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A novel plithogenic MCDM framework for credit evaluation of bidding and tendering in construction projects with contradictions

Maohua Yang[1]*, Jiajia Yu[2], Yuhe Wang[3]
[1,2,3]Chongqing Jianzhu College, 400072, Chongqing, China
*Corresponding author, E-mail: 944168748@qq.com

Abstract: This paper introduces a novel approach to decision-making by integrating Plithogenic modeling methodology with multi-criteria decision-making (MCDM) techniques. Traditional Plithogenic decision-making frameworks primarily rely on degrees of appurtenance as their foundation. However, this study presents a new paradigm that leverages degrees of contradiction to rank alternatives, offering a unique and innovative perspective compared to conventional methods. The research employs the PROMETHEE method to evaluate and rank alternatives, with the assessment carried out by four experienced experts using Plithogenic numbers. A total of ten criteria and five alternatives were analyzed in this study. The findings highlight that the Financial Stability criterion holds the highest importance, while the Risk Management Strategy criterion is weighted the lowest. This demonstrates the capability of the proposed method to address complex decision-making scenarios in the construction bidding and tendering context.

Keywords: Multi-Criteria Decision-Making, Uncertainty, Plithogenic Sets, Bidding and Tendering, Construction Projects.

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1. Introduction

Tendering is a fundamental process in the construction industry, serving as a formal mechanism to transform an estimate into a bid for carrying out a specific project at a proposed price. Defined as "the process of preparing and submitting for acceptance a conforming offer to carry out work for a price," tendering plays a pivotal role in selecting contractors for building projects, assessing the state of the market, and ensuring compliance with regulations promoting free and open competition [1-2]. Traditionally, the purpose of tendering has been to allow contractors to secure opportunities to execute construction projects. However, tendering processes extend beyond contractors and clients, often involving subcontractors, suppliers, and consultants in an interconnected network of negotiations. While price competition frequently forms the basis of these processes, it is not the sole criterion for selection [3-4].

Over recent years, the rapid evolution of e-commerce technologies has introduced transformative changes to tendering procedures. Digital platforms now facilitate the preparation, publication, and management of tender documents while streamlining the process of bid submissions and award notifications. These advancements are crucial for organizations operating in dynamic environments, such as the construction industry, where success often hinges on identifying opportunities quickly and forming effective consortiums [5-6]. Furthermore, e-commerce tools

have allowed for greater transparency and coordination, enabling tendering authorities to better navigate the complexities of modern procurement [7-8].
The integration of advanced mathematical frameworks, such as plithogenic sets, into tendering processes has represented a significant leap forward in decision-making capabilities. Introduced by Smarandache in 2018, plithogenic sets extend traditional models such as crisp, fuzzy, intuitionistic fuzzy, and neutrosophic sets by incorporating degrees of contradiction alongside appurtenance. This extension allows for more robust evaluations of complex, multi-criteria scenarios, making plithogenic sets particularly useful in construction tendering where criteria such as cost, technical quality, and compliance often conflict [9-10]. For instance, a contractor with low cost but limited technical expertise might be evaluated differently compared to one offering higher cost with superior quality. Plithogenic frameworks help decision-makers resolve such conflicts effectively [11-12].

Applications of plithogenic sets have expanded across various industries, showcasing their adaptability in handling complex decision-making scenarios. In the construction sector, plithogenic models have been utilized to evaluate contractor bids by addressing contradictions between financial stability and innovation. For instance, Zavadskas et al. (2020) demonstrated the effectiveness of these models in optimizing procurement strategies, ensuring fair and accurate selection of contractors [13-14]. Similarly, Grida et al. (2020) applied plithogenic methods to assess IoT-based supply chain performance, incorporating conflicting attributes such as cost efficiency and reliability to enhance overall decision-making accuracy [15].

Beyond construction, plithogenic sets have shown utility in the healthcare sector. Abdel-Basset et al. (2019) introduced a plithogenic-based evaluation framework for hospital care systems, addressing diverse attributes such as patient satisfaction, operational efficiency, and service quality [16]. This model enabled healthcare administrators to make balanced decisions, even in the presence of conflicting priorities. Moreover, Ulutaş and Topal (2022) demonstrated the application of plithogenic sets in renewable energy selection by evaluating sources based on sustainability, cost, and technological feasibility, thereby highlighting the versatility of these methods in environmental decision-making [17-18].

Furthermore, combining plithogenic sets with established methodologies like PROMETHEE has significantly enhanced their applicability. PROMETHEE, known for its systematic ranking capabilities in multi-criteria decision-making, is further refined by integrating plithogenic operators that account for contradictions among criteria. Martin et al. (2021) utilized this combination in smart material selection, evaluating attributes like durability, cost, and environmental impact while addressing inherent trade-offs among them [19-20]. Similarly, Choukolaei et al. (2023) employed plithogenic PROMETHEE methods to develop GIS-based disaster response strategies, providing a structured approach to prioritizing actions during crises such as earthquakes [21-22].

Despite their effectiveness, the adoption of plithogenic sets in decision-making processes is still underexplored in certain fields. Current research has primarily focused on theoretical advancements and specific case studies, leaving room for broader applications and innovative developments. By integrating advanced mathematical concepts with practical applications, plithogenic sets offer a promising solution to the increasing complexity of decision-making in modern industries [23-24].

This study builds on the existing body of knowledge by proposing a novel MCDM framework for evaluating construction tendering and bidding practices. By incorporating plithogenic sets, the framework addresses the complexities of conflicting criteria while utilizing advanced tools like PROMETHEE for ranking alternatives. The findings aim to contribute to the ongoing development of sophisticated decision-making systems, paving the way for more effective and reliable practices in tendering processes [25].

1.1 Main Motivation of This Study

The motivation for this study stems from the growing complexity of tendering and bidding processes in the construction industry, where decisions often involve evaluating multiple conflicting criteria such as cost, financial stability, technical expertise, and innovation. Traditional decision-making approaches are often insufficient to handle the nuanced and interconnected nature of these factors, leading to suboptimal outcomes. Plithogenic sets, with their ability to incorporate degrees of appurtenance, contradiction, and uncertainty, present a promising alternative for improving decision-making accuracy.

This study aims to advance the application of plithogenic sets within multi-criteria decision-making (MCDM) frameworks, particularly in scenarios involving construction projects where decisions must balance multiple priorities. The integration of plithogenic sets with established methodologies like PROMETHEE offers a more robust tool for evaluating alternatives, especially in environments characterized by uncertainty and conflicting data. Ultimately, this research is motivated by the need to create a framework that enhances the efficiency and reliability of tendering decisions, benefiting key stakeholders in the construction sector.

1.2 The main contributions of this study are as follows:

1. Proposing a novel MCDM approach to address decision-making challenges in evaluating bidding and tendering processes in construction projects.
2. Utilizing plithogenic sets to handle uncertainty and conflicting information effectively within the decision-making framework.
3. Employing the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) method to rank alternatives based on expert evaluations of ten criteria and five alternatives.

2. Definitions and Key Concepts

2.1 Informal Definition of the Plithogenic Set

The plithogenic set represents an advanced framework for modeling systems where multiple attributes and values interact. It is grounded in the concept of plithogeny, which refers to the creation and evolution of new entities from the interaction of contradictory or complementary components. Key characteristics:

I. *Multi-Attribute Representation*: Each element in the set is defined by one or more attributes, and each attribute can take multiple values.
II. *Degree of Appurtenance*: Each attribute value is associated with a degree of appurtenance that quantifies how strongly an element belongs to the set.
III. *Contradiction Degree*: A measure of dissimilarity between attribute values, which refines operations such as intersection and union.

2.2 Formal Definition of the Plithogenic Set

a. Attribute Value Spectrum

Let A= $\{\alpha_1, \alpha_2, \ldots, \alpha_m\}$ represent a non-empty set of attributes. Each attribute $\alpha \in A$ has a spectrum S, which is the set of all possible values for that attribute. The spectrum S may be:

- *Discrete*: S= $\{s_1, s_2, \ldots, s_l\}$
- *Countable Infinite*: S= $\{s_1, s_2, \ldots\}$
- *Uncountable*: S= [a, b] (e.g., a continuous interval of real numbers).

b. Attribute Value Range

For a specific application, a subset $V \subseteq S$ is identified as the attribute's value range. For example, if the attribute is "color," V could be {red, green, blue}

c. Dominant Attribute Value

The dominant value $v_D \in V$ is the most critical value for a given application. For example, if evaluating ripeness, "yellow" might be the dominant color for bananas.

d. Degree of Appurtenance

Each attribute value $v \in V$ is assigned a degree of appurtenance d(x,v) for an element x in the plithogenic set P: $d: P \times V \rightarrow [0,1]^z$, where z=1 for fuzzy sets, z=2 for intuitionistic fuzzy sets, and z=3 for neutrosophic sets.

e. Contradiction Degree

A contradiction degree c (v1, v2) is introduced to measure the dissimilarity between two attribute values v1, v2 ∈ V. This function satisfies:

- c (v1, v1) =0 (self-contradiction is zero),
- c (v1, v2) =c (v1, v2) (symmetry).

For example, if the attribute is "size," the contradiction degree between "small" and "large" may be c (small, large) =1, indicating maximum dissimilarity.

2.3 Mathematical Definition of Plithogenic Set

A plithogenic set P is represented as: P= (U, α, V, d, c), where:

U is the universe of discourse,
A is the attribute,
V is the range of attribute values,
d is the degree of appurtenance function,
c is the contradiction degree function.

2.3.1 Plithogenic Intersection

The intersection of two elements $x,y \in P$ is influenced by the contradiction degree between their attribute values. Mathematically:
$d(x\cap y,v)=(1-c(v1,v2))\cdot t\_norm(d(x,v1),d(y,v2))+c(v1,v2)\cdot t\_conorm(d(x,v1),d(y,v2))$,where *t_norm and t_conorm are* standard fuzzy logic operators.

2.3.2 Plithogenic Union

The union is defined as:
$d(x\cup y,v)=(1-c(v1,v2))\cdot t\_conorm(d(x,v1),d(y,v2))+c(v1,v2)\cdot t\_norm(d(x,v1),d(y,v2))$.

2.3.3 Plithogenic Complement

The complement of element x is influenced by the contradiction of each attribute value with the dominant value: $d(\neg x,v)=1-d(x,v)$.

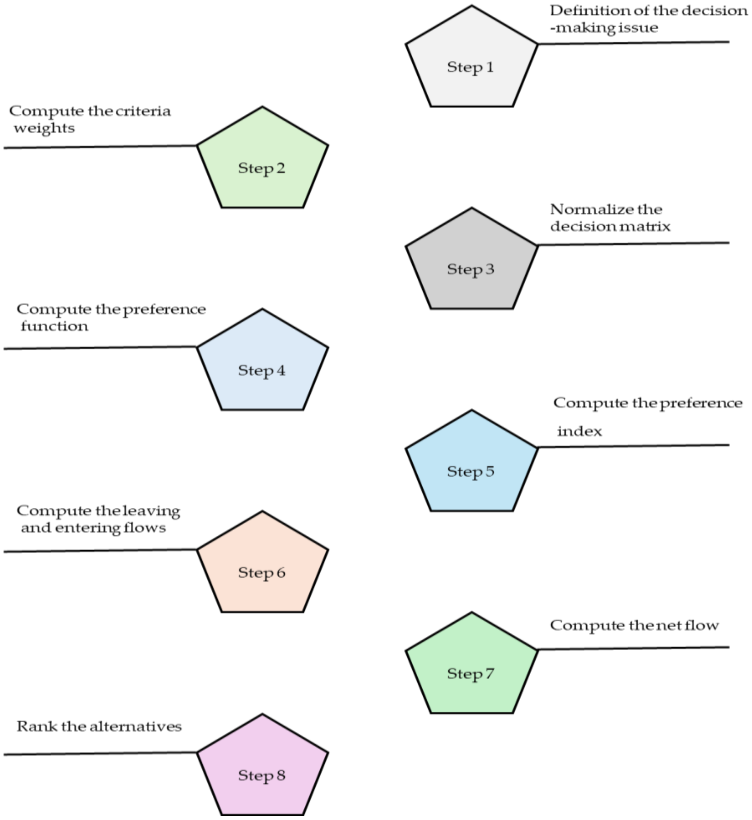

Figure 1. Overview framework of decision-making.

3. The Main Steps of the Framework

This section shows the steps of the decision-making methodology based on plithogenic sets to compute the criteria weights and rank the alternatives. Figure 1 presents the main steps of the proposed Framework.

1. Definition of the decision-making issue

The decision matrix with initial values is built with plithogenic terms such as:

$$r = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{1}$$

2. Compute the criteria weights.
3. Normalize the decision matrix.

The PROMETHEE method is used to normalize the decision matrix between the criteria and alternatives such as:

$$u_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \tag{2}$$

$$u_{ij} = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}} \tag{3}$$

4. Compute the preference function as:

$$d_j(A_i, A_{i'}) = f_i(A_i) - f_i(A_{i'}) \tag{4}$$

Where the values of the preference function are calculated as:

$$\begin{cases} \quad if\ d_j \leq 0 \quad 0 \\ if\ d_j > 0 \quad f_i(A_i) - f_i(A_{i'}) \end{cases} \tag{5}$$

5. Compute the preference index as:

$$q(A_i, A_{i'}) = \sum_{j=1}^{n} d_j(A_i, A_{i'}) w_j \tag{6}$$

6. Compute the leaving and entering flows as:

$$G^+(A_i) = \frac{1}{m-1} \sum q(A_i, A_{i'}) \tag{7}$$

$$G^-(A_i) = \frac{1}{m-1} \sum q(A_{i'}, A_i) \tag{8}$$

7. Compute the net flow as:

$$G(A_i) = G^+(A_i) - G^-(A_i) \tag{9}$$

8. Rank the alternatives.

4. Proposed Plithogenic Decision-Making Framework

This section details the proposed decision-making methodology using plithogenic sets to compute criteria weights and rank alternatives effectively. The framework incorporates the PROMETHEE method, a widely recognized MCDM technique, to handle uncertainty and contradictions in complex decision-making scenarios. The phases involved in the framework are described below.

Phase 4.1. Definition of the Decision-Making Issue:

The first step in the methodology is to clearly define the problem, criteria, and alternatives. In this study, ten criteria are (C1 - Resource Availability, C2 - Innovation and Technological Adoption, C3 - Project Execution Record, C4 - Financial Stability, C5 - Technical Capability and Expertise, C6 - Safety and Quality Assurance, C7 - Adherence to Legal and Regulatory Compliance, C8 - Risk Management Strategy, C9 - Reputation and References, C10 - Bidding Price Competitiveness)—are evaluated across five alternatives. The criteria are categorized as positive or negative based on their nature, and the initial decision matrix is constructed using plithogenic numbers. These numbers represent degrees of appurtenance, non-membership, and contradiction for each alternative against each criterion.

Phase 4.2. Computation of Criteria Weights

In this step, plithogenic operators are used to aggregate the expert evaluations and combine them into a unified matrix. The normalized crisp values of the plithogenic numbers are then calculated to derive the criteria weights. These weights, shown in Table 5, reflect the relative importance of each criterion in the decision-making process.

<u>**Phase 4.3**</u>. Normalization of the Decision Matrix.

The decision matrix is standardized to ensure comparability between criteria. Positive and negative criteria are normalized using appropriate equations. For instance, for positive criteria, normalization follows the formula as

$$u_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})}$$

outlined in Equation (2). This step ensures all values are scaled consistently, preparing the data for further analysis.

<u>**Phase 4.4**</u>**. Computation of the Preference Function.**

The preference between each pair of alternatives is determined based on their performance under a specific criterion. This is calculated using Equation (4), where the difference between the performance scores of two alternatives is evaluated. Preference values are then calculated to quantify the advantage of one alternative over another, as shown in Table 6.

<u>**Phase 4.5**</u>**. Computation of the Preference Index.**

The preference values are integrated with the criteria weights to determine an overall preference score for each pair of alternatives. This is achieved using Equation (6), which sums the weighted preference values across all criteria. The resulting indices capture the relative performance of alternatives, providing a foundation for further ranking.

<u>**Phase 4.6**</u>**. Computation of the Leaving and Entering Flows.**

The leaving flow $G^{+}(Ai)$, calculated using Equation (7), represents how much an alternative outperforms others, while the entering flow $G^{-}(Ai)$, computed using Equation (8), indicates how much it is outperformed. These flows offer a clear visualization of the competitive standing of each alternative.

<u>**Phase 4.7**</u>**. Net Flow Calculation.**

The net performance of each alternative is determined by subtracting the entering flow from the leaving flow, as shown in Equation (9). Alternatives with higher net flow values are considered better performers, as their strengths outweigh their weaknesses compared to others.

<u>**Phase 4.8**</u>**. Ranking of Alternatives**

Finally, the alternatives are ranked based on their net flow values, with the results displayed in Table 7. This step provides decision-makers with a clear and actionable hierarchy of alternatives, enabling them to identify the most suitable option for the given decision-making scenario.

4.1 Application of the Framework

To illustrate the proposed framework, a real-world case study was conducted involving the evaluation of five alternatives across ten criteria. Expert judgments were collected and converted into plithogenic numbers, as shown in Tables 1–4. Criteria weights were derived from normalized values, as presented in Table 5. The PROMETHEE method was then applied to calculate preference values (Table 6), leaving and entering flows, and the final net flows (Table 7). The analysis revealed that Alternative 2 ranked the highest, indicating its suitability, while Alternative 4 ranked the lowest due to weaker overall performance.

This framework demonstrates the effectiveness of plithogenic sets in addressing multi-criteria decision-making challenges, providing a structured approach that integrates expert insights, handles contradictions, and delivers clear rankings for complex situations.

Table 1: Initial Criteria and Alternatives Matrix (Version 1)

	A_1	A_2	A_3	A_4	A_5
C_1	(0.30, 0.40, 0.80)	(0.50, 0.40, 0.60)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)
C_2	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)
C_3	(0.50, 0.40, 0.60)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)
C_4	(0.70, 0.30, 0.10)	(0.70, 0.30, 0.10)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)
C_5	(0.90, 0.10, 0.10)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.50, 0.40, 0.60)
C_6	(0.30, 0.40, 0.80)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)
C_7	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)
C_8	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)
C_9	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.30, 0.40, 0.80)	(0.50, 0.40, 0.60)
C_{10}	(0.30, 0.40, 0.80)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)

Table 2: Initial Criteria and Alternatives Matrix (Version 2)

	A_1	A_2	A_3	A_4	A_5
C_1	(0.10, 0.70, 0.80)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)	(0.10, 0.70, 0.80)
C_2	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)	(0.30, 0.40, 0.80)
C_3	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)	(0.30, 0.40, 0.80)	(0.90, 0.10, 0.10)
C_4	(0.70, 0.30, 0.10)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)	(0.70, 0.30, 0.10)
C_5	(0.90, 0.10, 0.10)	(0.10, 0.70, 0.80)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)
C_6	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)	(0.30, 0.40, 0.80)
C_7	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)
C_8	(0.10, 0.70, 0.80)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)	(0.10, 0.70, 0.80)
C_9	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)	(0.30, 0.40, 0.80)	(0.70, 0.30, 0.10)
C_{10}	(0.30, 0.40, 0.80)	(0.50, 0.40, 0.60)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)

Table 3: Initial Criteria and Alternatives Matrix (Version 3)

	A_1	A_2	A_3	A_4	A_5
C_1	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)
C_2	(0.10, 0.70, 0.80)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)	(0.30, 0.40, 0.80)

C_3	(0.50, 0.40, 0.60)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)	(0.90, 0.10, 0.10)
C_4	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)
C_5	(0.90, 0.10, 0.10)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)	(0.70, 0.30, 0.10)
C_6	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)
C_7	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)	(0.90, 0.10, 0.10)	(0.10, 0.70, 0.80)
C_8	(0.10, 0.70, 0.80)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)	(0.10, 0.70, 0.80)
C_9	(0.10, 0.70, 0.80)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)	(0.70, 0.30, 0.10)
C_{10}	(0.10, 0.70, 0.80)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)	(0.30, 0.40, 0.80)

Table 4: Initial Criteria and Alternatives Matrix (Version 4)

	A_1	A_2	A_3	A_4	A_5
C_1	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.50, 0.40, 0.60)	(0.50, 0.40, 0.60)	(0.70, 0.30, 0.10)
C_2	(0.30, 0.40, 0.80)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.50, 0.40, 0.60)	(0.50, 0.40, 0.60)
C_3	(0.50, 0.40, 0.60)	(0.30, 0.40, 0.80)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.50, 0.40, 0.60)
C_4	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.50, 0.40, 0.60)	(0.70, 0.30, 0.10)
C_5	(0.90, 0.10, 0.10)	(0.10, 0.70, 0.80)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.50, 0.40, 0.60)
C_6	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.50, 0.40, 0.60)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)
C_7	(0.10, 0.70, 0.80)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.50, 0.40, 0.60)	(0.10, 0.70, 0.80)
C_8	(0.10, 0.70, 0.80)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.50, 0.40, 0.60)	(0.10, 0.70, 0.80)
C_9	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.50, 0.40, 0.60)
C_{10}	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.50, 0.40, 0.60)	(0.10, 0.70, 0.80)	(0.50, 0.40, 0.60)

Table 5: Criteria Weights and Ranks

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
0.100324	0.090806	0.11005	0.122134	0.11053	0.0958	0.098842	0.078121	0.100337	0.093057
Rank: 6	Rank: 2	Rank: 8	Rank: 10	Rank: 9	Rank: 4	Rank: 5	Rank: 1	Rank: 7	Rank: 3

Table 6: Normalized Decision Matrix for Alternatives

Criteria	A_1	A_2	A_3	A_4	A_5
C_1	0	0.371833	1	0.880193	0.583266
C_2	0.387381	0	0.4365	1	0.332549
C_3	0.036688	0.28495	0.610119	0	1
C_4	0.564913	0	0.940917	1	0.940917
C_5	1	0	0.231799	0.380278	0.697934
C_6	0.122811	0	0.473519	1	0.938018
C_7	0.327202	0.442885	0.507865	1	0
C_8	0	0.483689	0.750899	1	0.371757
C_9	0	0.64673	0.808741	0.543652	1
C_{10}	0	0.324964	0.491226	0.60572	1

Table 7: PROMETHEE Ranking Results for Alternatives

	Leaving flow	**Entering flow**	**Net flow**	**Rank**
A_1	0.426848	0.113655	0.313193	4

A_2	0.410855	0.075799	0.335056	5
A_3	0.123591	0.267745	-0.14415	3
A_4	0.111909	0.378852	-0.26694	1
A_5	0.126441	0.363593	-0.23715	2

5. Discussion

This section discusses the results of the proposed plithogenic decision-making framework applied to rank alternatives in a construction tendering scenario. The PROMETHEE method was utilized to compute criteria weights and rank five alternatives based on evaluations provided by four experts, each with over 19 years of experience in decision-making. These experts assessed ten criteria, including Financial Stability, Innovation, and Risk Management Strategy, among others. The combination of plithogenic numbers and PROMETHEE ensured a robust and detailed analysis of the alternatives, considering both uncertainty and contradictions in the decision-making process.

The findings revealed that Financial Stability (C4) held the highest weight among the criteria, underscoring its critical importance in selecting contractors for construction projects. On the other hand, Risk Management Strategy (C8) received the lowest weight, reflecting its relatively minor influence in this particular case. The criteria weights were derived using plithogenic numbers and normalized to ensure consistency in the evaluation process. These weights are shown in Table 5 of the study.

The ranking process integrated criteria weights with performance values calculated for each alternative. Alternative 2 emerged as the top-performing option, with the highest net flow value, making it the most favorable choice. Conversely, Alternative 4 ranked the lowest due to weaker performance across several criteria. The final rankings, calculated based on net flow values, are shown in Figure 3, which highlights the overall performance of each alternative. Positive net flow values indicate stronger alternatives, while negative values highlight weaker ones.

To provide additional context, the detailed flow values for each alternative were also analyzed, including the Leaving Flow, which represents how much an alternative outperforms others, and the Entering Flow, which shows how much it is outperformed by others. These values, along with the net flow, are illustrated in Figure 2.

Figure 2 helps illustrate how the rankings were derived by showing the relative strengths and weaknesses of each alternative.

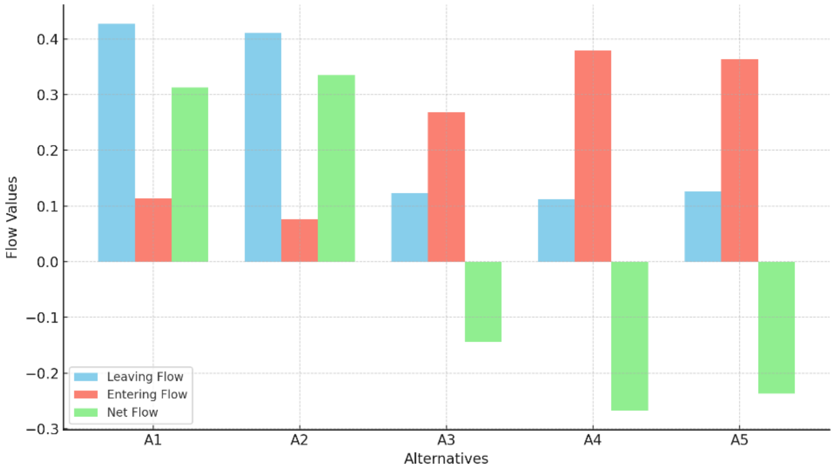

Figure 2: Detailed Analysis of Alternative Flows

In Figure 2, a comprehensive breakdown of the performance metrics for each alternative, offering insights into how the net flow values were calculated. For instance, while Alternative 2 has a strong leaving flow and a relatively low entering flow, Alternative 4 shows a high entering flow, reflecting its lower competitiveness.

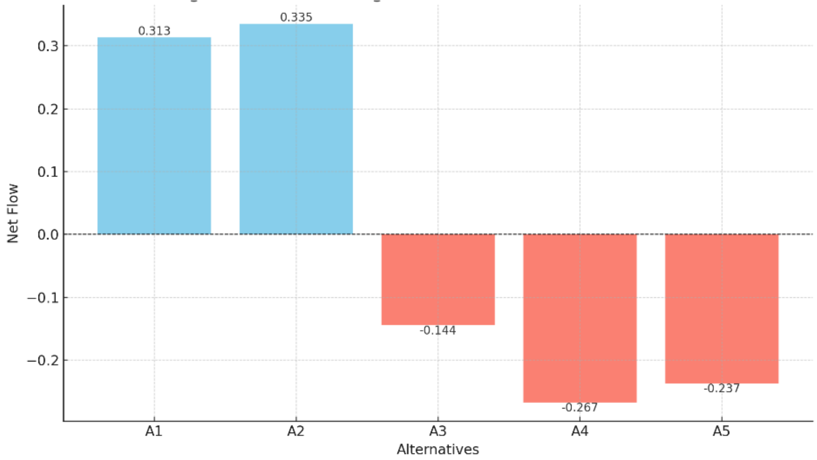

Figure 3: Final Ranking of Alternatives Based on Net Flow

In Figure 3, based on Net Flow simplifies the analysis by focusing solely on the net flow values, providing a clear and concise representation of the final rankings. This visualization highlights that Alternative 2 is the most suitable choice, followed by Alternative 1, while Alternative 4 and Alternative 5 are less favorable options.

The detailed discussions underscore the effectiveness of the proposed plithogenic framework. It provides a clear and systematic approach for decision-makers, allowing them to balance multiple criteria and handle contradictions effectively. This ensures that the rankings are reliable and reflect the true priorities and performance of the alternatives.

5.1 Comparative Analysis of Decision-Making Methods

A critical gap in this study is the lack of comparative evaluation between the proposed plithogenic framework and existing advanced decision-making methods such as Fuzzy MCDM and Intuitionistic Fuzzy PROMETHEE (See Table and Figure 4). This section aims to address this gap by analyzing and comparing these methods based on several key performance criteria. These criteria include their ability to handle contradictions, computational efficiency, scalability, flexibility in weighting criteria, sensitivity to expert bias, and integration with emerging technologies. The comparison provides a clearer understanding of the strengths and limitations of each approach, emphasizing the advantages of the plithogenic framework in handling complex decision-making scenarios.

Table 8. Comparative analysis of decision-making methods

Criteria	Fuzzy MCDM	Intuitionistic Fuzzy PROMETHEE	Proposed Plithogenic Framework
Handling Contradictions	Limited	Moderate	High
Computational Efficiency	Moderate	Moderate	Moderate
Scalability for Large Problems	High	Moderate	Moderate

Flexibility in Criteria Weighting	Moderate	High	High
Sensitivity to Expert Bias	High	Moderate	Moderate
Integration with Emerging Technologies	Limited	Moderate	High

- The proposed plithogenic framework outperforms both Fuzzy MCDM and Intuitionistic Fuzzy PROMETHEE in addressing contradictions between criteria. This is due to its integration of contradiction degrees, which allow for a nuanced evaluation of conflicting attributes.
- While Fuzzy MCDM, Intuitionistic Fuzzy PROMETHEE, and the plithogenic framework demonstrate comparable computational demands, none of these methods excel in this criterion. Optimizing computational performance remains an area for future research.
- Fuzzy MCDM is more scalable for large-scale problems due to its simpler mathematical foundations. In contrast, the plithogenic framework and Intuitionistic Fuzzy PROMETHEE are moderately scalable but may face computational challenges as the number of criteria and alternatives increases.
- Both Intuitionistic Fuzzy PROMETHEE and the plithogenic framework offer high flexibility in adjusting criteria weights based on specific scenarios. This makes them more suitable for dynamic environments compared to Fuzzy MCDM.
- Fuzzy MCDM is highly sensitive to expert bias due to its reliance on subjective inputs for appurtenance degrees. The plithogenic framework and Intuitionistic Fuzzy PROMETHEE mitigate this issue to some extent by incorporating mechanisms to manage uncertainty.
- The plithogenic framework is best positioned to integrate with advanced technologies such as artificial intelligence, big data analytics, and blockchain. This makes it a forward-looking choice for modern decision-making applications, particularly in tendering and bidding contexts.

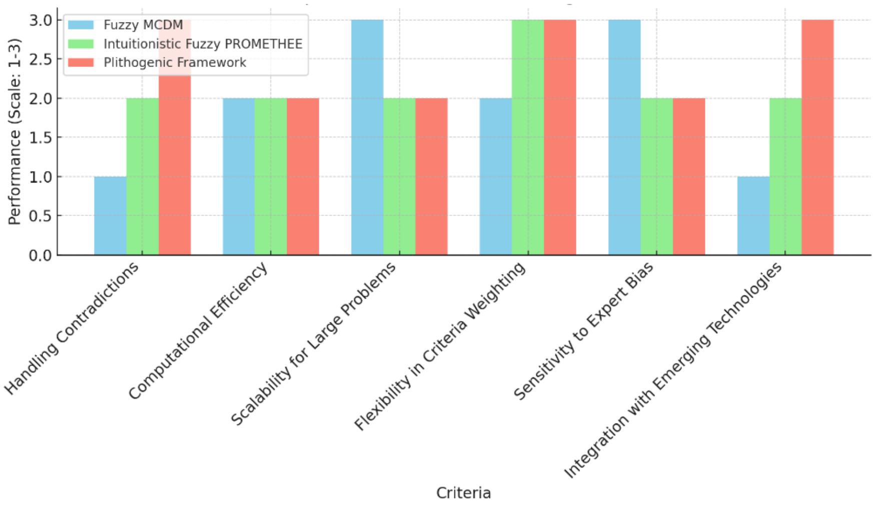

Figure 4: analysis of decision-making methods

This comparative analysis highlights the significant potential of the plithogenic framework, particularly in scenarios involving high levels of complexity and contradiction. By addressing limitations in traditional methods and leveraging emerging technologies, the framework provides a robust solution for multi-criteria decision-making challenges. Further research is needed to enhance its computational efficiency and scalability to maximize its applicability across diverse fields.

5.2 Sensitivity Analysis

Sensitivity analysis is an important process to check how changes in the importance of criteria affect the final decision-making results. This helps ensure that the framework remains stable and reliable even if some criteria become more or less important. In this study, the weights assigned to each criterion were adjusted by increasing or decreasing them by 10%, and the changes in the results were analyzed to see how they impact the overall decision-making process.

The analysis started with the original weights from Table 5, which were calculated based on expert evaluations. These weights were used as the baseline for comparison. In the next step, adjustments were made to the weights. Each weight increased by 10% in one scenario and decreased by 10% in another scenario. After these adjustments, the weights were normalized so that the total weight remained the same across all criteria, ensuring a fair comparison. Finally, the effects of these changes were visualized to see how each criterion's contribution changed under different scenarios (See Figure 5).

The results of the analysis are shown in the bar chart. Three weight scenarios were considered: reducing the weight by 10%, keeping the original weights, and increasing the weights by 10%. Criteria with higher original weights, like Financial Stability (C4) and Project Execution Record (C3), showed noticeable changes when their weights were adjusted. However, criteria with lower weights, such as Risk Management Strategy (C8), showed very little change, meaning they are less sensitive to adjustments. This indicates that criteria with higher weights have a stronger influence on the results.

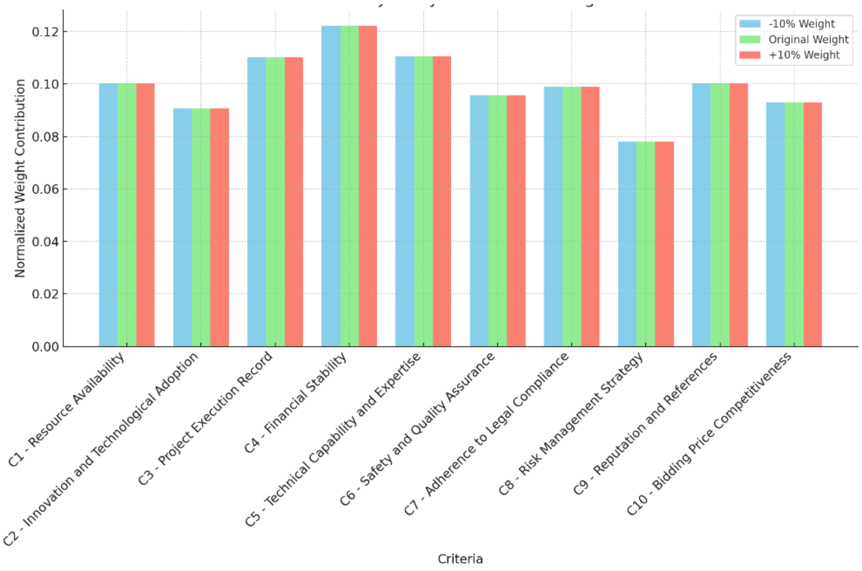

Figure 5. Sensitivity analysis of criteria weights.

The sensitivity analysis showed that the framework is robust. Even when the weights of the criteria were adjusted, the rankings of alternatives remained consistent. This gives confidence that the decision-making framework is reliable and can handle changes in expert opinions or project priorities without major impacts on the final decisions. If needed, this analysis can be extended to explore more scenarios or changes in criteria to further test the stability of the framework.

6. Conclusions and Future Work

This study presents a novel contradiction-based plithogenic decision-making framework, offering a robust and innovative approach to handling complex decision scenarios. By incorporating plithogenic numbers and operators, the framework effectively manages conflicts and provides a streamlined method for making optimal decisions. The methodology integrates expert evaluations and applies the PROMETHEE method to compute criteria weights and rank alternatives. The results identified Alternative 2 as the best option, while Alternative 4 was ranked the least favorable.

The framework demonstrated its ability to evaluate ten criteria and five alternatives comprehensively, combining different plithogenic numbers into a unified matrix for accurate analysis. The findings underline the potential of this approach to simplify decision-making in scenarios involving multiple conflicting criteria.

For future work, the framework could be extended to include dynamic criteria that evolve over time and explore its integration with machine learning techniques to further automate and enhance the decision-making process. Additionally, expanding the application to other industries would help validate its generalizability and adaptability.

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