION COEFFICIENTS OF LNSS

In the LNN environment, this section proposes a multicriteria group DM method based on the weighted correlation coefficients of LNSs.

Regarding a multicriteria group DM problem in LNN setting, there is the set of alternatives $H = \{h_1, h_2, \ldots, h_m\}$ to be assessed on the basis of the criteria set $E = \{e_1, e_2, \ldots, e_n\}$. Then, the set of q decision makers are denoted by $D = \{d_1, d_2, \ldots, d_q\}$. Thus, the i-th decision maker d_i gives the suitable assessments of each alternative h_k ($k = 1, 2, \ldots, m$) over each criterion e_j ($j = 1, 2, \ldots, n$) and his/her assessment values are presented by an LNS $G_k^i = \{g_{k1}^i, g_{k2}^i, \ldots, g_{kn}^i\}$, where $g_{kj}^i = \langle g_{t_{kj}}^i, g_{u_{kj}}^i, g_{v_{kj}}^i \rangle$ is an LNN obtained from the specified linguistic term set $L = \{g_0, g_1, \ldots, g_p\}$ for $g_{t_{kj}}^i, g_{u_{kj}}^i, g_{v_{kj}}^i \in L$ ($i = 1, 2, \ldots, q$; $j = 1, 2, \ldots, n$; $k = 1, 2, \ldots, m$). Thus, the i-th decision matrix of LNNs $G^i = \left(g_{kj}^i\right)_{m\times n}$ ($i = 1, 2, \ldots, q$) can be established in LNN setting.

In the multicriteria group DM problem, set the weight vector of criteria as $\boldsymbol{\alpha} = (\alpha_1, \alpha_2, \ldots, \alpha_n)$ with $\alpha_k \in [0, 1]$ and $\sum_{j=1}^{n}\alpha_j = 1$ to indicate the importance of criteria e_j ($j = 1, 2, \ldots, n$), and then set the weight vector of decision makers as $\boldsymbol{\beta} = (\beta_1, \beta_2, \ldots, \beta_q)$ with $\beta_j \in [0, 1]$ and $\sum_{i=1}^{q}\beta_i = 1$ to indicate the importance of decision makers d_i ($i = 1, 2, \ldots, q$).

Thus, the multicriteria group DM method using the weighted correlation coefficients of LNSs can be applied to the multicriteria group DM problem and presented by the following decision steps:

Step 1: By Eq. (1), an aggregated LNN $g_{kj} = \langle g_{t_{kj}}, g_{u_{kj}}, g_{v_{kj}} \rangle$ is yielded by the weighted aggregation formula:

$$g_{kj} = LNN - WAA(g_{kj}^1, g_{kj}^2, \ldots, v_{kj}^q) = \sum_{i=1}^{q}\beta_i g_{kj}^i = \left\langle g_{p - p\prod_{i=1}^{q}\left(1-\frac{t_{kj}^i}{p}\right)^{\beta_i}}, g_{p\prod_{i=1}^{q}\left(\frac{u_{kj}^i}{p}\right)^{\beta_i}}, g_{p\prod_{i=1}^{q}\left(\frac{v_{kj}^i}{p}\right)^{\beta_i}} \right\rangle. \quad (6)$$

Then, the aggregated matrix of LNNs is constructed as follows:

$$G = \begin{bmatrix} G_1 \\ G_2 \\ \vdots \\ G_m \end{bmatrix} = \begin{bmatrix} g_{11} & g_{12} & \cdots & g_{1n} \\ g_{21} & g_{22} & \cdots & g_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ g_{m1} & g_{m2} & \cdots & g_{mn} \end{bmatrix}.$$

Step 2: In terms of the concept of an ideal solution/alternative, the ideal solution obtained from the aggregated matrix G is $G^* = \{g_1^*, g_2^*, \ldots, g_n^*\}$, where $g_j^* = \langle g_{t_j^*}, g_{u_j^*}, g_{v_j^*} \rangle = \langle \max_k(g_{t_{kj}}), \min_k(g_{u_{kj}}), \min_k(g_{v_{kj}}) \rangle$ ($j = 1, 2, \ldots, n$; $k = 1, 2, \ldots, m$) is an ideal LNN.

Step 3: By Eq. (4) or Eq. (5), the weighted correlation coefficient between G_k ($k = 1, 2, \ldots, m$) and G^* for h_k is calculated by the following formula:

$$C_{w1}\left(G_k, G^*\right) = \sum_{j=1}^{n}\alpha_j\left(1 - \frac{\sqrt{(t_{kj}-t_j^*)^2 + (u_{kj}-u_j^*)^2 + (v_{kj}-v_j^*)^2}}{\sqrt{t_{kj}^2 + u_{kj}^2 + v_{kj}^2} + \sqrt{(t_j^*)^2 + (u_j^*)^2 + (v_j^*)^2}}\right) \quad (7)$$

or

$$C_{w2}\left(G_k, G^*\right) = \sum_{j=1}^{n}\alpha_j\left(1 - \frac{\sqrt{(t_{kj}-t_j^*)^2 + (u_{kj}-u_j^*)^2 + (v_{kj}-v_j^*)^2}}{\max\left(\sqrt{t_{kj}^2 + u_{kj}^2 + v_{kj}^2}, \sqrt{(t_j^*)^2 + (u_j^*)^2 + (v_j^*)^2}\right)}\right). \quad (8)$$

Step 4: All alternatives h_k ($k = 1, 2, \ldots, m$) are ranked corresponding to the values of $C_{w1}(G_k, G^*)$ or $C_{w2}(G_k, G^*)$, and then the best one is selected according to the biggest value.

Step 5: End.

4. An Illustrative Example Regarding the DM Problem of MTOs

In order to effectively cure some disease for a patient in clinical medicine, physicians usually need to obtain the best medical treatment option (MTO) among potential MTOs for the patient, which is a medical DM problem. Then, a suitable MTO given by a physician may be difficult owing to various factors, such as treatment effect, cost, and side effects for a patient. However, the DM problem of MTOs usually implies inconsistent, incomplete, and indeterminate linguistic evaluation information, along with truth, falsity, indeterminacy linguistic information given by physicians in the treatment issue of a patient. Thus, the multicriteria group DM method with LNN information very suits the DM problem of MTOs.

In this section, the proposed group DM method is applied to the multicriteria group DM problem of MTOs as an illustrative example to indicate the applicability of the proposed multicriteria group DM method in the LNN setting.

Considering a DM problem of MTOs for a potential patient with verruca plantaris, the treatment team of three physicians, including chief physician (d_1), deputy chief physician (d_2), physician (d_3), needs to obtain a suitable MTO for the patient with verruca plantaris. Then, five potential MTOs (alternatives) are provided by carbon dioxide laser (h_1), high-frequency therapeutic instrument (h_2), microwave therapeutic instrument (h_3), cryotherapy (h_4), and apoxesis (h_5). The three physicians will assess them regarding the three requirements (criteria): the probability of a cure (e_1), the severity of some uncertain side effects (e_2), and the treatment cost (e_3). To consider the importance of the three criteria and the three physicians, the weight vector of the three criteria e_j (j = 1, 2, 3) is provided by $\alpha = (\alpha_1, \alpha_2, \alpha_3) = (0.4, 0.3, 0.3)$ and the weight vector of the three physicians is specified by β = (0.38, 0.34, 0.28), where all the weight values are specified by decision-makers/experts.

Then, the three physicians are requested to suitably assess these MTOs for the patient with verruca plantaris from the predefined linguistic term set $L = \{g_0$ = extremely poor, g_1 = very poor, g_2 = poor, g_3 = slightly poor, g_4 = fair, g_5 = slightly good, g_6 = good, g_7 = very good, g_8 = extremely good$\}$ for p = 8 in LNN setting, and then they give the following three LNN matrices:

$$G^1 = \begin{bmatrix} G_1^1 \\ G_2^1 \\ G_3^1 \\ G_4^1 \\ G_5^1 \end{bmatrix} = \begin{bmatrix} <g_6,g_2,g_4> & <g_2,g_4,g_6> & <g_6,g_2,g_5> \\ <g_6,g_2,g_4> & <g_7,g_6,g_5> & <g_4,g_3,g_2> \\ <g_4,g_3,g_2> & <g_4,g_2,g_6> & <g_7,g_1,g_4> \\ <g_6,g_2,g_3> & <g_2,g_2,g_2> & <g_4,g_2,g_6> \\ <g_2,g_4,g_5> & <g_7,g_6,g_4> & <g_7,g_2,g_5> \end{bmatrix},$$

$$G^2 = \begin{bmatrix} G_1^2 \\ G_2^2 \\ G_3^2 \\ G_4^2 \\ G_5^2 \end{bmatrix} = \begin{bmatrix} <g_7,g_2,g_3> & <g_3,g_3,g_4> & <g_6,g_2,g_3> \\ <g_6,g_1,g_3> & <g_7,g_5,g_4> & <g_5,g_2,g_1> \\ <g_5,g_2,g_1> & <g_5,g_1,g_4> & <g_7,g_1,g_3> \\ <g_5,g_1,g_2> & <g_3,g_2,g_1> & <g_5,g_2,g_4> \\ <g_3,g_3,g_4> & <g_7,g_5,g_3> & <g_6,g_2,g_3> \end{bmatrix},$$

$$G^3 = \begin{bmatrix} G_1^3 \\ G_2^3 \\ G_3^3 \\ G_4^3 \\ G_5^3 \end{bmatrix} = \begin{bmatrix} <g_6,g_2,g_1> & <g_3,g_4,g_3> & <g_6,g_1,g_3> \\ <g_7,g_2,g_2> & <g_6,g_3,g_2> & <g_5,g_2,g_1> \\ <g_4,g_1,g_1> & <g_5,g_1,g_4> & <g_7,g_1,g_2> \\ <g_7,g_2,g_1> & <g_3,g_2,g_2> & <g_5,g_2,g_4> \\ <g_4,g_3,g_2> & <g_7,g_3,g_2> & <g_6,g_1,g_3> \end{bmatrix}.$$

In the DM problem of MTOs, the proposed multicriteria group DM approach can be depicted by the following decision procedure:

Step 1: By Eq. (6), the aggregated LNN matrix is yielded as follows:

$$G = \begin{bmatrix} G_1 \\ G_2 \\ G_3 \\ G_4 \\ G_5 \end{bmatrix} = \begin{bmatrix} <g_{6.3755},g_{2.0000},g_{2.4208}> & <g_{2.6217},g_{3.6693},g_{4.3153}> & <g_{6.0000},g_{1.6245},g_{3.6801}> \\ <g_{6.3755},g_{1.6245},g_{2.9804}> & <g_{6.7689},g_{4.6141},g_{3.5523}> & <g_{4.6341},g_{2.3522},g_{1.3195}> \\ <g_{4.3307},g_{1.9105},g_{1.3195}> & <g_{4.6341},g_{1.3195},g_{4.7043}> & <g_{7.0000},g_{1.0000},g_{2.9804}> \\ <g_{6.1654},g_{1.6245},g_{1.9105}> & <g_{2.6217},g_{2.0000},g_{1.6245}> & <g_{4.6341},g_{2.0000},g_{4.7043}> \\ <g_{2.9700},g_{3.3659},g_{3.5523}> & <g_{7.0000},g_{4.6141},g_{2.9804}> & <g_{6.4843},g_{1.6245},g_{3.6801}> \end{bmatrix}.$$

Step 2: Corresponding to the ideal LNN $g_j^* = <g_{t_j^*}, g_{u_j^*}, g_{v_j^*}> = <\max_k(g_{t_{kj}}), \min_k(g_{u_{kj}}), \min_k(g_{v_{kj}})>$ (j = 1, 2, 3; k = 1, 2, 3, 4, 5), the ideal solution (the ideal LNS) obtained from the aggregated LNN matrix G is given as follows:

$$G^* = \{g_1^*, g_2^*, g_3^*\} = \{<g_{6.3755}, g_{1.6245}, g_{1.3195}>, <g_{7.0000}, g_{1.3195}, g_{1.6245}>, <g_{7.0000}, g_{1.0000}, g_{1.3195}>\}.$$

Step 3: By Eq. (7) or Eq. (8), the values of the correlation coefficient between G_k (k = 1, 2, 3, 4, 5) and G^* are given below:

$C_{w1}(G_1, G^*) = 0.7749$, $C_{w1}(G_2, G^*) = 0.8138$, $C_{w1}(G_3, G^*) = 0.8072$, $C_{w1}(G_4, G^*) = 0.7606$, and $C_{w1}(G_5, G^*) = 0.7428$;

or $C_{w2}(G_1, G^*) = 0.5725$, $C_{w2}(G_2, G^*) = 0.6609$, $C_{w2}(G_3, G^*) = 0.6417$, $C_{w2}(G_4, G^*) = 0.5929$, and $C_{w2}(G_5, G^*) = 0.5215$.

Step 4: Corresponding to these correlation coefficient values, all the alternatives are ranked as $h_2 > h_3 > h_1 > h_4 > h_5$ or $h_2 > h_3 > h_4 > h_1 > h_5$. Hence, the best MTO with the biggest value is h_2 (high frequency therapeutic instrument).

Obviously, the two ranking orders indicate a little difference between h_1 and h_4 corresponding to different correlation coefficients, then their best MTO indicates the same result h_2 (high-frequency therapeutic instrument) for the patient with verruca plantaris.

In practical applications, however, the different correlation coefficients may result in the different ranking orders, then the physicians may select some correlation coefficient depending on their preference and/or medical treatment requirements.

5. COMPARATIVE ANALYSIS WITH EXISTING RELATIVE METHODS

For the comparative convenience in LNS setting, we introduced the two weighted correlation coefficients of LNSs from [28]:

$$R_{w1}(G_k, G^*) = \frac{\sum_{j=1}^{n} \alpha_j (t_{kj} t_j^* + u_{kj} u_j^* + v_{kj} v_j^*)}{\sqrt{\sum_{j=1}^{n} \alpha_j (t_{kj}^2 + u_{kj}^2 + v_{kj}^2)} \times \sqrt{\sum_{j=1}^{n} \alpha_j [(t_j^*)^2 + (u_j^*)^2 + (v_j^*)^2]}}, \quad (9)$$

$$R_{w2}(G_k, G^*) = \frac{\sum_{j=1}^{n} \alpha_j (t_{kj} t_j^* + u_{kj} u_j^* + v_{kj} v_j^*)}{\max\left\{\sum_{j=1}^{n} \alpha_j (t_{kj}^2 + u_{kj}^2 + v_{kj}^2), \sum_{j=1}^{n} \alpha_j [(t_j^*)^2 + (u_j^*)^2 + (v_j^*)^2]\right\}} \quad (10)$$

By Eqs. (9) and (10), we obtain the values of the correlation coefficients between G_k (k = 1, 2, 3, 4, 5) and G^* and indicate all the decision results in Table **1**.

In Table **1**, the ranking orders of the proposed two correlation coefficients in this study and the correlation coefficients in another study [28] indicate their difference, which

Table 1. Decision results regarding various correlation coefficients between G_k and G^*.

Correlation Coefficient	Correlation Coefficient Value	Ranking Order	The Best MTO
$R_{w1}(G_k, G^*)$ [28]	0.8627, 0.9238, 0.9214, 0.8733, 0.8732	$h_2 > h_3 > h_4 > h_5 > h_1$	h_2
$R_{w2}(G_k, G^*)$ [28]	0.8390, 0.8787, 0.8373, 0.7299, 0.8254	$h_2 > h_1 > h_3 > h_5 > h_4$	h_2
$C_{w1}(G_k, G^*)$	0.7749, 0.8138, 0.8072, 0.7606, 0.7428	$h_2 > h_3 > h_1 > h_4 > h_5$	h_2
$C_{w2}(G_k, G^*)$	0.5725, 0.6609, 0.6417, 0.5929, 0.5215	$h_2 > h_3 > h_4 > h_1 > h_5$	h_2

shows that ranking orders depend on different correlation coefficients. However, the best MTO among all ranking orders is h_2 (high frequency therapeutic instrument) for the patient with verruca plantaris, which can be used for physicians' medical treatment. Obviously, the proposed group DM method is feasible and suitable since the same decision result is obtained from all correlation coefficients.

CONCLUSION

This study first proposed two correlation coefficients of LNSs as a new complement. Then a multicriteria group DM method was presented by using the weighted correlation coefficients. An illustrative example regarding the DM problem of MTOs was provided to demonstrate the applicability of the proposed multicriteria group DM approach in the LNN setting. By comparative analysis with existing relative methods using correlation coefficients in the LNN setting, the developed DM method is effective in the DM problem of MTOs with LNN information and provides a new way for linguistic medical DM problems. In the next work, we shall further use the proposed correlation coefficients for medical image processing and medical clustering analysis in the LNN setting.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

No Animals/Humans were used for studies that are base of this research.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

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The authors declare no conflict of interest, financial or otherwise.

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REFERENCES

[1] F. Smarandache, *Neutrosophy: Neutrosophic probability, set, and logic.,* American Research Press: Rehoboth, USA, 1998.

[2] Z. B. Fang, and J. Ye. "Multiple attribute group decision-making method based on linguistic neutrosophic numbers", *Symmetry,* vol. 9, no. 7, 111, pp. 1-12, 2017. http://dx.doi.org/10.3390/sym9070111

[3] S. Broumi, A. Bakali, M. Talea, F. Smarandache, K.P. Krishnan Kishore, and R. Şahin, "Shortest path problem under interval valued neutrosophic setting", *Int. J. Adv. Trends Comp. Sci. Eng.,* vol. 8, no. 1, pp. 216-222, 2019.

[4] S. Broumi, A. Dey, M. Talea, A. Bakali, F. Smarandache, D. Nagarajan, M. Lathamaheswari, and R. Kumar, *Shortest path problem using Bellman algorithm under neutrosophic environment.,* Complex & Intelligent Systems, 2019, pp. 1-8.

[5] S. Broumi, M. Talea, A. Bakali, P.K. Singh, and F. Smarandache, "Energy and spectrum analysis of interval valued neutrosophic graph using MATLAB", *Neutrosophic Sets and Systems,* vol. 24, pp. 46-60, 2019.

[6] J. Ye, "Generalized ordered weighted simplified neutrosophic cosine similarity measure for multiple attribute group decision making", *Int. J. Cogn. Inform. Nat. Intell.,* vol. 14, no. 1, pp. 51-62, 2020. http://dx.doi.org/10.4018/IJCINI.2020010104

[7] L.A. Zadeh, "The concept of a linguistic variable and its application to approximate reasoning Part I", *Inf. Sci.,* vol. 8, pp. 199-249, 1975. http://dx.doi.org/10.1016/0020-0255(75)90036-5

[8] F. Herrera, E. Herrera-Viedma, and L. Verdegay, "A model of consensus in group decision making under linguistic assessments", *Fuzzy Sets Syst.,* vol. 79, pp. 73-87, 1996. http://dx.doi.org/10.1016/0165-0114(95)00107-7

[9] F. Herrera, and E. Herrera-Viedma, "Linguistic decision analysis: Steps for solving decision problems under linguistic information", *Fuzzy Sets Syst.,* vol. 115, pp. 67-82, 2000. http://dx.doi.org/10.1016/S0165-0114(99)00024-X

[10] Z.S. Xu, "A method based on linguistic aggregation operators for group decision making with linguistic preference relations", *Inf. Sci.,* vol. 166, pp. 19-30, 2004. http://dx.doi.org/10.1016/j.ins.2003.10.006

[11] Z.S. Xu, "A note on linguistic hybrid arithmetic averaging operator in multiple attribute group decision making with linguistic information", *Group Decis. Negot.,* vol. 15, pp. 593-604, 2006. http://dx.doi.org/10.1007/s10726-005-9008-4

[12] J.M. Merigó, M. Casanovas, and L. Martínez, "Linguistic aggregation operators for linguistic decision making based on the Dempster-Shafer theory of evidence", *Int. J. Uncertain. Fuzziness Knowl. Based Syst.,* vol. 18, pp. 287-304, 2010. http://dx.doi.org/10.1142/S0218488510006544

[13] Y.J. Xu, J.M. Merigó, and H.M. Wang, "Linguistic power aggregation operators and their application to multiple attribute group decision making", *Appl. Math. Model.,* vol. 36, pp. 5427-5444, 2012. http://dx.doi.org/10.1016/j.apm.2011.12.002

[14] J.M. Merigó, M. Casanovas, and D. Palacios-Marqués, "Linguistic group decision making with induced aggregation operators and probabilistic information", *Appl. Soft Comput.,* vol. 24, pp. 669-678, 2014. http://dx.doi.org/10.1016/j.asoc.2014.08.035

[15] Z.S. Xu, "Uncertain linguistic aggregation operators based approach to multiple attribute group decision making under uncertain linguistic environment", *Inf. Sci.,* vol. 168, pp. 171-184, 2004. http://dx.doi.org/10.1016/j.ins.2004.02.003

[16] Z.S. Xu, "Induced uncertain linguistic OWA operators applied to group decision making", *Inf. Sci.,* vol. 7, pp. 231-238, 2006.

[17] G.W. Wei, "Uncertain linguistic hybrid geometric mean operator and its application to group decision making under uncertain linguistic environment", *Int. J. Uncertain. Fuzziness,* vol. 17, pp. 251-267, 2009. http://dx.doi.org/10.1142/S021848850900584X

[18] B. Peng, C. Ye, and S. Zeng, "Uncertain pure linguistic hybrid harmonic averaging operator and generalized interval aggregation operator based approach to group decision making", *Knowl. Base. Syst.,* vol. 36, pp. 175-181, 2012. http://dx.doi.org/10.1016/j.knosys.2012.06.008

[19] J. Ye, "Multiple attribute decision-making method based on linguistic cubic variables", *J. Intell. Fuzzy Syst.,* vol. 34, pp. 2351-2361, 2018. http://dx.doi.org/10.3233/JIFS-171413

[20] X. P. Lu, and J. Ye, "Dombi aggregation operators of linguistic cubic variables for multiple attribute decision making", *Information,* vol. 9, p. 188, 2018. http://dx.doi.org/10.3390/info9080188

[21] Z.B. Fang, and J. Ye, "Multiple attribute group decision-making method based on linguistic neutrosophic numbers", *Symmetry (Basel),* vol. 9, no. 111, 2017. http://dx.doi.org/10.3390/sym9070111

[22] K. Mondal, S. Pramanik, and B.C. Giri, Multi-criteria group decision making based on linguistic refined neutrosophic strategy.*New trends in neutrosophic theory and applications.,* vol. Vol. 2. Pons Editions: Brussels, 2018, pp. 125-139.

[23] J. Ye, "Linguistic neutrosophic cubic numbers and their multiple attribute decision-making method", *Information,* vol. 8, 2017. http://dx.doi.org/10.3390/info8030110

[24] F. Smarandache, *Neutrosophy: Neutrosophic probability, set, and logic.*. American Research Press: Rehoboth, USA, 1998.

[25] L. L. Shi, and J. Ye, "Cosine measures of linguistic neutrosophic numbers and their application in multiple attribute group decision-making", *Information,* vol. 8, p. 117, 2017.

[26] L.L. Shi, and J. Ye, "Multiple attribute group decision-making method using correlation coefficients between linguistic neutrosophic numbers", *J. Intell. Fuzzy Syst.,* vol. 35, pp. 917-925, 2018. http://dx.doi.org/10.3233/JIFS-171652

[27] P.D. Liu, and X.L. You, "Bidirectional projection measure of linguistic neutrosophic numbers and their application to multi-criteria group decision making", *Comput. Ind. Eng.,* vol. 128, pp. 447-457, 2019. http://dx.doi.org/10.1016/j.cie.2018.12.052

[28] Y.F. Zhu, W.H. Cui, and J. Ye, "New correlation coefficients between linguistic neutrosophic numbers and their group decision making method", *J. New Theory,* vol. 28, pp. 74-83, 2019.

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