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SVPNN-ARAS STRATEGY FOR MCGDM UNDER SINGLE-VALUED PENTAPARTITIONED NEUTROSOPHIC NUMBER ENVIRONMENT

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Abstract

The aim of the paper is to extend the ARAS (Additive Ratio ASsessment) strategy to the single-valued pentapartitioned neutrosophic number environment which we call the SVPNN-ARAS strategy. The single-valued pentapartitioned neutrosophic number is the extension of fuzzy number and neutrosophic number. It comprehensively deals with uncertainty as it replaces indeterminacy with three independent entities, namely, contradiction, ignorance, and unknown. To develop a decision-making strategy, the arithmetic averaging operator for pentapartitioned numbers is defined and its basic properties are established. Single valued pentapartitioned number is a suitable mathematical tool to deal with uncertainty comprehensively. The SVPNN-ARAS strategy effectively evaluates and ranks feasible alternatives. In this paper, the ARAS strategy for multi-criteria group decision-making in a pentapartitioned neutrosophic number environment is developed. To demonstrate the applicability of the proposed strategy, a green supplier selection problem is solved and sensitivity analysis is performed to reflect the impacts of weighting of the decision makers and criteria on ranking the alternatives.

Keywords: ARAS, fuzzy set, MCDM, MCGDM, neutrosophic set, pentapartitioned neutrosophic set

1. INTRODUCTION

To deal with uncertainty, Zadeh (1965) grounded the Fuzzy Set (FS) that defined the degree of Membership Function (MF). Atanassov (1986) treated the degree of non-MF as an independent entity and proposed the Intuitionistic FS (IFS). However, FSs and IFSs are incapable of dealing uncertainty with inconsistency, and indeterminacy which do exist in real-life decision-making problems. To tackle the issues of inconsistency and indeterminacy, Smarandache (1998) treated the degree of indeterminacy-MF as an independent entity and introduced the Neutrosophic Set (NS) to

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tackle inconsistency, indeterminacy, and uncertainty. Wang et al. (2010) grounded the Single Valued NS (SVNS) as a simple and easily understandable form of NSs. Using four-valued logic (Belnap,1977) and multi-valued logic (Smarandache, 2013), Quadripartition SVNS (QSVNS) (Chatterjee et al., 2016) was introduced. Mallick and Pramanik (2020) introduced Pentapartitioned NS (PNS) by incorporating contradiction, ignorance, and unknown membership degrees in place of indeterminacy to deal with uncertainty comprehensively. Pramanik (2023) presented the Interval PNS (IPNS) using PNS (Mallick & Pramanik, 2020) and interval NS (Wang et al., 2005). A review of the applications of NS was studied by El-Hefenawy et al. (2016). An overview of NSs was presented by Broumi et al. (2018). A review of the applications of NS was studied by El-Hefenawy et al. (2016). An overview of NSs and SVNSs was presented by Broumi et al. (2018) and Pramanik (2022) respectively. Various applications and theoretical developments of NSs and SVNSs were presented in the two edited volumes by Smarandache and Pramanik (2016, 2018). Khan et al. (2018) presented a systematic review of decision-making algorithms in extended NS environments. Pramanik et al. (2018) presented the contributions of selected Indian researchers in neutrosophic decision-making strategies. Nguyen et al. (2019) presented a survey of the NSs in biomedical diagnoses. Pramanik (2020) and Zhang et al. (2020) presented an overview of rough NSs. Muzaffar et al. (2020) presented an overview of neutrosophic logic and its classification. Peng and Dai (2020) documented a bibliometric analysis of NSs.

Multi-Criteria Group Decision Making (MCGDM) involves multiple Decision-Makers (DMs) and conflicting criteria and ranks the options. The history of Multi-Criteria Decision-Making (MCDM) strategies and their different approaches and applications were deeply studied (Triantaphyllou, 2000; Köksalan et al., 2011) in the literature. There exists a vast literature on MCDM in the crisp set environment (Figueira et al., 2004; Nikolić et al., 2015; Greco et al., 2016; Biswas & Pamucar, 2021), FS environment (Šmidovnik & Grošelj, 2021; Mimović et al., 2021; Xu & Zhang, 2022) and SVNS environment (Ye, 2014; Karabašević et al., 2020). In the PNS setting, Das et al., (2021b) presented the tangent similarity-based Multi-Criteria Decision-Making (MCDM) strategy in the PNS environment by extending the works of Mondal and Pramanik (2015b) in the SVNS environment. Das et al., (2021a) presented the GRA-based MCDM strategy in the PNS environment by extending GRA (Biswas et al., 2014) based MCDM strategy in the SVNS environment. Saha et al. (2022) presented Dice similarity-based MCDM strategy in the Single Valued PNS (SVPNS) environment. PNSs. Majumder et al. (2023) presented the pentapartitioned neutrosophic weighted hyperbolic tangent similarity measure in determining the most significant environmental risks during the COVID-19 pandemic. Das et al. (2022) and Quek et al. (2022) presented the pentapartitioned neutrosophic graphs. Broumi et al. (2022) presented the interval pentapartitioned neutrosophic graphs.

Research gap: No studies involving Additive Ratio ASsessment (ARAS) in the Single Valued Pentapartitioned Neutrosophic Number (SVPNN) setting have been reported so far in the literature.

Motivation: To develop SVPNN-ARAS in the SVPNN setting to fill the research gap.

The aims of the paper:

- to introduce the pentapartitioned weighted arithmetic aggregation operator in the PNN environment and establish its basic properties
- to develop a new ARAS strategy for group decision-making using the proposed aggregation operator in the SVPNN environment
- to solve an illustrative example of a green supplier selection problem to reflect the applicability of the developed strategy

The structure of the remaining part of the paper is as follows: Section 2 presents a literature review of the ARAS strategy. Section 3 presents the basics of PNNs. In Section 4, the SVPNN-ARAS strategy is developed. Section 5 solves a green supplier selection problem using the developed strategy and includes a sensitivity analysis of the findings. Section 6 presents the conclusions of the paper.

2. LITERATURE REVIEW

Zavadskas and Turskis (2010) grounded the ARAS strategy that is simple and easy to apply for various real-life MCDM problems. Zavadskas et al. (2010) employed the ARAS strategy in choosing the best choice for redeveloping buildings. The ARAS strategy with grey numbers was developed by Turskis and Zavadskas (2010b). Balezentiene and Kusta (2012) employed the ARAS strategy for issues of greenhouse gas. Stanujkić et al. (2013) presented some comparative analysis of MCDM strategies including ARAS strategy. Stanujkić (2015) presented the group decision-making with the ARAS strategy using linguistic variables for a faculty website evaluation process. Karabašević et al. (2015) and Stanujkić et al. (2015) used the SWARA and ARAS strategies to solve the personnel selection problem. Karabašević et al. (2016a,b) employed the SWARA and ARAS strategies for the ranking of companies and personnel selection respectively. Stanujkić et al. (2017) developed the ARCAS strategy by integrating the SWARA and ARAS strategies. The ARAS strategy (Koçak et al., 2018) was employed in subcontractor selection with eight alternatives and eleven t criteria. The ARAS strategy was employed by Ghram and Frikha (2019) hierarchical decision problem. Pinem et al. (2020) presented the ELECTRE, SMART, and ARAS strategies to determine the priority in dealing with the earthquake-affected areas.

Turskis and Zavadskas (2010a) presented the ARAS strategy in the FS setting. In the interval-valued IFS environment, the ARAS strategy was developed by Büyüközkan and Göçer (2018) dealing with a case study for a digital supply chain. Liu and Cheng (2019) incorporated probability multi-valued neutrosophic numbers in the ARAS strategy. Mallick and Pramanik (2021) developed the ARAS strategy for MCGDM in the trapezoidal NS setting. Adali et al. (2023) integrated the CRITIC and ARAS in the SVNS environment. Tanackov et al. (2022) presented the ARAS strategy in the interval rough set environment. An overview of the ARAS strategy was documented by Liu and Xu (2021) by presenting theoretical development, applications, and future challenges.

3. PENTAPARTITIONED NEUTROSOPHIC NUMBER (PNN)

Definition 1. Assume that is a PNS and an element of is, denoted by $\iota = \left\langle \tau_\iota, c_\iota, g_\iota, u_\iota, \phi_\iota \right\rangle$

where τ_t denotes the truth Membership Degree (MD), c_t denotes contradiction MD, g_t denotes an ignorance MD, u_i denotes unknown MD and ϕ_t denotes a falsity D of t such that for each $\xi \in \Pi$, $\tau_\iota, c_\iota, g_\iota, u_\iota, \phi_\iota \in [0,1]$ and $0 \le \tau_\iota(\xi) + c_\iota(\xi) + g(\xi)_\iota + u_\iota(\xi) + \phi(\xi)_\iota \le 5$. Then, $\iota = \langle \tau_\iota, c_\iota, g_\iota, u_\iota, \phi_\iota \rangle$ is simply called a PNN (Mallick & Pramanik, 2020).

Definition 2. Assume that $\iota_1, \iota_2 \in PNN$. Then the following additive and multiplication operations hold:

$$\iota_1 + \iota_2 = \left\langle \begin{matrix} \tau_{\iota_1} + \tau_{\iota_2} - \tau_{\iota_1}.\tau_{\iota_2}, c_{\iota_1} + c_{\iota_2} - c_{\iota_1}.c_{\iota_2}, \\ g_{\iota_1}.g_{\iota_2}, u_{\iota_1}.u_{\iota_2}, \phi_{\iota_1}.\phi_{\iota_2} \end{matrix} \right\rangle \quad (1)$$

$$\iota_1.\iota_2 = \left\langle \begin{matrix} \tau_{\iota_1}.\tau, c_{\iota_1}.c_{\iota_2}, g_{\iota_1} + g_{\iota_2} - g_{\iota_1}.g_{\iota_2}, \\ u_{\iota_1} + u_{\iota_2} - u_{\iota_1}.u_{\iota_2}, \phi_{\iota_1} + \phi_{\iota_2} - \phi_{\iota_1}.\phi_{\iota_2} \end{matrix} \right\rangle \quad (2)$$

Proposition 1. For any $\wp, \wp_1, \wp_2, \wp_3 \in PNN$ the following operations hold:

i. $\wp_1 + \wp_2 = \wp_2 + \wp_1$

ii. $(\wp_1 + \wp)_2 + \wp_3 = \wp_1 + (\wp_2 + \wp_3)$

iii. $\wp_1 \wp_2 = \wp_2 . \wp_1$

iv. $(\wp_1 . \wp_2) . \wp_3 = (\wp_1 . \wp_2) . \wp_3$

v. $\gamma\wp = \left\langle \begin{matrix} 1-(1-\tau_\wp)^\gamma, 1-(1-c_\wp)^\gamma, \\ (g_\wp)^\gamma, (u_\wp)^\gamma, (\phi_\wp)^\gamma \end{matrix} \right\rangle, \gamma \in N$

vi. $\wp^\gamma = \left\langle \begin{matrix} (\tau_\wp)^\gamma, (c_\wp)^\gamma, 1-(1-g_\wp)^\gamma, \\ 1-(1-u_\wp)^\gamma, 1-(1-\phi_\wp)^\gamma \end{matrix} \right\rangle, \gamma \in N$

vii. $\gamma(\wp_1 + \wp_2) = \gamma\wp_1 + \gamma\wp_2, \gamma \in N$

viii. $(\gamma_1 + \gamma_2)\wp = \gamma_1\wp + \gamma_2\wp, \gamma_1, \gamma_2 \in N$

3.1. Score function

Definition 3. The score function of a SVPNN $\eta = \langle t_\eta, c_\eta, g_\eta, u_\eta, \phi_\eta \rangle$ is defined as

$$Sc(\eta) = \frac{t_\eta + c_\eta}{2} + \frac{g_\eta + u_\eta + \phi_\eta}{3} \quad (3)$$

where the score value lies between [0,2].

Definition 4. The accuracy function of $\eta = \langle t_\eta, c_\eta, g_\eta, u_\eta, \phi_\eta \rangle$ are defined by

$$Ac(\eta) = \frac{t_\eta + c_\eta + g_\eta - u_\eta - \phi_\eta}{2} \quad (4)$$

where the accuracy value lies between $\left[-1, \frac{3}{2}\right]$.

Property 1: Score function of a SVPNN lies between [0,2].

Proof: Let $\eta = \langle t_\eta, c_\eta, g_\eta, u_\eta, \phi_\eta \rangle$ be a SVPNN. Since $t_\eta, c_\eta, g_\eta, u_\eta, \phi_\eta \in [0,1]$,

$$0 \le t_\eta \le 1, 0 \le c_\eta \le 1, 0 \le g_\eta \le 1, 0 \le u_\eta \le 1, 0 \le \phi_\eta \le 1$$

So, $$\begin{gathered} 0 \le t_\eta + c_\eta \le 2 \\ \Rightarrow 0 \le \frac{t_\eta + c_\eta}{2} \le 1 \end{gathered}$$

$$\begin{gathered} 0 \le g_\eta + u_\eta + \phi_\eta \le 3 \\ \Rightarrow 0 \le \frac{g_\eta + u_\eta + \phi_\eta}{3} \le 1 \end{gathered}$$

$$\begin{gathered} 0 \le \frac{t_\eta + c_\eta}{2} + \frac{g_\eta + u_\eta + \phi_\eta}{3} \le 1 + 1 \\ \Rightarrow 0 \le Sc(\eta) \le 2 \end{gathered}$$

This completes the proof.

Property 2: Accuracy function of $\eta = \langle t_\eta, c_\eta, g_\eta, u_\eta, \phi_\eta \rangle$ lies between $\left[-1, \frac{3}{2}\right]$.

Proof: Since $t_\eta, c_\eta, g_\eta, u_\eta, \varphi_\eta \in [0,1]$

Then

$$0 \le t_\eta \le 1, 0 \le c_\eta \le 1, 0 \le g_\eta \le 1, 0 \le u_\eta \le 1, 0 \le \phi_\eta \le 1$$

$$-2 \le t_\eta + c_\eta + g_\eta - u_\eta - \phi_\eta \le 3$$

$$\Rightarrow -1 \le \frac{t_\eta + c_\eta + g_\eta - u_\eta - \phi_\eta}{2} \le \frac{3}{2}$$

$$\Rightarrow -1 \le Ac(\eta) \le \frac{3}{2}$$

This completes the proof.

Definition 5. Let $\eta_i = \langle \tau_{\eta_i}, c_{\eta_i}, g_{\eta_i}, u_{\eta_i}, \phi_{\eta_i} \rangle$ ($i=1,2,...m$) be a collection of PNNs. A pentapartitioned neutrosophic weighted arithmetic aggregation operator (PNWAA) is defined by:

$$PNWAA(\eta_1, \eta_2, ..., \eta_m) = \sum_{i=1}^{m} w_i \eta_i$$

where $w=(w_1, w_2,...,w_m)^T$ is the weight of η_i($i=1,2,...,m$) with $0 \le w_i \le 1$ and $\sum_{i=1}^{n} w_i = 1$

Theorem 1: Consider a collection of PNNs $\eta_i = \langle \tau_{\eta_i}, c_{\eta_i}, g_{\eta_i}, u_{\eta_i}, \phi_{\eta_i} \rangle (i = 1, 2, ...m)$ with associated weighted vector $w=(w_1, w_2,...,w_m)^T$ where $0 \le w_i \le 1$ and $\sum_{i=1}^{n} w_i = 1$.

Then

$$PNWAA(\eta_1, \eta_2, ..., \eta_m) = \sum_{i=1}^{m} w_i \eta_i$$

$$= w_1\eta_1 + w_2\eta_2 + ... + w_m\eta_m$$

$$= \left\langle \begin{array}{l} 1 - \prod_{i=1}^{n} (1-\tau_{\eta_i})^{w_i}, 1 - \prod_{i=1}^{n} (1-c_{\eta_i})^{w_i}, \\ \prod_{i=1}^{n} (g_{\eta_i})^{w_i}, \prod_{i=1}^{n} (u_{\eta_i})^{w_i}, \prod_{i=1}^{n} (\phi_{\eta_i})^{w_i} \end{array} \right\rangle$$

Proof: By definition, for $w_1 \in w$ and $\eta_1 \in PNN$

$$w_1\eta_1 = \left\langle \begin{array}{l} 1-(1-\tau_{\eta_1})^{w_1}, 1-(1-c_{\eta_1})^{w_1}, \\ (g_{\eta_1})^{w_1}, (u_{\eta_1})^{w_1}, (\phi_{\eta_1})^{w_1} \end{array} \right\rangle$$

Thus, the expression trivially holds for n=1. Similarly, for $w_2 \in w$ and $\eta_2 \in PNN$

$$w_2\eta_2 = \left\langle \begin{array}{l} 1-(1-\tau_{\eta_2})^{w_2}, 1-(1-c_{\eta_2})^{w_2}, \\ (g_{\eta_2})^{w_2}, (u_{\eta_2})^{w_2}, (\phi_{\eta_2})^{w_2} \end{array} \right\rangle$$

Therefore, we can write,

$$PNNWAA(\eta_1, \eta_2) = w_1\eta_1 + w_2\eta_2$$

$$= \left\langle \begin{array}{l} \{1-(1-\tau_{\eta_1})^{w_1}\} + \{1-(1-\tau_{\eta_2})^{w_2}\} - \{1-(1-\tau_{\eta_1})^{w_1}\}\{1-(1-\tau_{\eta_2})^{w_2}\}, \\ \{1-(1-c_{\eta_1})^{w_1}\} + \{1-(1-c_{\eta_2})^{w_2}\} - \{1-(1-c_{\eta_1})^{w_1}\}\{1-(1-c_{\eta_2})^{w_2}\}, \\ \{(g_{\eta_1})^{w_1}(g_{\eta_2})^{w_2}\}, \{(u_{\eta_1})^{w_1}(u_{\eta_2})^{w_2}\}, \{(\phi_{\eta_1})^{w_1}(\phi_{\eta_2})^{w_2}\} \end{array} \right\rangle$$

$$= \left\langle \begin{array}{l} \{1-(1-\tau_{\eta_1})^{w_1}\}\{(1-\tau_{\eta_2})^{w_2}\}, 1-\{1-(1-\tau_{\eta_1})^{w_1}\}\{(1-\tau_{\eta_2})^{w_2}\}, \\ \{1-(1-c_{\eta_1})^{w_1}\}\{1-(1-c_{\eta_2})^{w_2}\}, \{1-(1-c_{\eta_1})^{w_1}\}\{(1-c_{\eta_2})^{w_2}\}, \\ \{(g_{\eta_1})^{w_1}(g_{\eta_2})^{w_2}\}, \{(u_{\eta_1})^{w_1}(u_{\eta_2})^{w_2}\}, \{(\phi_{\eta_1})^{w_1}(\phi_{\eta_2})^{w_2}\} \end{array} \right\rangle$$

Thus, the expression holds true for n = 1, 2. Further suppose that the expression holds for n=k, $k \in N$ .Then it follows that,

$$PNWAA(\eta_1, \eta_2, ..., \eta_k)$$

$$= \left\langle \begin{array}{l} 1 - \prod_{i=1}^{k} (1-\tau_{\eta_i})^{w_i}, 1 - \prod_{i=1}^{k} (1-c_{\eta_i})^{w_i}, \\ \prod_{i=1}^{k} (g_{\eta_i})^{w_i}, \prod_{i=1}^{k} (u_{\eta_i})^{w_i}, \prod_{i=1}^{k} (\phi_{\eta_i})^{w_i} \end{array} \right\rangle$$

Now, for n = k+1, one obtains,

$$PNWAA(\eta_1, \eta_2, ..., \eta_k, \eta_{k+1}) = \sum_{i=1}^{k+1} w_i \eta_i = \sum_{i=1}^{k} w_i \eta_i + w_{k+1}\eta_{k+1}$$

$$= \left\langle 1 - \prod_{i=1}^{k} (1-\tau_{\eta_i})^{w_i}, 1 - \prod_{i=1}^{k} (1-c_{\eta_i})^{w_i}, \prod_{i=1}^{k} (g_{\eta_i})^{w_i}, \prod_{i=1}^{k} (u_{\eta_i})^{w_i}, \prod_{i=1}^{k} (\phi_{\eta_i})^{w_i} \right\rangle$$

$$+ \left\langle 1-(1-\tau_{\eta_{k+1}})^{w_{k+1}}, 1-(1-c_{\eta_{k+1}})^{w_{k+1}}, (g_{\eta_{k+1}})^{w_{k+1}}, (u_{\eta_{k+1}})^{w_{k+1}}, (\phi_{\eta_{k+1}})^{w_{k+1}} \right\rangle$$

$$= \left\langle \begin{array}{l} \left\{1 - \prod_{i=1}^{n} (1-\tau_{\eta_i})^{w_i}\right\} + \{1-(1-\tau_{\eta_{k+1}})^{w_{k+1}}\} - \left\{1 - \prod_{i=1}^{n} (1-\tau_{\eta_i})^{w_i}\right\}\{1-(1-\tau_{\eta_{k+1}})^{w_{k+1}}\}, \\ \left\{1 - \prod_{i=1}^{n} (1-c_{\eta_i})^{w_i}\right\} + \{1-(1-c_{\eta_{k+1}})^{w_{k+1}}\} - \left\{1 - \prod_{i=1}^{n} (1-c_{\eta_i})^{w_i}\right\}\{1-(1-c_{\eta_{k+1}})^{w_{k+1}}\} \\ \prod_{i=1}^{n} (g_{\eta_i})^{w_i}(g_{\eta_{k+1}})^{w_{k+1}}, \prod_{i=1}^{n} (u_{\eta_i})^{w_i}(u_{\eta_{k+1}})^{w_{k+1}}, \prod_{i=1}^{n} (\phi_{\eta_i})^{w_i}(\phi_{\eta_{k+1}})^{w_{k+1}} \end{array} \right\rangle$$

$$= \left\langle 1 - \prod_{i=1}^{k+1} (1-\tau_{\eta_i})^{w_i}, 1 - \prod_{i=1}^{k+1} (1-c_{\eta_i})^{w_i}, \prod_{i=1}^{k+1} (g_{\eta_i})^{w_i}, \prod_{i=1}^{k+1} (u_{\eta_i})^{w_i}, \prod_{i=1}^{k+1} (\phi_{\eta_i})^{w_i} \right\rangle$$

Hence, in general, the expression

$$PNWAA(\eta_1,\eta_2,....,\eta_m) = \left\langle \begin{array}{l} 1-\prod_{i=1}^{n}\left(1-\tau_{\eta_i}\right)^{w_i}, 1-\prod_{i=1}^{n}\left(1-c_{\eta_i}\right)^{w_i}, \\ \prod_{i=1}^{n}\left(g_{\eta_i}\right)^{w_i}, \prod_{i=1}^{n}\left(u_{\eta_i}\right)^{w_i}, \prod_{i=1}^{n}\left(\phi_{\eta_i}\right)^{w_i} \end{array} \right\rangle \quad (5)$$

holds true $\forall n \in N$

This completes the proof.

Theorem 2: The PNWAA operator satisfies the following properties:

i. Consistency: $PNWAA(\eta_1,\eta_2,......,\eta_p) \in PNN$

ii. Idempotency: $PNWAA(\eta,\eta,......,\eta) = \eta$

iii. $PNWAA(\eta_1,\eta_2,......,\eta_p) = PNWAA(\eta_p,\eta_{p-1},......,\eta_1)$

iv. Let ϕ be the permutation on (1, 2…., p) then

$$PNWAA(\eta_{\phi(1)},\eta_{\phi(2)},......,\eta_{p(\phi)}) = PNWAA(\eta_1,\eta_2,......,\eta_n)$$

Proof: (i)The proof of (i) is straight- forward.

(ii) $w_1\eta + w_2\eta + ... + w_p\eta = (w_1 + w_2 + ... + w_p)\eta = \eta$

Since $\sum_{i=1}^{p} w_i = 1$

(iii) Since

$$PNWAA(\eta_1,\eta_2,.....,\eta_p) = \sum_{i=1}^{p} w_i\eta_i$$
$$= w_1\eta_1 + w_2\eta_2 + ... + w_p\eta_p = w_p\eta_p + w_{p-1}\eta_{p-1} + ... + w_1\eta_1$$
$$= PNWAA(\eta_p,\eta_{p-1},......,\eta_1)$$

(iv) Suppose that ϕ is a permutation on (1,2, …., n). Then,

$$PNWAA(\eta_{\phi(1)},\eta_{\phi(2)},.....,\eta_{p(\phi)}) = \sum_{i=1}^{p} w_i(\eta_{\phi(i)})\eta_{\phi(i)}$$
$$= w_1(\eta_{\phi(1)})\eta_{\phi(1)} + w_2(\eta_{\phi(2)})\eta_{\phi(2)} + ... + w_p(\eta_{\phi(p)})\eta_{\phi(p)}$$
$$= w_1\eta_1 + w_2\eta_2 + ... + w_p\eta_p \text{ (using } (viii) \text{ of proposition 1)}$$
$$= PNWAA(\eta_1,\eta_2,....,\eta_p)$$

This completes the proof.

4. SVPNS-ARAS STRATEGY FOR GROUP DECISION MAKING

Let $\tau=\{\tau_1, \tau_2,...,\tau_L\}$ be a set of L alternatives, $\chi=\{\chi_1,\chi_2,...,\chi_M\}$ be a set of M attributes, and $\omega=\{\omega_1,\omega_2,...,\omega_N\}^T$ be the weight vector of N DMs with $0\leq\omega_n\leq1$, and $\sum_{n=1}^{N}\omega_n = 1.$

Further, suppose that the weight γ_m is assigned to the attribute χ_m such that $0\leq\gamma_m\leq1$, $\sum_{m=1}^{M}\gamma_m = 1.$

The ARAS strategy for group decision making (see Figure1) is developed using the following steps.

Step 1: Construct the decision matrices

Assume that $\Delta'^n = (\alpha'^n_{lm})_{L\times M}$ is the decision matrix of nth DM where α'^n_{lm} denotes the rating of the alternative τ_i over the attribute χ_m provided by the nth DM in terms of PNNs. Then we obtain

$$\Delta'^n = (\alpha'^n_{lm})_{L\times M} = \begin{pmatrix} \alpha'^n_{11} & \alpha'^n_{12} & \alpha'^n_{1M} \\ \alpha'^n_{21} & \alpha'^n_{22}\ldots & \alpha'^n_{2M} \\ \vdots & \ddots & \vdots \\ \alpha'^n_{L1} & \alpha'^n_{L2}\cdots & \alpha'^n_{LM} \end{pmatrix} \quad (6)$$

where n = 1, 2, …, N.

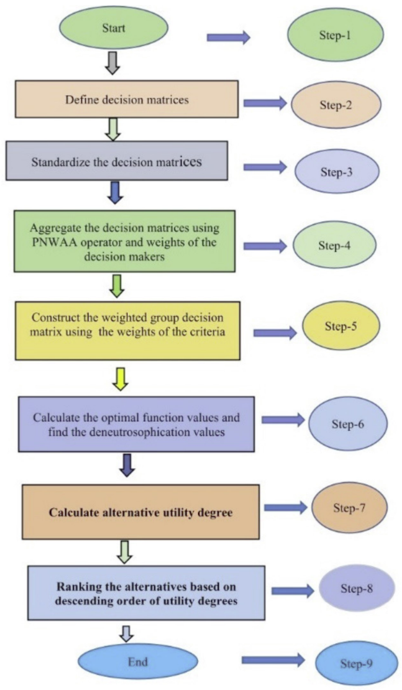

Figure 1. Flowchart of the developed ARAS strategy using PNWAA operator

Step 2: Standardize the decision matrices

We eliminate the impact of different physical dimensions and measurements by standardizing the decision matrices $(\alpha'^{n}_{lm})_{L\times M}$ as follows: For the entry $\alpha''^{n}_{lm} = \left\langle t''^{n}_{lm}, c''^{n}_{lm}, g''^{n}_{lm}, u''^{n}_{lm}, f''^{n}_{lm} \right\rangle (n = 1,2,.....N)$ in the matrix Δ'^{n} is considered as:

i. For benefit criterion, no change

$$\alpha''^{n}_{lm} = \left\langle t''^{n}_{lm}, c''^{n}_{lm}, g''^{n}_{lm}, u''^{n}_{lm}, f''^{n}_{lm} \right\rangle (n = 1,2,.....N) \tag{6}$$

ii. For cost criterion, complement is considered

$$\alpha''^{n}_{lm} = \left\langle f'^{n}_{lm}, u'^{n}_{lm}, 1 - g'^{n}_{lm}, c'^{n}_{lm}, t'^{n}_{lm} \right\rangle (n = 1,2,.....N) \tag{7}$$

Then, the standardized decision matrix is obtained as:

$$\Delta''^{n} = (\alpha''^{n}_{lm})_{L\times M} = \begin{pmatrix} \alpha''^{n}_{11} & \alpha''^{n}_{12} & \alpha''^{n}_{1M} \\ \alpha''^{n}_{21} & \alpha''^{n}_{22}\ldots & \alpha''^{n}_{2M} \\ \vdots & \ddots & \vdots \\ \alpha''^{n}_{L1} & \alpha''^{n}_{L2}\cdots & \alpha''^{n}_{LM} \end{pmatrix} \tag{8}$$

Step 3: Formulate the Aggregated Decision Matrix (ADM) $\Delta = (\delta_{lm})_{L\times M}$ using the PNWAA operator

$$\begin{aligned} & PNWAA_{\omega}\left(\alpha''^{1}_{lm}, \alpha''^{2}_{lm}, ..., \alpha''^{N}_{lm}\right) \\ & = \omega_1 \alpha''^{1}_{lm} \oplus \omega_2 \alpha''^{2}_{lm} \oplus \ldots \oplus \omega_N \alpha''^{N}_{lm} \\ & = \left\langle \begin{matrix} 1 - \prod_{n=1}^{M}\left(1 - t''^{n}_{lm}\right)^{\omega_n}, 1 - \prod_{n=1}^{M}\left(1 - c'''^{n}_{lm}\right)^{\omega_n}, \\ \prod_{n=1}^{M}\left(g''^{n}_{lm}\right)^{\omega_n}, \prod_{n=1}^{M}\left(u''^{n}_{lm}\right)^{\omega_n}, \prod_{n=1}^{M}\left(f''^{n}_{lm}\right)^{\omega_n} \end{matrix} \right\rangle \end{aligned} \tag{9}$$

Then we obtain

$$\Delta = (\delta_{lm})_{L\times M} = \begin{pmatrix} \delta_{11} & \delta_{12} & \delta_{1M} \\ \delta_{21} & \delta_{22}\ldots & \delta_{2M} \\ \vdots & \ddots & \vdots \\ \delta_{L1} & \delta_{L2}\cdots & \delta_{LM} \end{pmatrix} \tag{10}$$

where δ_{im} is the element of ADM Δ.

Step 4: Establish the weighted ADM using the criteria weights

Using the scalar multiplication with PNNs and criteria weights with the formula

(Eq. 11), we obtain $\hat{\delta}_{lm}$ as the weighted rating as follows.

$$\hat{\delta}_{lm} = \delta_{lm} * \gamma_m, \quad l = 1,2,....L; m = 1,2,...,M \tag{11}$$

$$\hat{\Delta} = (\hat{\delta}_{lm})_{L\times M} = \begin{pmatrix} \hat{\delta}_{11} & \hat{\delta}_{12} & \hat{\delta}_{1M} \\ \hat{\delta}_{21} & \hat{\delta}_{22}\dots & \hat{\delta}_{2M} \\ \vdots & \ddots & \vdots \\ \hat{\delta}_{L1} & \hat{\delta}_{L2}\cdots & \hat{\delta}_{LM} \end{pmatrix} \tag{12}$$

Step 5: Calculate the Optimal Function Values (OFVs)

The OFV denoted by S_l' is obtained as:

$$S_l' = \bigoplus_{m=1}^{M} \hat{\delta}_{lm}, l = 1,2,....,L. \tag{13}$$

The S_i denotes the deneutrosphication values using the score value (3) as follows:

$$S_l = Sc\left(S_l'\right) = \frac{t_{S_l'} + c_{S_l'}}{2} + \frac{g_{S_l'} + u_{S_l'} + f_{S_l'}}{3} \tag{14}$$

Step 6: Calculate the alternative utility degree (AUD)

The AUD τ_i is presented as:

$$\Xi_l = \frac{Sc\left(S_l'\right) =}{Sc\left(S_l'^{*}\right)}; l = 1,2,...,L. \tag{15}$$

Here the ideal best

$$Sc\left(S_l'^{*}\right) = \max\left\{Sc(S_1'), Sc(S_2'),...,Sc(S_L')\right\}$$

Step 7: Rank the alternatives

Ranking is done based on the descending order of Ξ_l. The highest value of Ξ_l indicates the best choice.

Step 8: End

4. ILLUSTRATIVE EXAMPLE OF GREEN SUPPLIER SECTION PROBLEM

This section presents an illustrative problem of green supplier selection to reflect the applicability of the SVPNS-ARAS strategy. Suppose a motors company plans to incorporate environment healthy features into the product design stage with the aim of protecting the environment and achieving sustainable development of the social economy. To do this, the motor company wishes to choose the best option. After initial screening, four suppliers are considered for whole evaluation process.

Suppliers are:

i. Alien Energy (α_1),
ii. Aryav Green Energy Pvt Ltd.(α_2),
iii. Novus Green Energy Systems Limited (α_3), and
iv. GreenAge India Resources Pvt. Ltd (α_4).

The motor company employs three experts to form a group of DM_S hiring from three consultancy departments: DM_1 is hired from the production department; DM_2 is hired from the purchasing department; DM_3 is hired from the quality inspection department. Selected three criteria for evaluation are:

i. product quality (κ_1),
ii. pollution control (κ_2), and
iii. environment management (κ_3).

Let the weight vectors of the criteria and DMs be ω=(0.28, 0.31, 0.41) and weights of the DMs be ν=(0.25, 0.41, 0.34) respectively.

Step 1: The decision matrices are formulated as:

$$\Delta'^{1} = \begin{array}{cccc} & \kappa_1 & \kappa_2 & \kappa_3 \\ \alpha_1 & \langle 0.48, 0.32, 0.45, 0.21, 0.27\rangle & \langle 0.53, 0.52, 0.58, 0.56, 0.34\rangle & \langle 0.74, 0.75, 0.56, 0.45, 0.43\rangle \\ \alpha_2 & \langle 0.74, 0.42, 0.42, 0.37, 0.28\rangle & \langle 0.45, 0.22, 0.71, 0.58, 0.29\rangle & \langle 0.54, 0.55, 0.56, 0.38, 0.31\rangle \\ \alpha_3 & \langle 0.71, 0.53, 0.7, 0.65, 0.75\rangle & \langle 0.53, 0.45, 0.75, 0.58, 0.69\rangle & \langle 0.74, 0.527, 0.621, 0.32, 0.48\rangle \\ \alpha_4 & \langle 0.51, 0.57, 0.64, 0.62, .48\rangle & \langle 0.62, 0.45, 0.42, 0.81, 0.55\rangle & \langle 0.87, 0.425, 0.248, 0.59, 0.34\rangle \end{array}$$

$$\Delta'^{2} = \begin{array}{cccc} & \kappa_1 & \kappa_2 & \kappa_3 \\ \alpha_1 & \langle 0.68, 0.62, 0.35, 0.51, 0.36\rangle & \langle 0.35, 0.72, 0.52, 0.62, 0.34\rangle & \langle 0.64, 0.82, 0.92, 0.55, 0.43\rangle \\ \alpha_2 & \langle 0.64, 0.38, 0.58, 0.75, 0.48\rangle & \langle 0.85, 0.52, 0.82, 0.42, 0.39\rangle & \langle 0.74, 0.55, 0.85, 0.23, 0.41\rangle \\ \alpha_3 & \langle 0.61, 0.87, 0.28, 0.47, 0.35\rangle & \langle 0.36, 0.71, 0.22, 0.58, 0.5\rangle & \langle 0.74, 0.553, 0.56, 0.42, 0.26\rangle \\ \alpha_4 & \langle 0.22, 0.62, 0.44, 0.79, 0.25\rangle & \langle 0.82, 0.46, 0.78, 0.4, 0.32\rangle & \langle 0.65, 0.56, 0.348, 0.23, 0.34\rangle \end{array}$$

$$\Delta'^{3} = \begin{array}{cccc} & \kappa_1 & \kappa_2 & \kappa_3 \\ \alpha_1 & \langle 0.48, 0.65, 0.45, 0.31, 0.47\rangle & \langle 0.53, 0.62, 0.43, 0.3, 0.32\rangle & \langle 0.64, 0.82, 0.42, 0.25, 0.53\rangle \\ \alpha_2 & \langle 0.84, 0.26, 0.45, 0.37, 0.38\rangle & \langle 0.85, 0.52, 0.21, 0.5, 0.39\rangle & \langle 0.64, 0.35, 0.56, 0.48, 0.31\rangle \\ \alpha_{4,} & \langle 0.81, 0.72, 0.36, 0.27, 0.35\rangle & \langle 0.53, 0.65, 0.33, 0.4, 0.29\rangle & \langle 0.64, 0.427, 0.321, 0.32, 0.38\rangle \\ \alpha_4 & \langle 0.41, 0.77, 0.24, 0.52, 0.22\rangle & \langle 0.92, 0.75, 0.52, 0.39, 0.25\rangle & \langle 0.77, 0.725, 0.458, 0.39, 0.34\rangle \end{array}$$

Step 2: Normalization is not required as criteria are benefit type.

Step 3: Using PNWAA operator (9), ADM is obtained as:

$$\Delta = \begin{array}{cccc} & \kappa_1 & \kappa_2 & \kappa_3 \\ \alpha_1 & \langle 0.573859, 0.572613, 0.405941, 0.344923, 0.366808\rangle & \langle 0.463176, 0.644556, 0.500954, 0.472225, 0.333064\rangle & \langle 0.668128, 0.804593, 0.62245, 0.400084, 0.461682\rangle \\ \alpha_2 & \langle 0.7481, 0.352445, 0.490806, 0.494327, 0.387458\rangle & \langle 0.792433, 0.458056, 0.497775, 0.483102, 0.362158\rangle & \langle 0.665057, 0.49007, 0.664496, 0.33487, 0.347652\rangle \\ \alpha_3 & \langle 0.716396, 0.767311, 0.383488, 0.422136, 0.423464\rangle & \langle 0.466577, 0.637209, 0.343126, 0.511167, 0.450303\rangle & \langle 0.709581, 0.506697, 0.4756, 0.357743, 0.344807\rangle \\ \alpha_4 & \langle 0.368465, 0.66958, 0.393217, 0.64501, 0.281767\rangle & \langle 0.835313, 0.582485, 0.58212, 0.473073, 0.336901\rangle & \langle 0.763113, 0.599036, 0.351038, 0.348324, 0.34\rangle \end{array},$$

Step 4: The weighted ADM is constructed as:

$$\hat{\Delta} = \begin{array}{cccc} & \kappa_1 & \kappa_2 & \kappa_3 \\ \alpha_1 & \langle 0.212456, 0.211812, 0.776908, 0.74227, 0.755166\rangle & \langle 0.175391, 0.27433, 0.807118, 0.792476, 0.711186\rangle & \langle 0.363794, 0.487982, 0.823347, 0.686882, 0.728418\rangle \\ \alpha_2 & \langle 0.320258, 0.114564, 0.819322, 0.820964, 0.766837\rangle & \langle 0.385787, 0.172961, 0.805527, 0.79809, 0.729892\rangle & \langle 0.361386, 0.241284, 0.845711, 0.638556, 0.648439\rangle \\ \alpha_3 & \langle 0.297317, 0.335191, 0.764629, 0.785465, 0.786156\rangle & \langle 0.177015, 0.269713, 0.717779, 0.812184, 0.780884\rangle & \langle 0.397662, 0.251526, 0.845711, 0.656091, 0.646258\rangle \\ \alpha_4 & \langle 0.120752, 0.266604, 0.770011, 0.884461, 0.701405\rangle & \langle 0.428305, 0.237204, 0.845578, 0.792917, 0.713716\rangle & \langle 0.445934, 0.312499, 0.651022, 0.648953 0.642549\rangle \end{array}$$

Step 5: The OFV S_l' is obtained as:

$$S_l' = \bigoplus_{m=1}^{3} \hat{\delta}_{lm}, l = 1, 2, 3, 4. \quad (16)$$

$$Sc(S_1') = 1.08417, Sc(S_2') = 1.28666,$$
$$Sc(S_3') = 1.131979, Sc(S_4') = 1.068661$$

Here the ideal best

$$Sc\left(S_l'^{*}\right) = \max\{1.08417, 1.28666, 1.131979, 1.068661\}$$

So, $Sc\left(S_l'^{*}\right) = 1.28666$

Step 6: The utility degree Ξ_l is obtained as:

$$\Xi_l = \frac{Sc(S')_l}{(S'^{b})}; l = 1, 2, 3, 4. \quad (17)$$

Step 7: Rank the alternatives

$$\Xi_1 = 0.842624, \Xi_2 = 1, \Xi_3 = 0.879781, \Xi_4 = 0.83057.$$

Therefore $\Xi_2 \succ \Xi_3 \succ \Xi_1 \succ \Xi_4$.
Ranking order is obtained as $\alpha_2 > \alpha_3 > \alpha_1 > \alpha_4$.

Therefore 2nd alternative α_2 is the best option.

5.1. Sensitivity analysis

Any MCDM strategy aims to reduce the bias and tries to ensure the reliability of the solution (Pamučar et al., 2017). The weights of the decision makers play a significant role in the ranking order of the alternatives. Therefore, changes in the weights of the decision-makers may impact the final ranking of the MCDM strategy. Therefore, a sensitivity analysis is required to be performed to examine the stability of the solution subject to variations in the weights of the decision-makers in a prescribed situation Considering the different weights of the decision-makers with fixed weights of the criteria, the ranking results are shown in Table 1. From Table 1, it is found that 1st rank and 2nd rank remain unchanged but the ranking order of 3rd position and 4th position gets changed. So, it shows that the weights of the decision makers play a role in ranking order. Similarly, considering the different weights of the criteria with fixed weights of the decision makers, the ranking results are shown in Table 2. From Table 2, we see that the ranking order remains unchanged in this problem. So, in this case, we see that the weights of the decision-maker play a more important role than criteria weights in ranking order in this case.

6. CONCLUSIONS

We define and establish the basic properties of the weighted arithmetic aggregation operator for SVNNs and proves its basic properties. Using the developed aggregation operator, we propose a new outranking ARAS strategy for MCGDM in the SVPNN environment that deals with a complex MAGDM problem. The advantages of the developed strategy are that it handles uncertainty comprehensively; it refers to a flexible scientific strategy. This paper solves a green supplier selection problem in PNN environment which is a new in PNN literature. The developed SVPNS-ARAS strategy can be used to handle other MAGDM issues such as electronic supply chain (Deepu & Ravi, 2021), teacher selection (Mondal & Pramanik, 2014), selection of bricks (Mondal & Pramanik, 2015a), etc. In the

Table 1. Ranking results with the variation of weights of the criteria

DM1	DM2	DM3	C1	C2	C3		A1	A2	A3	A4
0.15	0.5	0.35	0.28	0.31	0.41	OFV	1.095042821	1.299461347	1.118629865	1.060369261
						UD	0.842690024	1	0.86084143	0.816006991
						Ranking	3	1	2	4
0.2	0.35	0.45	0.28	0.31	0.41	OFV	1.074685326	1.286858538	1.12473876	1.080270976
						UD	0.835122827	1	0.874018646	0.839463357
						Ranking	4	1	2	3
0.25	0.41	0.34	0.28	0.31	0.41	OFV	1.084170107	1.286660073	1.131979227	1.068661147
						UD	0.84262362	1	0.87978116	0.830569962
						Ranking	3	1	2	4
0.33	0.33	0.33	0.28	0.31	0.41	OFV	1.067732874	1.267384469	1.139200086	1.069461178
						UD	0.842469902	1	0.89885945	0.84383358
						Ranking	4	1	2	3
0.4	0.3	0.3	0.28	0.31	0.41	OFV	1.071062123	1.26833072	1.153225078	1.077975208
						UD	0.844465777	1	0.909246149	0.849916314
						Ranking	4	1	2	3

Table 2. Ranking results with the variation of weights of the criteria

DM1	DM2	DM3	C1	C2	C3		A1	A2	A3	A4
0.25	0.41	0.34	0.33	0.33	0.33	OFV	1.062768408	1.281534201	1.138558068	1.071829636
						UD	0.829293962	1	0.888433758	0.836364572
						Ranking	4	1	2	3
0.25	0.41	0.34	0.35	0.35	0.3	OFV	1.053677395	1.277422458	1.141273841	1.074435635
						UD	0.824846758	1	0.893419591	0.841096862
						Ranking	4	1	2	3
0.25	0.41	0.34	0.4	0.28	0.32	OFV	1.056499717	1.268740319	1.139279044	1.06176357
						UD	0.8327157	1	0.897961004	0.836864582
						Ranking	4	1	2	3
0.25	0.41	0.34	0.2	0.45	0.35	OFV	1.072977068	1.299743782	1.136737507	1.090955398
						UD	0.825529542	1	0.874585693	0.83936175
						Ranking	4	1	2	3

future, we will introduce objective weight method for criteria and new methods for determining weights of decision makers in the proposed SVPNN- ARAS strategy to improve the capacity of the proposed MCGDM strategy.

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“SVPNN-ARAS” СТРАТЕГИЈА ЗА МКДО У ОКРУЖЕЊУ СА ЈЕДНО-ВРЕДНОСНОМ ПЕНТАПАРТИЦИЈОМ НЕУТРОЗОФСКИМ БРОЈЕВИМА

Surapati Pramanik

Извод

Циљ рада је да прошири АРАС (“Additive Ratio Assessment”) стратегију на једновредносно пентапартиционисано неутрозофско окружење које називамо “SVPNN-ARAS” стратегијом. Пентапартиционисани неутрозофски број са једном вредношћу је проширење фази броја и неутрозофског броја. Свеобухватно се бави неизвесношћу пошто неодређеност замењује са три независна ентитета, наиме, контрадикцијом, незнањем и непознатим. Да би се развила стратегија доношења одлука, дефинисан је оператор аритметичког усредњавања за пентапартиционисане бројеве и установљена су његова основна својства. Пентапартиционисани број са једном вредношћу је погодан математички алат за свеобухватно суочавање са несигурношћу. “SVPNN-ARAS” стратегија ефикасно процењује и рангира изводљиве алтернативе. У овом раду је развијена АРАС стратегија за вишекритеријумско групно одлучивање у пентапартиционисаном окружењу неутрозофских бројева. Да би се демонстрирала примењивост предложене стратегије, решава се проблем избора зеленог добављача и врши се анализа осетљивости како би се одразили утицаји пондерисања доносилаца одлука и критеријума на рангирање алтернатива.

Кључне речи: АРАС, фази скуп, МКДО, МКГДО, неутрозофски скуп, пентапартиционисани неутрозофски скуп

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