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Single-Valued Pentapartitioned Neutrosophic Exponential Similarity Measure under SVPNS Environment and Its Application in the Selection of Bacteria

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Abstract: The purpose of this paper is to introduce a novel similarity measure, the single-valued pentapartitioned neutrosophic exponential similarity measure (SVPNESM), and the single-valued pentapartitioned neutrosophic weighted exponential similarity measure (SVPNWESM) under the single-valued pentapartitioned neutrosophic set (SVPNS) environment for selecting bacteria on concrete mortar to improve compressive strength and to reduce water absorption, porosity and chloride permeability. In order to improve the properties of concrete, bacteria must fulfill requirements such as increased compressive strength, decreased water absorption capacities, reduced porosity, decreased chloride permeability etc. A novel approach for selecting suitable bacteria in concrete mortar is presented in this study based on such requirements. In this study, suitable bacteria is selected from four bacteria for concrete mortar based on 4 criteria with fixed bacteria concentrations of 10^5. Based on this study, Bacillus subtitles is selected among four alternatives as suitable. Furthermore, the proposed MADM method is shown to be well suited to this problem after it has been compared with two existing methods.

Keywords: *SVPNS*; *SVPNESM*; *SVPNWESM*; *MADM*.

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1. Introduction:

The concept of fuzzy set (FS) was first grounded by Zadeh [48] in the year 1965 to deal with different real world problems having uncertainty. In a FS, each element has a membership value lies in the interval [0, 1]. Afterwards, Atanassov [3] felt that the non-membership of a mathematical expression has also plays a vital role in solving the problems having uncertainty, and established the concept of intuitionistic fuzzy set (IFS) by generalizing the notion of FS. In every IFS, each element has both membership and non-membership values lies in the interval [0, 1]. Till now, many researchers around the globe applied the concept of FS, IFS and their extensions in the area of theoretical research and practical research. Many times, uncertainty events will also have some indeterminacy part, which can't be expressed by using the idea of crisp set, FS and IFS. Keep in mind, Smarandache [42] grounded the idea of neutrosophic set (NS) by generalizing the concept of FS and IFS to deal with the uncertainty events having indeterminacy. In an NS, each element has truth, indeterminacy and false membership values respectively lies in the interval [0, 1]. In 2010, Wang et al. [44] introduced the idea of single-valued neutrosophic set (SVNS) by extending the notion of NS. The notion of SVNS is more effective in dealing with the uncertainty events having indeterminate information. Till now, many mathematicians around the globe used the notion of SVNS and their extensions in theoretical [5-6, 10-16, 43] as well as in the several branches of this real world such as weaver selection [18], location selection [33-34], medical diagnosis [19, 35-36], fault diagnosis [45-46], and other decision making problems [4, 21-22, 24, 28-31, 47].

The concept of single-valued pentapartitioned neutrosophic set (SVPNS) was grounded by Mallick and Pramanik [27] by dividing the indeterminacy membership function into three independent membership function namely contradiction membership function, ignorance membership function and unknown membership function. Later on, Das et al. [7] grounded the notion of single-valued pentapartitioned neutrosophic Q-ideals of single-valued pentapartitioned neutrosophic Q-algebra. In 2021, Das et al. [9] established the single-valued pentapartitioned neutrosophic tangent similarity measure of similarities between the SVPNSs under SVPNS environment, and proposed a MADM technique under the SVPNS environment. In 2021, Das et al. [8] proposed a MADM technique based on grey relational analysis under the SVPNS environment. Later on, Das and Tripathy [17] extended the notion of topology on SVPNSs, and grounded the concept of pentapartitioned neutrosophoic topological space. Thereafter, Majumder et al. [26] established an MADM strategy based on cosine similarity measure under the SVPNS environment for the selection of most significant risk factor of COVID-19 in economy. Recently, Radha and Mary [37] introduced the idea of pentapartitioned neutrosophic pythagorean soft set as an extension of quadripartitioned neutrosophic pythagorean soft set.

The rest of this article has been designed as follows:

Section-2 presents several basic definitions and operations on SVPNSs those are very useful for developing the main results of this paper. Section 3 represents the concept of SVPNESM and SVPNWESM of similarities between two SVPNSs . A MADM strategy using SVPNWESM under the SVPNS environment is discussed in section-4. In section-5 the proposed MADM strategy is applied to a real world problem. Finally, in section 6, a comparative study has been conducted to validate the results obtained from the proposed method. In section-7, wrap up the work presented in this article.

List of abbreviations are shown in below:

Short Terms	
Single-Valued Neutrosophic Set	SVNS
Multi-Attribute Decision Making	MADM
Single-Valued Pentapartitioned Neutrosophic Set	SVPNS
Single-Valued Pentapartitioned Neutrosophic Exponential Similarity Measure	SVPNESM
Single-Valued Pentapartitioned Neutrosophic Weighted Exponential Similarity Measure	SVPNWCSM
Decision Matrix	DM
Positive Ideal Alternative	PIA

2. Some Relevant Definitions:

In this section some basic definitions and results are described .

Assume that *V* be a universe of discourse. Then *A*, a SVPNS [27] over *V* is defined by:

$$A=\left\{\left(t,\partial_A(t),\wp_A(t),\Im_A(t),\square_A(t),\ell_A(t)\right):t\in V\right\}.$$

Here, ∂_A, $\wp_A$, $\Im_A$, $\square_A$ and ℓ_A are the truth, contradiction, ignorance, unknown and false membership functions from *V* to the unit interval [0, 1] respectively i.e., $\partial_A(t)$, $\wp_A(t)$, $\Im_A(t)$, $\square_A(t)$ and $\ell_A(t)\in[0,1]$, for each $t\in V$. So, $0\le\partial_A(t)+\wp_A(t)+\Im_A(t)+\square_A(t)+\ell_A(t)\le 1$, for each $t\in V$.

The absolute SVPNS (1_{PN}) [27] and the null SVPNS (0_{PN}) over a fixed set *V* are defined as follows:

(*i*) $1_{PN}=\{(t,1,1,0,0,0):t\in V\}$,

(*ii*) $0_{PN}=\{(t,0,0,1,1,1):t\in V\}$.

Let $A=\left\{\left(t,\partial_A(t),\wp_A(t),\Im_A(t),\square_A(t),\ell_A(t)\right):t\in V\right\}$ and $B=\left\{\left(t,\partial_B(t),\wp_B(t),\Im_B(t),\square_B(t),\ell_B(t)\right):t\in V\right\}$ be any two [27] SVPNSs over *V*. Then,

(*i*) $A\subseteq B$ if and only if $\partial_A(t)\le\partial_B(t)$, $\wp_A(t)\le\wp_B(t)$, $\Im_A(t)\ge\Im_B(t)$, $\square_A(t)\ge\square_B(t)$, $\ell_A(t)\ge\ell_B(t)$, for all $t\in V$.

(*ii*) $A^c=\left\{\left(t,\ell_A(t),\square_A(t),1-\Im_A(t),\wp_A(t),\partial_A(t)\right):t\in V\right\}$;

$(iii)\ A\cup B=\left\{\left(t,\max\left\{\partial_A(t),\partial_B(t)\right\},\max\left\{\wp_A(t),\wp_B(t)\right\},\min\left\{\Im_A(t),\Im_B(t)\right\},\min\left\{\square_A(t),\square_B(t)\right\},\min\left\{\ell_A(t),\ell_B(t)\right\}\right):t\in V\right\}$

$(iv)\ A\cap B=\left\{\left(t,\min\left\{\partial_A(t),\partial_B(t)\right\},\min\left\{\wp_A(t),\wp_B(t)\right\},\max\left\{\Im_A(t),\Im_B(t)\right\},\max\left\{\square_A(t),\square_B(t)\right\},\max\left\{\ell_A(t),\ell_B(t)\right\}\right):t\in V\right\}$

Example 2.1. Suppose that A = {(p, 0.6, 0.1, 0.3, 0.4, 0.5), (q, 0.9, 0.1, 0.2, 0.2, 0.1)} and B = {(p, 0.9, 0.2, 0.2, 0.1, 0.4), (q, 1.0, 0.3, 0.1, 0.2, 0.1)} be two SVPNSs over a universe of discourse V = {p, q}. Then,

(i) $A \subseteq B$;

(ii) A^c = {(p, 0.5, 0.4, 0.7, 0.1, 0.6), (q, 0.1, 0.2, 0.8, 0.1, 0.9)} and B^c = {(p, 0.4, 0.1, 0.8, 0.2, 0.9), (q, 0.1, 0.2, 0.9, 0.3, 1.0)};

(iii) $A \cup B$ = {(p, 0.9, 0.2, 0.2, 0.1, 0.4), (q, 1.0, 0.3, 0.1, 0.2, 0.1)};

(iv) $A \cap B$ = {(p, 0.6, 0.1, 0.3, 0.4, 0.5), (q, 0.9, 0.1, 0.2, 0.2, 0.1)}.

3. Single-Valued Pentapartitioned Neutrosophic Exponential Similarity Measure:

The notion of SVPNESM is discussed in the current section. This notion depends on similarities between two SVPNSs. In this section, some basic results on SVPNESM and SVPNWESM are discussed.

Definition 3.1. Suppose that A and B be two SVPNSs over a fixed set V such as $A=\left\{\left(t,\partial_A(t),\wp_A(t),\Im_A(t),\square_A(t),\ell_A(t)\right):t\in V\right\}$ an $B=\left\{\left(t,\partial_B(t),\wp_B(t),\Im_B(t),\square_B(t),\ell_B(t)\right):t\in V\right\}$. Then, the SVPNESM of similarities between A and B is denoted by $P_{SVPNESM}(A,B)$ and is defined by:

$$P_{SVPNESM}(A,B)=\frac{1}{n}\sum_{t\in V}e^{-\left[\left|\partial_A(t)-\partial_B(t)\right|+\left|\wp_A(t)-\wp_B(t)\right|+\left|\Im_A(t)-\Im_B(t)\right|+\left|\square_A(t)-\square_B(t)\right|+\left|\ell_A(t)-\ell_B(t)\right|\right]^2} \qquad \text{..................(1)}$$

Theorem 3.1. Let $P_{SVPNESM}(A,B)$ be the SVPNESM between the SVPNSs A and B. Then, the following holds:

1) $0\le P_{SVPNESM}(A,B)\le 1$;

2) $P_{SVPNESM}(A,B)=P_{SVPNESM}(B,A)$;

3) $P_{SVPNESM}(A,B)=1\Leftrightarrow A=B$.

Proof.

1) Since $\left|\partial_A(t)-\partial_B(t)\right|\ge 0$, $\left|\wp_A(t)-\wp_B(t)\right|\ge 0$, $\left|\Im_A(t)-\Im_B(t)\right|\ge 0$, $\left|\square_A(t)-\square_B(t)\right|\ge 0$ and $\left|\ell_A(t)-\ell_B(t)\right|\ge 0$ for all $t\in V$ then from (1) $P_{SVPNESM}(A,B)\ge 0$

Also, since exponential function is monotonically decreasing for all values in the set $\Box^{+} \cup \{0\}$, so from the equation (1) it is clear that $P_{SVPNESM}(A,B) \le 1$.

Hence, $0 \le P_{SVPNESM}(A,B) \le 1$

2) From the equation (1),

$$P_{SVPNESM}(A,B) = \frac{1}{n}\sum_{t\in V} e^{-\left[|\partial_A(t)-\partial_B(t)|+|\wp_A(t)-\wp_B(t)|+|\Im_A(t)-\Im_B(t)|+|\Box_A(t)-\Box_B(t)|+|\ell_A(t)-\ell_B(t)|\right]^2}$$
$$= \frac{1}{n}\sum_{t\in V} e^{-\left[|\partial_B(t)-\partial_A(t)|+|\wp_B(t)-\wp_A(t)|+|\Im_B(t)-\Im_A(t)|+|\Box_B(t)-\Box_A(t)|+|\ell_B(t)-\ell_A(t)|\right]^2}$$
$$= P_{SVPNESM}(B,A)$$

Hence $P_{SVPNESM}(A,B) = P_{SVPNESM}(B,A)$

3) Let us assume that *A* and *B* be two SVPNSs over *V* such that *A*=*B*. This implies,

$\partial_A(t)-\partial_B(t)=0$, $\wp_A(t)-\wp_B(t)=0$, $\Im_A(t)-\Im_B(t)=0$, $\Box_A(t)-\Box_B(t)=0$ and $\ell_A(t)-\ell_B(t)=0$, for all $t\in V$. Therefore, $|\partial_A(t)-\partial_B(t)|=0$, $|\wp_A(t)-\wp_B(t)|=0$, $|\Im_A(t)-\Im_B(t)|=0$, $|\Box_A(t)-\Box_B(t)|=0$ and $|\ell_A(t)-\ell_B(t)|=0$ for all $t\in V$. Hence, from (1),

$$P_{SVPNESM}(A,B) = \frac{1}{n}\sum_{t\in V} e^{0} = \frac{1}{n}\sum_{t\in V} 1 = \frac{n}{n} = 1.$$

Conversely, let $P_{SVPNESM}(A,B)=1$. This implies, $|\partial_A(t)-\partial_B(t)|=0$, $|\wp_A(t)-\wp_B(t)|=0$, $|\Im_A(t)-\Im_B(t)|=0$, $|\Box_A(t)-\Box_B(t)|=0$ and $|\ell_A(t)-\ell_B(t)|=0$ for all $t\in V$. Therefore,

$\partial_A(t)=\partial_B(t)$, $\wp_A(t)=\wp_B(t)$, $\Im_A(t)=\Im_B(t)$, $\Box_A(t)=\Box_B(t)$ and $\ell_A(t)=\ell_B(t)$, for all $t\in V$.

Hence, *A* =*B*.

Theorem 3.2. If *A*, *B* and *C* be three SVPNSs over *U* such that *A* ⊆ *B* ⊆*C*, then $P_{SVPNESM}(A,B) \ge P_{SVPNESM}(A,C)$ $P_{SVPNESM}(B,C) \ge P_{SVPNESM}(A,C)$.

Proof. Assume that *A*, *B* and *C* be three SVPNSs over a fixed set *V* such that *A* ⊆ *B* ⊆ *C*. Therefore, $\partial_A(t)\le\partial_B(t)$, $\wp_A(t)\le\wp_B(t)$, $\Im_A(t)\ge\Im_B(t)$, $\Box_A(t)\ge\Box_B(t)$, $\ell_A(t)\ge\ell_B(t)$, $\partial_A(t)\le\partial_B(t)$, $\wp_A(t)\le\wp_C(t)$, $\Im_A(t)\ge\Im_C(t)$, $\Box_A(t)\ge\Box_C(t)$, $\ell_A(t)\ge\ell_C(t)$, for all $t\in V$.

We have,

$\left|\partial_A(t)-\partial_B(t)\right| \le \left|\partial_A(t)-\partial_C(t)\right|$, $\left|\wp_A(t)-\wp_B(t)\right| \le \left|\wp_A(t)-\wp_C(t)\right|$, $\left|\square_A(t)-\square_B(t)\right| \le \left|\square_A(t)-\square_C(t)\right|$,

$\left|\ell_A(t)-\ell_B(t)\right| \le \left|\ell_A(t)-\ell_C(t)\right|$

Therefore,

$$P_{SVPNESM}(A,B)=\frac{1}{n}\sum_{t\in V} e^{-\left[\left|\partial_A(t)-\partial_B(t)\right|+\left|\wp_A(t)-\wp_B(t)\right|+\left|\Im_A(t)-\Im_B(t)\right|+\left|\square_A(t)-\square_B(t)\right|+\left|\ell_A(t)-\ell_B(t)\right|\right]^2}$$
$$\ge \frac{1}{n}\sum_{t\in V} e^{-\left[\left|\partial_A(t)-\partial_C(t)\right|+\left|\wp_A(t)-\wp_C(t)\right|+\left|\Im_A(t)-\Im_C(t)\right|+\left|\square_A(t)-\square_C(t)\right|+\left|\ell_A(t)-\ell_C(t)\right|\right]^2}$$
$$= P_{SVPNESM}(A,C)$$

Hence, $P_{SVPNESM}(A,B) \ge P_{SVPNESM}(A,C)$

Further,

$\left|\partial_B(t)-\partial_C(t)\right| \le \left|\partial_A(t)-\partial_C(t)\right|$, $\left|\wp_B(t)-\wp_C(t)\right| \le \left|\wp_A(t)-\wp_C(t)\right|$, $\left|\square_B(t)-\square_C(t)\right| \le \left|\square_A(t)-\square_C(t)\right|$,

$\left|\ell_B(t)-\ell_C(t)\right| \le \left|\ell_A(t)-\ell_C(t)\right|$

Therefore,

$$P_{SVPNESM}(B,C)=\frac{1}{n}\sum_{t\in V} e^{-\left[\left|\partial_B(t)-\partial_C(t)\right|+\left|\wp_B(t)-\wp_C(t)\right|+\left|\Im_B(t)-\Im_C(t)\right|+\left|\square_B(t)-\square_C(t)\right|+\left|\ell_B(t)-\ell_C(t)\right|\right]^2}$$
$$\ge \frac{1}{n}\sum_{t\in V} e^{-\left[\left|\partial_A(t)-\partial_C(t)\right|+\left|\wp_A(t)-\wp_C(t)\right|+\left|\Im_A(t)-\Im_C(t)\right|+\left|\square_A(t)-\square_C(t)\right|+\left|\ell_A(t)-\ell_C(t)\right|\right]^2}$$
$$= P_{SVPNESM}(A,C)$$

Hence, $P_{SVPNESM}(B,C) \ge P_{SVPNESM}(A,C)$.

Definition 3.2. Let us consider two SVPNSs A and B over a fixed set V such as $A=\left\{\left(t,\partial_A(t),\wp_A(t),\Im_A(t),\square_A(t),\ell_A(t)\right):t\in V\right\}$ and $B=\left\{\left(t,\partial_B(t),\wp_B(t),\Im_B(t),\square_B(t),\ell_B(t)\right):t\in V\right\}$.

Then, the single valued pentapartitioned neutrosophic weighted exponential similarity measure (SVPNWESM) of the similarities between two SVPNSs *A* and *B* is defined as follows:

$$P_{SVPNWESM}(A,B)=\frac{1}{n}\sum_{t\in V} w_t \times e^{-\left[\left|\partial_A(t)-\partial_B(t)\right|+\left|\wp_A(t)-\wp_B(t)\right|+\left|\Im_A(t)-\Im_B(t)\right|+\left|\square_A(t)-\square_B(t)\right|+\left|\ell_A(t)-\ell_B(t)\right|\right]^2} \quad \text{.................(2)}$$

where, $\sum_{t\in V} w_t = 1$

In view of the above theorems, the two following two propositions can be formulated.

Proposition 3.1. If $P_{SVPNWESM}(A,B)$ be the single valued pentapartitioned neutrosophic weighted sine similarity measure of similarities between the SVPNSs *A* and *B*. Then,

1) $0 \le P_{SVPNWESM}(A,B) \le 1$;

2) $P_{SVPNWESM}(A,B) = P_{SVPNWESM}(B,A)$;

3) $P_{SVPNWESM}(A,B) = 1 \, iff \; A = B$.

Proposition 3.2. If A, B and C be three SVPNSs over U such that $A \subseteq B \subseteq C$, then $P_{SVPNWESM}(A,B) \ge P_{SVPNWESM}(A,C)$, $P_{SVPNWESM}(B,C) \ge P_{SVPNWESM}(A,C)$.

4. MADM Strategy Using SVPNWESM under SVPNS Environment:

In this section, an attempt is made to propose a MADM model under the SVPNS environment using the SVPNWESM.

In a MADM problem, let us consider two sets $E = \{\theta_1, \theta_2, \theta_3, ..., \theta_n\}$ and $F = \{\mu_1, \mu_2, \mu_3, ..., \mu_m\}$ of all possible alternatives and attributes respectively. Then, a decision maker can give their evaluation information for each alternative $\theta_i \, (i = 1, 2, ..., m)$ with respect to the each attribute $\mu_j \, (j = 1, 2, ..., k)$ by a SVPNS. By using the decision maker's whole evaluation information, a decision matrix (DM) can be formed.

The steps of the proposed MADM strategy are discussed below. Figure 1 represents the flow chart of the proposed MADM strategy.

Step-1. Formation of DM by using SVPNS.

Suppose, the decision maker gives their evaluation information by using the SVPNS $K_{\theta_i} = \{(\mu_j, \partial_{ij}(\theta_i, \mu_j), \wp_{ij}(\theta_i, \mu_j), \Im_{ij}(\theta_i, \mu_j), \square_{ij}(\theta_i, \mu_j), \ell_{ij}(\theta_i, \mu_j))\}$ for each alternative $\theta_i \, (i = 1, 2, ..., m)$ with respect to the attributes $\mu_j \, (j = 1, 2, ..., k)$, where

$$\left(\partial_{ij}(\theta_i, \mu_j), \wp_{ij}(\theta_i, \mu_j), \Im_{ij}(\theta_i, \mu_j), \square_{ij}(\theta_i, \mu_j), \ell_{ij}(\theta_i, \mu_j)\right) = (\theta_i, \mu_j) \text{(say)} \quad (i = 1, 2, ..., m \text{ and } j = 1, 2, ..., k)$$

indicates the evaluation information of alternatives $\theta_i \, (i = 1, 2, ..., m)$ with respect to the attribute $\mu_j \, (j = 1, 2, ..., k)$.

The decision matrix (DM) can be expressed as follows:

$$\begin{array}{c} \\ \theta_1 \\ \theta_2 \\ \vdots \\ \theta_m \end{array} \begin{array}{c} \begin{array}{cccc} \mu_1 & \mu_2 & \cdots & \mu_k \end{array} \\ \begin{pmatrix} (\theta_1, \mu_1) & (\theta_1, \mu_2) & \cdots & (\theta_1, \mu_k) \\ (\theta_2, \mu_1) & (\theta_2, \mu_2) & \cdots & (\theta_2, \mu_k) \\ \vdots & \vdots & \vdots & \vdots \\ (\theta_m, \mu_1) & (\theta_m, \mu_2) & \cdots & (\theta_m, \mu_k) \end{pmatrix} \end{array}$$

Step-2. Determination of the Weights for Each Attribute.

In every MADM strategy, the determination of weights for every attributes is an important task. If the information of attributes' weight is completely unknown, then the decision maker can use the compromise function to calculate the weights for each attribute.

The compromise function of λ_j for each θ_j is defined as follows:

$$\lambda_j = \sum_{i=1}^{m}\left[3+\partial_{ij}\left(\theta_i,\mu_j\right)+\wp_{ij}\left(\theta_i,\mu_j\right)-\Im_{ij}\left(\theta_i,\mu_j\right)-\Box_{ij}\left(\theta_i,\mu_j\right)+\ell_{ij}\left(\theta_i,\mu_j\right)\right]\Big/5 \text{.................(3)}$$

. Then, the weight of the *j*-th attribute is defined by $w_j = \dfrac{\lambda_j}{\sum_{j=1}^{k}\lambda_j}$.................(4)

Here, $\sum_{j=1}^{k} w_j = 1$

Step-3. Selection of the Positive Ideal Alternative (PIA).

In this step, the decision maker can form the PIA by using the maximum operator for all the attributes.

The positive ideal alternative (PIA) I^+ is defined as follows:

$$\mathrm{I}^+ = \left(\nu_1^+, \nu_2^+, \nu_3^+, ..., \nu_k^+\right) \text{.................(5)}$$

Where, $\nu_j^+ = \Big(\max\left\{\partial_{ij}\left(\theta_i,\mu_j\right): i=1,2,...,m\right\}, \max\left\{\wp_{ij}\left(\theta_i,\mu_j\right): i=1,2,...,m\right\}, \min\left\{\Im_{ij}\left(\theta_i,\mu_j\right): i=1,2,...,m\right\},$
$\min\left\{\Box_{ij}\left(\theta_i,\mu_j\right): i=1,2,...,m\right\}, \min\left\{\ell_{ij}\left(\theta_i,\mu_j\right): i=1,2,...,m\right\}\Big)$.................(6), $j=1,2,...,k$

Step-4. Determination of the SVPNWESM between the PIA and $K_{\theta_i}\left(i=1,2,...,m\right)$.

In this step, the SVPNWESM between the decision elements from the decision matrix and the PIA is calculated by using eq. (2).

Step-5. Ranking Order of the Alternatives.

Finally, the ranking order of alternatives is determined based on the ascending order of SVPNWESM between the PIA and the decision elements from the decision matrix. The alternative associated with the highest SVPNWESM value is the most suitable alternatives.

The flowchart of the proposed MADM-strategy is given as follows:

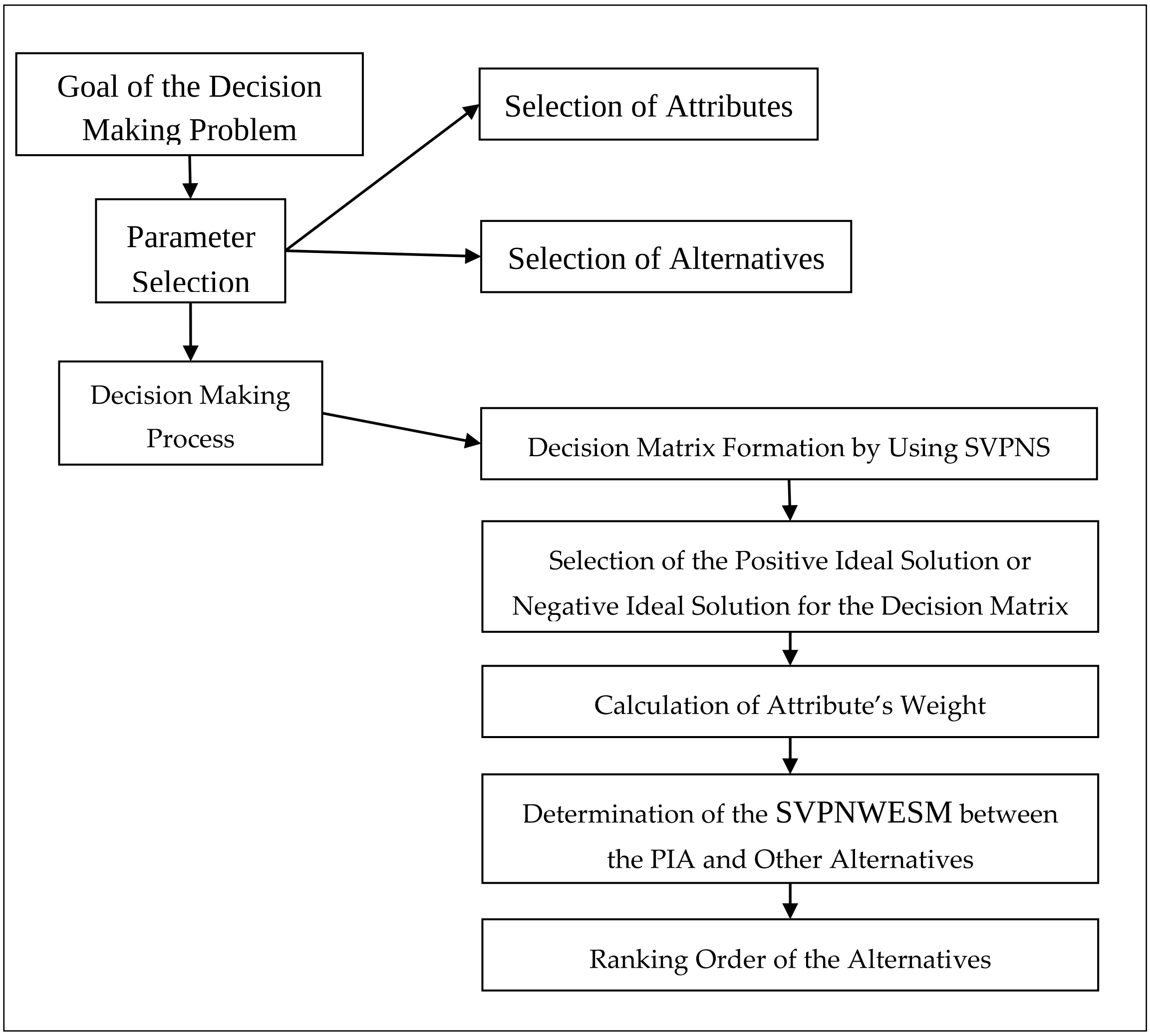

Figure- 1: Proposed MADM-Strategy

5. Application of the Proposed MADM Strategy for Selecting Suitable Bacteria in Concrete Mortar under the SVPNS Environment:

The calcite producing bacterium has been used in this research work to study its effect on strength and permeation properties of concrete. The calcite produced by the bacteria in the concrete pores, densities the matrix which results not only in improvement of compressive strength but also reduces the pore size, thereby, improving the permeation properties. Further, the rate of calcite precipitation is dependent upon the type of bacteria and the concentration of the bacteria.

Bio mineralization process depends on the types of bacteria. Selection of bacteria is a key factor in the bio mineralization process. Bacteria must fulfill some of the requirements for improving the properties of concrete. It must be able to adjust to alkaline atmosphere in concrete for the production of calcium carbonate, it should produce copious amount of calcium carbonate without being affected by calcium ion concentration, it must be able to withstand high pressure and should be oxygen brilliant to consume much oxygen and minimize corrosion of steel.

The selection of the bacteria is depend on the survive capability of bacteria in the alkaline environment. Shewanella species bacterium able to survive up to 6 to 7 days inside the concrete, due to calcite precipitation and clogging of pores inside the concrete matrix. This life span and pathogenic property are the disadvantages of using as self-healing agent for a longer period. Generally, researchers used some alkali-resistant, calcite precipitating, ureolytic bacteria of the Bacillus genus like Bacillus subtillis, Bacillus sphaericus, Bacillus cereus, Bacillus magaterium etc. [1-2, 19-20, 23, 25, 32, 38-40].

From literature review it is concluded that these bacteria could survive up to hundreds of years without nutrients and can able to withstand environmental chemicals, high mechanical stresses as well as ultraviolet radiations [41]. Generally, in case of ureolytic process, urea generates a huge amount of CO_2 and urea produces ammonia, which has a foul smell. So that to reveal from this situation researchers to investigate the calcite precipitating, alkali-resistant non-ureolytic bacteria. Afterwards the study showed aerobic alkaliphilic spore forming bacteria in concrete lead to the precipitation of $CaCO_3$. Table 1 represents the list of bacteria used to concrete mortar base on compressive strength, water absorption capacities, porosity, chloride permeability as output.

Table 1: List of Bacteria and Their Effect on Concrete Mortar

Bacteria	Concentration (μ_1)	Material (μ_2)	Compressive strength(28 days) (μ_3)	Water absorption reduction (28 days) (μ_4)	Porosity reduction (28 days) (μ_5)	Chloride permeability reduction (28 days) (μ_6)
Bacillus sphaericus (θ_1)[20]	10^5	Mortar	18.30%	89.00%	45.00%	10.00% - 40.00%
Bacillus cohnii (Nonureolytic) (θ_2) [40]	10^5	Mortar	26.23%			
Bacillus subtilis (θ_3) [32]	10^5	Mortar	27.00% (54 Map)	23.00%		
S. pasteurii (θ_4) [38]	10^5	Mortar	22.00% (28 Map)	13.00%		

The decision hierarchy of the current MADM problem is given below:

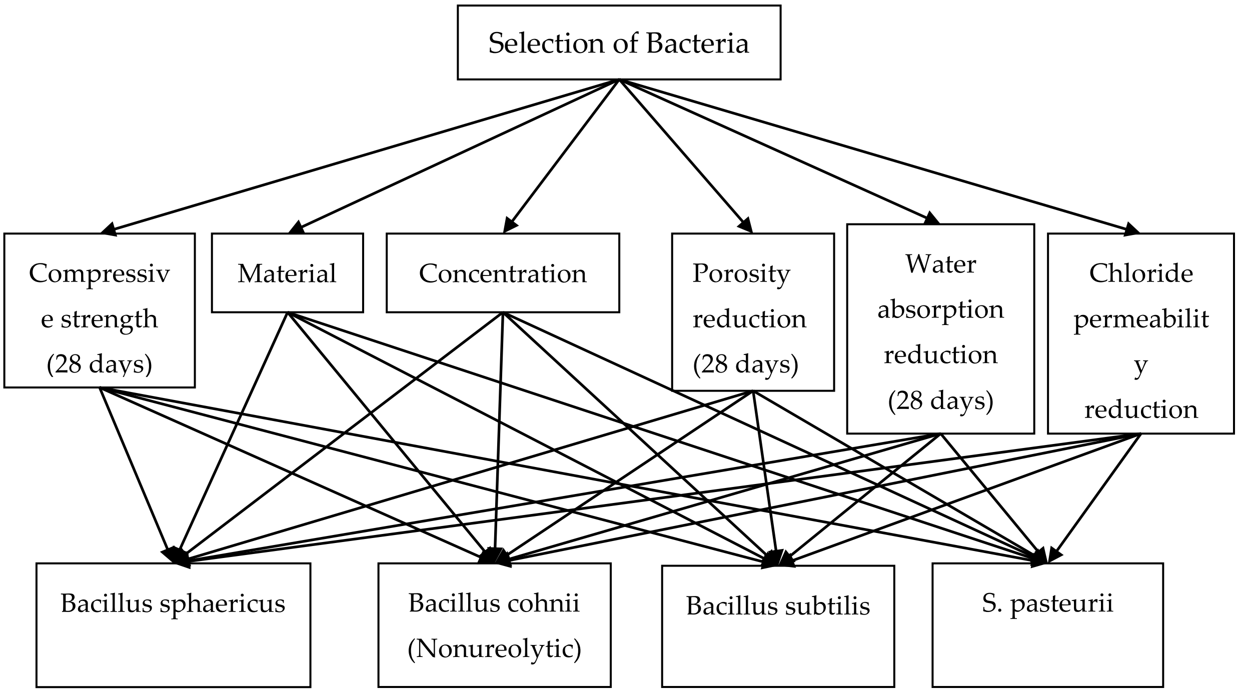

Figure- 2: Decision Hierarchy of the Current MADM-Problem

Figure-2 represents decision hierarchy of the Current MADM-Problem and steps involve in the current MADM problem is presented as follows:

By using the evaluation information for all alternatives given by the decision makers, prepare the decision matrix in Table-2.

Table-2: Decision Matrix

	μ_1	μ_2	μ_3	μ_4	μ_5	μ_6
θ_1	(0.8,0.2,0.3,0.1,0.2)	(0.9,0.1,0.1,0.0,0.1)	(0.6,0.2,0.4,0.2,0.3)	(0.8,0.1,0.2,0.0,0.2)	(0.8,0.1,0.2,0.2,0.2)	(0.9,0.1,0.1,0.1,0.1)
θ_2	(0.9,0.1,0.2,0.0,0.1)	(0.7,0.2,0.3,0.2,0.2)	(0.7,0.1,0.1,0.1,0.3)	(0.9,0.0,0.1,0.2,0.1)	(0.8,0.2,0.1,0.1,0.2)	(0.9,0.0,0.1,0.0,0.1)
θ_3	(0.9,0.1,0.2,0.0,0.1)	(0.7,0.0,0.3,0.2,0.2)	(0.9,0.0,0.1,0.0,0.1)	(0.9,0.0,0.1,0.1,0.1)	(0.9,0.0,0.1,0.0,0.1)	(0.9,0.0,0.1,0.1,0.1)
θ_4	(0.8,0.1,0.1,0.1,0.1)	(0.8,0.0,0.2,0.1,0.1)	(0.8,0.1,0.2,0.0,0.1)	(0.8,0.2,0.2,0.0,0.2)	(0.7,0.2,0.2,0.1,0.3)	(0.8,0.1,0.2,0.1,0.2)

Now, by using the eq. (5) & eq. (6), the PIA (I^{+}) is formed for the decision matrix is shown in Table-3:

Table-3: Positive Ideal Alternative

	μ_1	μ_2	μ_3	μ_4	μ_5	μ_6

θ_1	(0.8,0.2,0.3,0.1,0.2)	(0.9,0.1,0.1,0.0,0.1)	(0.6,0.2,0.4,0.2,0.3)	(0.8,0.1,0.2,0.0,0.2)	(0.8,0.1,0.2,0.2,0.2)	(0.9,0.1,0.1,0.1,0.1)
θ_2	(0.9,0.1,0.2,0.0,0.1)	(0.7,0.2,0.3,0.2,0.2)	(0.7,0.1,0.1,0.1,0.3)	(0.9,0.0,0.1,0.2,0.1)	(0.8,0.2,0.1,0.1,0.2)	(0.9,0.0,0.1,0.0,0.1)
θ_3	(0.9,0.1,0.2,0.0,0.1)	(0.7,0.0,0.3,0.2,0.2)	(0.9,0.0,0.1,0.0,0.1)	(0.9,0.0,0.1,0.1,0.1)	(0.9,0.0,0.1,0.0,0.1)	(0.9,0.0,0.1,0.1,0.1)
θ_4	(0.8,0.1,0.1,0.1,0.1)	(0.8,0.0,0.2,0.1,0.1)	(0.8,0.1,0.2,0.0,0.1)	(0.8,0.2,0.2,0.0,0.2)	(0.7,0.2,0.2,0.1,0.3)	(0.8,0.1,0.2,0.1,0.2s)
v_j^+	(0.9,0.2,0.1,0.0,0.1)	(0.9,0.2,0.1,0.0,0.1)	(0.9,0.2,0.1,0.0,0.1)	(0.9,0.2,0.1,0.0,0.1)	(0.9,0.2,0.1,0,0.1)	(0.9,0.1,0.1,0,0.1)

Weights of the attributes are obtained by using the eq. (3) & eq. (4). The weights of the attribute are $w_1 = 0.1710526$, $w_2 = 0.1602871$, $w_3 = 0.1602871$, $w_4 = 0.1698565$, $w_5 = 0.1662679$, $w_6 = 0.1722488$.

By using the eq. (2), obtained SVPNWESM of similarities between the PIA and the decision elements from the decision matrix as follows:

$SVPNWESM\left(\theta_1, I^+\right) = 0.1928416$,

$SVPNWESM\left(\theta_2, I^+\right) = 0.2077046$,

$SVPNWESM\left(\theta_3, I^+\right) = 0.2141489$,

$SVPNWESM\left(\theta_4, I^+\right) = 0.2044531$.

The ascending order of the SVPNWESM of similarities between the PIS and the decision elements from the decision matrix is as follows:

$$SVPNWESM\left(\theta_3, I^+\right) < SVPNWESM\left(\theta_2, I^+\right) < SVPNWESM\left(\theta_4, I^+\right) < SVPNWESM\left(\theta_1, I^+\right)$$

6. Comparative Study:

To verify the proposed result based on the SVPNWESM, an investigation has been conducted for the purpose of comparison with the existing MADM techniques [9, 26]. From the comparative Table-4, it is observed that the existing methods support the same performance as per the proposed method for best attribute. According to the Table-4 it is clear that the weighted values of all attribute are much closed for two existing methods. In case of proposed technique the weighted values of all attribute is not closed compare to existing tool, it helps to take better decision for considering attributes. So the proposed method is more effective compare to considering MADM methods.

Table-4: Comparative Study

Methods	Θ_1	Θ_2	Θ_3	Θ_4	Ranking Order
MADM Strategy Based on Tangent Similarity Measure under SVPNS Environment [9]	0.9802728	0.9834154	0.9855075	0.9810444	$\Theta_1 < \Theta_4 < \Theta_2 < \Theta_3$
MADM Strategy Based on Cosine Similarity Measure under SVPNS Environment [26]	0.834740	0.8349405	0.8357332	0.8348665	$\Theta_1 < \Theta_2 < \Theta_4 < \Theta_3$
Proposed MADM Strategy	0.1928416	0.2077046	0.2141489	0.2044531	$\Theta_1 < \Theta_4 < \Theta_2 < \Theta_3$

7. Conclusions: In this article, a novel MADM is proposed for selecting suitable bacteria in concrete mortar based on compressive strength, water absorption capacities, porosity, chloride permeability etc. The ranking order $\Theta_1 < \Theta_4 < \Theta_2 < \Theta_3$ is derived by the proposed method. It is obvious from the ranking order generated by the new method that alternative Θ_3 is the best among all alternatives. A comparison of the results obtained by the new MADM method is performed using different existing methods. Based on all methods, alternative Θ_3 i.e., Bacillus subtilis is the best alternative, and therefore, it is concluded that the proposed method is well suited for solving such a problem.

The main limitation of this paper is that it compares alternatives based on a fixed concentration of bacteria. In future work, the effect of different concentrations of bacteria will be tested after selecting the most suitable bacteria from among the four alternatives discussed in this paper.

Further, it is hoped that, the proposed MADM technique can also be used in solving other decision-making problems such as weaver selection [18], location selection [33-34], medical diagnosis [19, 35-36], fault diagnosis [45-46], etc.

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