PROMTHEE Plithogenic Pythagorean Hypergraphic Approach in Smart Materials Selection

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Abstract

The production sectors are optimizing its profit with the employment of smart materials at recent times and one of the challenges faced is the selection of smart materials. This article proposes a new decision-making method based on the approach of PROMTHEE plithogenic Pythagorean hypergraph. The efficiency of the proposed method is determined in the selection of smart materials that are significantly utilized in the production processes by the production sectors. In this research work, the decision making on smart material selection environment is characterized by four major influencing factors such as production processes, operational necessities, fiscal constraints and external effects with eighteen sub-factors. The main objective of this research work is to determine the core sub-factors persuading the selection of smart materials based on the five-point scale of expert's opinion represented as Pythagorean neutrosophic number. Out of eighteen sub-factors four significant factors belonging to each of the major factors were identified by this method. The plithogenic hypergraphs with Pythagorean representation are the extension of plithogenic hypergraphs and the novel decision - making method with the integration of PROMTHEE developed in this article will certainly benefit the decision makers on smart material selection. Comparative analysis on the criteria is also made based on Pythagorean neutrosophic sets & neutrosophic sets.

Keywords: Plithogenic sets, Pythagorean Neutrosophic number, Hypergraph, PROMTHEE, Smart materials

1.Introduction

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Decision making is a complicated and multi staged process which involves the selection of alternatives subjected to criteria satisfaction. The researchers have proposed various multi-criteria decision making methods (MCDM) such as Analytical hierarchal process, Analytical network process, TOPSIS, ELECTRE, DEMATEL,VIKOR,PROMTHEE and these MCDM methods are applied with reference to the needs. Incomplete descriptive information on the alternatives, multiple qualitative and quantitative criteria are some of the challenges of decision making and it can be handled by outranking methods. The most commonly used outranking method is PROMTHEE developed by Vincke and Brans in 1985. (The Preference Ranking Order Method for Enrichment Evaluation) This method is advantageous as it caters to partial and complete ranking of the alternatives. The compatibility nature of this outranking method has attracted the researchers and it has been extended to design optimal soultions to various MCDM problems and as a strategic tool in planning of natural resources. The method of PROMTHEE was extended to fuzzy PROMTHEE and it is applied in material selection, supply chain management, medical analysis. The subsequent extensions are intutionistic fuzzy PROMTHEE and neutrosophic PROMTHEE in which the criterion alternative satisfaction rate is expressed as intutionistic sets and neutrosophic sets respectively.

Smarandache [1] introduced plithogenic sets as an extension of crisp sets, fuzzy sets, intuitionistic sets and neutrosophic sets. The plithogenic sets are inclusive in nature as it considers the degree of appurtenance and contradiction with respect to the attributes. The process of making feasible decisions encompasses different entities and varied phases. The milieu of decision making is dependent on various factors and the highly significant attributes of the decision-making elements. Plithogenic sets are applied in multi attribute decision making in various perspectives. Abdel Basset et al [2] constructed a new plithogenic decision-making model for evaluating the medical care systems, Grida et al [3] measured the performance of IoT based supply chain. Quek et al [4] used the measures of entropy in the model framed for multi- attribute decision making. Abdel Basset et al [5] developed a combined multi criteria decision-making model to select the manufacturing industries also formulated a hybrid decision making method with deployment function to select the sustainability supply chain metrics. An integrated multi –criteria decision making method was also developed by Abdel Basset et al [6] to evaluate the financial performance of the manufacturing sectors. Smarandache [7] introduced the concept of plithogenic hypersoft sets by extending soft sets to hypersoft sets. Muhammad et al [8] proposed a new multi-criteria decision-making model based on the Plithogenic hypersoft sets. Shazia et al [9] discussed the application of plithogenic whole hypersoft sets in mullti attribute decision making by using the approach of frequency matrix and also developed the approach of Plithogenic Subjective Hyper-Super-Soft Matrices. Nivetha and Smarandache [10] discussed combined plithogenic hypersoft sets and its application in multi attribute decision making. Nivetha and Smarandache [11] developed the approach of concentric plithogenic hypergraphic approach based on plithogenic hypersoft sets and examined its efficiency in multi attribute decision making. Smarandache [12] coined plithogenic n super hypergraph by extending the concepts of hypergraph and n-super hypergraph. Nivetha and Smarandache [13] developed a multi attribute decision making model based on plithogenic n super hypergraph. The multi attribute plithogenic decision making models are highly compatible as it facilitates in making optimal decisions with the considerations of dominant attributes.

In the plithogenic decision making methods the expert's opinion is given significance and it is represented as neutrosophic numbers. The plithogenic aggregation operators are used to determine the aggregate expert's opinion. Jansi et al [14] generalized neutrosophic sets by the concept of Pythagorean neutrosophic set with the condition of $(\alpha(x))^2 + (\beta(x))^2 + (\gamma(x))^2 \leq 2$, where $\alpha(x)$, $\beta(x)$ and $\gamma(x)$ represent the truth, indeterminacy and falsity degrees. The truth and falsity neutrosophic components are dependent in pythagorean neutrosophic sets and the general dependence degree of all the three components is taken as ½ = 0.5. Jansi et al [14] developed the correlation measure between pythagorean neutrosophic sets and sternly substantiated the need of pythagorean neutrosophic sets in the field of medical analysis of diseases with symptoms . Yager [15] introduced a new class of pythagorean sets, which are discussed in different dimensions and are extensively used in varied decision-making scenario.The arguments in favour of pythagorean neutrosophic sets are taken into account and this has motivated to propose multi attribute decision making method with pythagorean plithogenic hypergraphic approach. The plithogenic hypergraph comprises of plithogenic envelopes with generalized representation of membership values, but it is confined to Pythagorean sets in plithogenic Pythagorean hypergraphs in the proposed approach, also the neutrosophic expert's opinion is more comprehensive and if the expert's opinion is of Pythagorean in nature, then this developed approach shall be adopted as the Pythagorean neutrosophic sets are the special case of neutrosophic sets. The decision-making method developed in this paper proposes a two-step processes. In the first phase the criteria for smart material selection is determined based on the pythagorean neutrosophic representation of expert's opinion. In the second phase the alternatives are ranked based on the any of the multi criteria decision making methods with criteria contradiction degree. Lazim Abdullah and Pinxin Goh [16] used the pythagorean representation of expert's opinion to select the feasible solid waste management methods. Carlos Granados [17] presented on Pythagorean Neutrosophic Pre-Open Sets. Ajay and Chellamani [18] discussed about Pythagorean Neutrosophic Fuzzy Graphs. Jansi and Mohana [19] developed the concepts of Pythagorean neutrosophic Subring of a ring.According to Pythagorean researchers, the representation of expert's opinion as pythagorean sets are highly compatible in

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making decisions. In this research work the method of PROMTHEE is used for ranking the alternatives in the second phase. Also based on the defuzzification method of neutrosophic sets proposed by Solairaju and Shahjahan [17] the method of defuzzifing pythagorean neutrosophic sets is suggested in this article. The expert's opinion based on the representations of pythagorean neutrosophic and neutrosophic expert's opinion with plithogenic operators in criterion selection is compared.

The structure of the remaining paper is as follows: the preliminaries are presented in section 2; the two step phases of multi criterion approach is developed in section 3; the proposed method is applied in smart materials selection in section 4; the results are discussed in section 5 and the last section concludes the work.

2. Preliminaries

This section presents the basic definitions required for the research work.

Definition 2.1 [14]

A Pythagorean set P is of the form $\{(x, A(x), C(x)): x \in X\}, A(x): X \to [0,1], C(x): X \to [0,1]$, where X is the universal set , A(x) & C(x) are the membership & non-membership degrees for each $x \in X$ satisfying the condition of $(A(x))^2 + (C(x))^2 \leq 1$.

Definition 2.2 [14]

A neutrosophic set N is of the form $\{(x, A(x), B(x), C(x)): x \in X\}, A(x): X \to [0,1], B(x): X \to [0,1]$, $C(x): X \to [0,1]$where X is the universal set , A(x) ,B(x)& C(x) are the degrees of membership, indeterminacy and non-membership for each $x \in X$.

Definition 2.3 [14]

A pythagorean neutrosophic set P_N is of the form $\{(x, \alpha(x), \gamma(x), \beta(x)): x \in X\}, \alpha(x): X \to [0,1], \beta(x): X \to [0,1]$, $\gamma(x): X \to [0,1]$where X is the universal set , α(x) , γ (x)& β(x) are the degrees of membership, indeterminacy and non-membership for each $x \in X$ satisfying the condition of $(\alpha(x))^2 + (\gamma(x))^2 + (\beta(x))^2 \leq 2$. Also if $\alpha(x)$ and $\beta(x)$ (where $0 \leq \alpha(x) + \beta(x) \leq 1$) are 100 % dependent then $0 \leq (\alpha(x))^2 + (\beta(x))^2 \leq 1$. If $\gamma(x)$ is independent 100% from $\alpha(x)$ and $\beta(x)$ with $0 \leq \alpha(x) + \gamma(x) + \beta(x) \leq 2$, then $(\alpha(x))^2 + (\gamma(x))^2 + (\beta(x))^2 \leq 2$.

Definition 2.4

A pythagorean neutrosophic set is a special case of neutrosophic set, based on the defuzzification method of Solairaju and Shahjahan [17] the Pythagorean neutrosophic set is transformed to Pythagorean set of the form <α , f >, where

$$f = \begin{cases} \gamma^2 + \frac{[1-\gamma^2-\beta^2][1-\gamma^2]}{[\gamma^2+\beta^2]} & if\ \gamma = 0 \\ \gamma^2 + \frac{[1-\gamma^2-\beta^2]\gamma^2]}{[\gamma^2+\beta^2]} & if\ 0 < \gamma^2 \leq 0.5 \\ \gamma^2 + [1-\gamma^2-\beta^2]\left[0.5 + \frac{\gamma^2-0.5}{\gamma^2+\beta^2}\right] & if\ 0.5 < \gamma^2 \leq 1 \end{cases}$$

3. Methodology

This section comprises of the steps involved in the proposed method. The method proposed consists of two phases in which pythagorean plithogenic approach is used in criterion selection in the first phase and in the later phase the method of PROMTHEE is used to rank the alternatives. Preference Ranking Organization method for Enrichment of Evaluations (PROMTHEE) developed Jean-Pierre Brans [18] to make optimal ranking of alternatives. This method is predominantly used in several decision-making environments on resources management in various dimensions. The method of PROMTHEE is extended to fuzzy PROMTHEE by combining the concept of fuzzy in handling uncertain aspects. Fuzzy PROMTHEE is applied to make feasible decisions on supply chain management. Intuitionistic and neutrosophic approaches in PROMTHEE method are the extensions of fuzzy PROMTHEE [19-21]. The representations of the expert's opinion are varied in each of the approaches and at some instances, interval-valued representations are also used. The Pythagorean neutrosophic sets integrated with PROMTHEE is used in making decisions on solid waste management. The linguistic variables stating the expert's opinion are quantified using Pythagorean sets. But to the best of the author's knowledge, plithogenic Pythagorean hypergraph approach is not so far used to make criterion selection. Also the

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representation of the sub-factors as plithogenic hypergraphs and the selection of the core sub-factors using aggregate plithogenic operators is the noteworthy phenomenon of the method.

Step 1: The decision-making problem is formulated with the selection of criteria and sub-criteria factors based on the expert's opinion ($E_1,E_2,..E_n$) together with Pythagorean neutrosophic linguistic rating scale.

Step 2: The criterion selection is made by the plithogenic hypergraph approach with the contradiction degree of the sub criteria belonging to each criterion and plithogenic aggregate operators. $E1 \wedge_p E2 = (a_1 \wedge_F a_2, \frac{1}{2}((b_1 \wedge_F b_2) + (b_1 v_F b_2)), c_1 v_F c_1)$. Based on the defuzzified scores the core criteria are selected.

Step 3: The decision making matrix consisting of the w alternatives together with the contradiction degree and the linguistic expert's opinion on g criteria satisfaction is constructed

Step 4: The aggregate decision-making matrix is determined by using the aggregate plithogenic operators.

Step 5: The normalized decision matrix N = [z_{bh}] is obtained

Where $z_{bh} = (\frac{\alpha_{bh}}{\gamma_h}, \frac{\beta_{bh}}{\gamma_h}, \frac{\gamma_{bh}}{\gamma_h})$ $\gamma_h = \max(\gamma_{bh})$ [Benefit criteria]

$z_{bh} = (\frac{\alpha_h}{\alpha_{bh}}, \frac{\alpha_h}{\beta_{bh}}, \frac{\alpha_h}{\gamma_{bh}})$ $\alpha_h = \min(\gamma\alpha_{bh})$ [Cost criteria]

Step 6: The weighted normalized matrix S = [j_{bh}] is obtained

Where $j_{bh} = z_{bh} * w_h$ b = 1,2,..w, h = 1,2,.. g

Step 7 : The preference function P (w_i,w_j) is defined as

P (w_i,w_j) = 0 if d (w_i,w_j) ≤ 0 [d (w_i,w_j) denotes the pairwise comparison of the alternatives]

= d (w_i,w_j) if d (w_i,w_j) > 0

Step 8 : The positive $O^+(w_k)$ and negative $O^-(w_k)$ outranking flows is calculated from the aggregate preference values.

Step 9: The net outranking flow N (w_k) = $O^+(w_k) - O^-(w_k)$ is calculated and the alternatives are ranked based on the values

4. Smart Material Selection using the Proposed Method

In this section, the proposed method is applied in criteria selection at first phase and in ranking of the alternatives in the second phase.

Phase I : Criteria Selection using Plithogenic Pythagorean Hypergraphic representation

The selection of the smart materials is based on the four major influencing factors and each factor has certain sub-factors. The criteria is selected from each of the sub-factors belonging to the core factors as represented in Table 4.1 and the expert's linguistic rating scale is given in Table 4.2.

- Production Processes
- Operational Necessities
- Fiscal Constraints
- External Effects

Table 4.1 List of Criteria

CRITERIA	SUB-CRITERIA

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Production Processes	P1 Flexibility P2 Adaptability P3 Reliability P4 Ductility P5 Malleability
Operational Necessities	O1 Resistivity O2 Solidity O3 Durability O4 Conductivity
Fiscal Constraints	F1Material Expenditure F2Manpower F3Maintenance F4Machinery F5Screening
External Effects	E1 Compatibility to production environment E2 Affordability by the production sector E3Nature of the material E4Deterioration rate

Table 4.2 Linguistic Criteria Significant Rating Scale

Linguistic Variable	Neutrosophic Representation
Very Highly Significant (HS)	(0.9,0.1,0.1)
Highly Significant (S)	(0.7,0.1,0.2)
Moderately Significant (MS)	(0.4,0.2,0.8)
Highly Insignificant (IS)	(0.1,0.1,0.9)
Very Highly Insignificant (HIS)	(0,0,0)

The plithogenic hypergraphic representation based on expert's opinion for each of the major criteria is presented in Table 4.3. In the graphical representation, the sub criteria of each criterion is considered as the vertices and each of the hyperedges represents the expert's opinion. The sub criterion weight is computed using plithogenic operators.

Table 4.3 Plithogenic Hypergraphic Representation of Major Criteria

Plithogenic Hypergraphic Representation	C	E1	E2	E3	$E1\wedge_p E2\wedge_p E3$	Crisp Score
Production Processes						
	P1	VHS	VHS	HS	(0.997,0.1,0.002)	**0.994**
	P2	HS	VHS	VHS	(0.992,0.1,0.002)	0.984
	P3	MS	MS	HS	(0.892,0.15,0.128)	0.618
	P4	VHS	MS	HS	(0.982,0.125,0.016)	0.964
	P5	HS	VHS	MS	(0.982,0.15,0.016)	0.964

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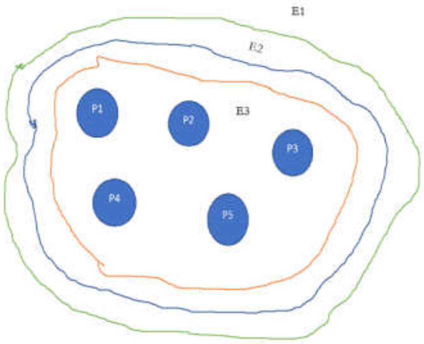
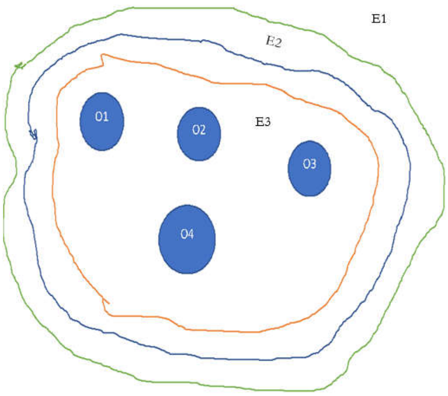
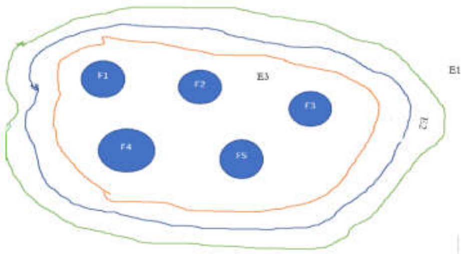
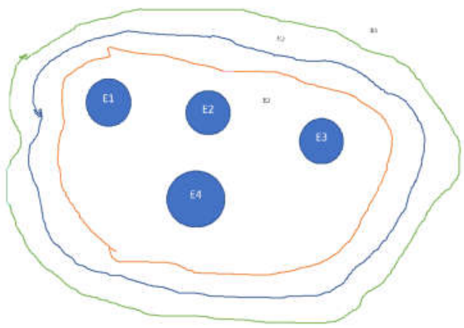
	**P1 > P2 > P3 & P4 > P3**					
Operational Necessities						
	**O1**	HS	VHS	VHS	(0.997,0.4995,0.002)	**0.994**
	O2	VHS	HS	VHS	(0.991,0.495,0.004)	0.984
	O3	HS	MS	HS	(0.838,0.491,0.144)	0.789
	O4	VHS	HS	VHS	(0.997,0.4995,0.002)	0.964
	O1 > O2 > O4 > O3					
Fiscal Constraints						
	**F1**	HS	VHS	VHS	(0.997,0.4995,0.002)	**0.99**
	F2	VHS	MS	HS	(0.982,0.499,0.016)	0.796
	F3	VHS	HS	VHS	(0.997,0.4995,0.002)	0.984
	F4	VHS	VHS	MS	(0.994,0.501,0.008)	0.796
	F5	VHS	HS	HS	(0.991,0.4975,0.004)	0.964
	F1 > F3 > F5 > F3 & F4					
External Effects						
	**E1**	**HS**	**HS**	**VHS**	(0.991,0.4975,0.004)	**0.994**
	E2	**MS**	**HS**	**HS**	(0.946,0.489,0.032)	**0.984**
	E3	**VHS**	**MS**	**HS**	(0.982,0.499,0.016)	**0.796**
	E4	**HS**	**MS**	**VHS**	(0.991,0.4975,0.004)	**0.964**
	E1 > E2 >E4 >E3					

Phase II – Selection of Alternatives using Plithogenic PROMTHEE

Table 4.4 Linguistic Rating Scale by the Experts for Alternatives & Criteria

Criterion Satisfaction of the alternatives Linguistic rate by the Experts		**Criterion vitality linguistic rating scale by the Experts**	
Very Highly Satisfied (VHS)	(0.9,0.1,0.1)	Very Highly Inessential (VHIE)	(0,0,0)

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Highly Satisfied (HS)	(0.8,0.2,01)	Highly Inessential (HIE)	(0.1,02,0.9)
Moderately Satisfied (MS)	(0.5,0.1,03)	Moderately Essential (ME)	(0.5,0.3,0.7)
Highly Dissatisfied (HD)	(0.1,0.1,0.9)	Highly Essential (HE)	(0.8,0.1,0.2)
Very Highly Dissatisfied (VHD)	(0,0,0)	Very Highly Essential (VHE)	(0.9,01,0.1)

Let S1, S2, S3, S4, S5 be the smart materials that are taken as the alternatives and the criterion satisfaction of the alternatives by the expert's opinon are presented in Table.4.5.

Table 4.5 Decision Making Matrix based on Expert's opinion

	Linguistic Weight	ME	HE	HE	VHE	HE	HE	VHE	HE	HE	ME	HE	VHE
Smart Materials (Alternatives)	**Contradiction Degree**	**E1**				**E2**				**E3**			
		C1	**C2**	**C3**	**C4**	**C1**	**C2**	**C3**	**C4**	**C1**	**C2**	**C3**	**C4**
S1	0	HS	MS	HS	HD	MS	HD	MS	HS	HS	HS	MS	HD
S2	0.2	MS	HS	HS	HS	MS	MS	MS	HS	MS	VHS	HD	MS
S3	0.4	VHS	HD	HS	VHS	HS	HS	HD	HS	MS	VHS	HS	HS
S4	0.6	HS	VHS	MS	VHS	HS	HS	HD	VHS	HD	HD	HS	HS
S5	0.8	HD	HS	HS	MS	VHS	HS	VHS	MS	HS	MS	HS	HS

Table 4.6 Aggregated Decision matrix

Smart Materials (Alternatives)	**Contradiction Degree**	**C1**	**C2**	**C3**	**C4**
S1	0	(0.32,0.205,0.433)	(0.04,0.17,0.937)	(0.2,0.14,0.559)	(0.008,0.14,0.991)
S2	0.2	(0.275,0.118,0.504)	(0.55,0176,0.716)	(0.15,0.14,0.79)	(0.45,0.20,0.34)
S3	0.4	(0.61,0.19,0.25)	(0.75,0.123,0.22)	(0.7,0.16,022)	(0.85,0.25,0.09)
S4	0.6	(0.72,0.18,0.16)	(0.56,0.14,0.41)	(0.634,0.12,0.26)	(0.86,0.24,0.07)
S5	0.8	(0.87,0.103,0.086)	(0.85,0.13,0.078)	(0.90,0.19,0.05)	(0..82,0.11,0.087)

Table 4.7 Final criterion weights

C1	**C2**	**C3**	**C4**
(0.1,0.233,0.9)	(0.8,0.1,0.2)	(0.8,0.1,0.2)	(0.8,0.1,0.2)

Table 4.8 Normalized decision making matrix

Smart Materials (Alternatives)	**C1**	**C2**	**C3**	**C4**
S1	(0.635,0.407,0.859)	(0.042,0.1814,1)	(0.253,0.177,0.707)	(0.008,0.141,1)
S2	(0.546,0.234,1)	(0.586,0.187,0.764)	(0.189,0.177,1)	(0.45,0.201,0.34)
S3	(1.21,0.37,0.49)	(0.8,0.13,0.234)	(0.88,0.202,0.278)	(0.85,0.25,0.09)
S4	(1.42,0.35,0.31)	(0.597,0.149,0.437)	(0.80,0.151,0.329)	(0.86,0.24,0.07)
S5	(1.72,0.204,0.171)	(0.91,0.139,0.083)	(1.139,0.241,0.063)	(0.82,0.11,0.08)

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Table 4.9 Weighted normalized decision making matrix

Smart Materials (Alternatives)	C1	C2	C3	C4
S1	(0.063,0.093,0.773)	(0.034,0.018,0.2)	(0.202,0.017,0.142)	(0.0065,0.0141,0.2)
S2	(0.054,0.05,0.9)	(0.469,0.018,0.152)	(0.15,0.017,0.2)	(0.36,0.02,0.068)
S3	(0.12,0.086,0.44)	(0.64,0.013,0.047)	(0.71,0.02,0.055)	(0.686,0.03,0.018)
S4	(0.14,0.08,0.285)	(0.478,0.015,0.087)	(0.64,0.02,0.065)	(0.69,0.02,0.014)
S5	(0.172,0.05,0.153)	(0.725,0.0134,0.0167)	(0.91,0.024,0.013)	(0.662,0.011,0.0175)

Table 4.10. Ranking of alternatives

Alternatives	Positive Outranking Flow	Negative Outranking Flow	Net Outranking Flow	Ranking of the Alternatives
S1	0.0145	0.9105	-0.896	5
S2	0.00775	0.70425	-0.6965	4
S3	0.63425	0.07925	0.555	2
S4	0.499	0.1315	0.3675	3
S5	0.74625	0.07625	0.67	1

4. Results and Discussion

Among thirteen criteria discussed under four major core factors, the core criteria are determined using the plithgothenic hypergraphic approach with Pythagorean representations. The expert's aggregate opinion is calculated and based on the final crisp score value the following criteria namely Flexibility, Resistivity, Material Expenditure and Compatibility to Production Environment are designated as the core criteria. The alternatives are ranked based on the net flow values. Table is constructed using the expert's opinion on the criterion satisfaction of the alternatives and the vitality of the criteria in smart materials selection. The contradiction degree of the alternatives is taken into account as each of the materials varies from one another in its nature and properties. The alternatives S1,S2,S3,,S5 are ranked as S5 >S3>S4>S2>S1

Conclusion

A new decision-making two phase method with PROMTHEE integrated with plithogenic hypergraphic approach is developed in this article. The efficiency of the proposed method is examined in smart material selection. The Pythagorean neutrosophic representation of the expert's opinion and its defuzzification approach used in this method is a novel initiative to explore the possible ways of quantifying the linguistic rating scales. Plithogenic PROMTHEE method with the contradiction degree of the alternatives is also an added novelty to the proposed decision-making method. The two-phase method of making decisions can further be validated by using other multi criteria decision-making methods in phase two to rank the alternatives, also comparative analysis of the efficiency of integrated plithogenic MCDM methods can be made. This method will definitely benefit the decision makers to make compatible decisions on the alternatives.

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