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Advancing Sustainable Mobility: Comparative Analysis of MCDM Methods with Plithogenic and Neutrosophic Sets

Igno Mary[1]
Research Scholar,
Department of Mathematics,
Vels Institute of Science, Technology and Advanced Studies,
Pallavaram, Chennai, India

S. Sandhiya[2]
Assistant Professor,
Department of Mathematics,
Vels Institute of Science, Technology and Advanced Studies,
Pallavaram, India

Abstract: This work analyzes Multi-Criteria Decision Making from a comparative perspective, applying the Plithogenic Neutrosophic technique for the first time. Two leading multi-criteria decision methodologies, TOPSIS and VIKOR, were studied side by side to compare various responses for dealing with vehicular air pollution. Real information from metropolises of differing pollution levels and numerous vehicle types forms the basis for the analysis. After evaluating opinions using Plithogenic Neutrosophic sets, the researchers compare information and report the findings in an informative radar graph. We can clearly see on this graph that electric vehicles outperform petrol, diesel and hybrid vehicles in addressing air pollution. The article shows that incorporating Plithogenic Neutrosophic sets into MCDM approaches is effective and underlines the value of informed decisions depending on real world information to face important issues with the transport sector and environment.

Keywords: Neutrosophic set, Plithogenic sets, Plithogenic neutrosophic sets, Applications, Extensions, VIKOR method

1. Introduction

Selecting the right marketing strategies has become a significant challenge for businesses that operate in today's lively and crowded market. The main source of this challenge is how much faster consumer habits are changing, due to digital growth, rising economies and technology [1]. As a result, companies can now connect more easily with people, leading to steady economic expansion but also making it harder to find the right ways to connect with many audience types. A range of marketing tactics such as content marketing, using social media, teaming up with influencers and traditional advertisement, support a brand in connecting with its audience [2].

MCDM allows you to assess a range of criteria at once and helps rank and pick the best solution. When dealing with unpredictable situations or having multiple marketing aims, this way helps analyze a range of strategies by important elements. When we study many aspects and how they are connected, MCDM supports the right way to achieve good results in strategy making. According to MCDM, choosing and assessing various strategies is key to finding marketing solutions that match what consumers

[1]ignomary.7115@gmail.com, [2]sandhiya86.sbs@velsuniv.ac.in

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want and the most recent market trends [3]. Therefore, marketing in this area can involve standard advertising, social media, content and collaborating with influencers [4]. The study also covers advanced tactics such as data-driven personalization, marketing on multiple platforms and marketing experiences. Every strategy comes with unique advantages that help achieve marketing goals like getting customers, letting people know your brand and boosting conversion rates, supporting overall informed decision-making.

A major part of this analysis is to assign a level of importance to each criterion and rate them prior to tackling marketing strategy decision-making challenges [5]. A number of things matter when deciding the right marketing strategies, including how much they cost, who will see them, how they can be noticed and what resources are needed [6]. Reliability, a background, brand image, easy data access and regulatory adherence are all critical in this assessment procedure. Achieving the right results and growing a marketing campaign also depend on how much it costs, how the targeted group reacts and whether required technology is available.

What sets this paper apart is the use of both VIKOR and TOPSIS techniques from MCDM to help solve hard decisions regarding selecting a marketing strategy, with Plithogenic Neutrosophic logic. Because of its Plithogenic logic, truth values may vary in different types: (i) classical logic, (ii) fuzzy logic, (iii) intuitionistic fuzzy logic and (iv) neutrosophic logic. Each type is made up of different attribute values, so issues with multiple and uncertain factors can be examined more precisely [6,7]. These MCDM techniques help to solve and arrange complex decisions in unique fashion. With VIKOR, a compromise solution is used to judge marketing alternatives when uncertainty is present [8]. Furthermore, TOPSIS works by choosing strategies that score high on all positives and are far from all negatives.

2. Preliminaries

2.1 Plithogenic Sets and its Classifications

Setting elements to multiple attribute values, with related relevance levels and types of contradiction functions is what we call plithogenic sets. They extend crisp, fuzzy, intuitionistic fuzzy and neutrosophic sets by letting sets have multiple degrees of membership and non-membership. Neutrosophic sets, as introduced by Smarandache, take into account the unclear and mismatched details of incomplete decision-making information. By including indeterminate membership, neutrosophic sets make fuzzy logic address universal states like neutral as well as typical truth and falsehood. Set in natural language, they can use imperfect data, providing an extra way to decide if traditional fuzzy sets aren't enough. Each individual attribute is used to characterize elements in plithogenic sets. Problems related to insufficient, unclear or wrong information are overcome effectively by using Neutrosophic sets. An A Neutrosophic set in X is normally represented as 1.

$$A = \{X(T_A(x), I_A(x); F_A(x)) \mid x \in X\} \quad (1)$$

The total number of these memberships for each x in (0,1) does not go over three. As a result, Neutrosophic sets make it possible to express what decision-makers prefer and prioritize, especially in situations when decision-maker responses are impacted by missing or unclear information.

$$0 \le T_A(x) + I_A(x) + F_A(x) \le 3 \quad (2)$$

Decision-makers can use Interval Neutrosophic Sets (INS) to deal with both uncertainty and inconsistency in their data. INS is designed as a Neutrosophic set, helping to handle imprecision by assigning the three levels of truth, falsehood and uncertainty as intervals and using degrees of membership, non-membership and hesitancy.

$$X = \left([T^L, T^U], [I^L, I^U], [F^L, F^U]\right) \quad (3)$$

The Interval Neutrosophic set gives an effective way to handle uncertain and contradictory information which makes it suitable for use in solving problems related to decision-making. INS stands out over other extensions of fuzzy sets by its set of benefits.

(i) Decision-makers using INS can present positive, negative or luminal beliefs using membership degree, non-membership degree and hesitation measures, unlike in fuzzy sets.

(ii) Instead of combining positive, negative and uncertain judgments as intuitionistic fuzzy sets do, INS lets people talk about them individually which is more flexible for decision makers to explain their different and opposing views.

2.2 Vise Kriterijumska Optimizaacija Kompromisno Resenje (VIKOR)

Opricovic proposed the method known as VIKOR[19], which is the acronym for Multi criteria optimization, and a compromise solution. It is one of the methods of MCDM that deals with conflicting criteria that can provide decisions. VIKOR is mainly based on vector normalization. Alternative ranking is mainly based on distance from their ideal alternatives. The steps involved in vikor are described below.

- Step 1 Based on the assessment of the decision-maker, the decision matrix is developed.
- Step 2 The normalized decision matrix is obtained by solving equation 4.

$$\left(f_{ij} \right)_{m*n} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (4)$$

where m defined the alternatives present and n defined the criteria present.

- Step 3: Determine parameters that are advantageous and non-beneficial. The highest value is selected for the beneficial criterion, the lowest value for the non-beneficial criteria is the lowest value, which is represented as (xi+), and the lowest worst value is the least value for the non-beneficial criteria and it is shown as (xi-).
- Step 4: By changing the values of (xi+) and (xi-) in equations 5 and 6, it is possible to determine the Si and Ri.

$$S_i = \sum_{j=1}^{n} w_j * \frac{f_j^* - f_{ij}}{f_j^* - f_j^-} \quad (5)$$

where the criteria weights that are crucial considerations are denoted by wj.

- Step 5: Evaluate the Qi value from the equation 6.

$$R_i = \max \left[w_j * \frac{f_j^* - f_{ij}}{f_j^* - f_j^-} \right] \quad (6)$$

$$Q_i = V^* \frac{S_i - S^*}{S^- - S^*} + \left(1 - V\right) * \frac{R_i - R^*}{R^- - R^+} \quad (7)$$

- Step 6: The performance value of the criteria is determined using the Qi. Sort the options according to their Qi values in descending order.
- Step 7: In order to determine the qualifications for rank two, step seven of the VIKOR technique must be completed.

Acceptable advantage, where m is the number of alternatives and A1 is the first and A2 is the second option in the Q ranking.

$$Q(A^2) - Q(A^1) \geq \frac{1}{m-1} \quad (7)$$

A1 should outperform S and R in order to have acceptable stability in rank Q. A compromised option is recommended if this requirement is not met.

(i) Both A1 and A2 will be considered a compromise option if condition 2 is not satisfied.

(ii) A1, A2, and potentially other options up to Am will be taken into consideration if condition 1 is not satisfied; equation 8 will be used to calculate Am.

$$A^m - Q(A^1) < \frac{1}{m-1} \quad (8)$$

2.3 Technique in Order of Preference by Similarity to Ideal Solution (TOPSIS)

In 1981, Hwang and Yoon [11] proposed TOPSIS, a MCDM method for solving multiple decision problems. To find the optimal solution, topsis used ranking the best alternatives from the Euclidian distance close to the positive ideal solution (PIS) and farthest from the negative ideal solution. The steps involved in TOPSIS are mentioned below.

- Step 1: compute a “decision matrix based on alternatives and criteria. Evaluate the alternatives according to the predetermined criteria.
- Step 2: Normalize the decision matrix using equation 9.

$$R = (r_{ij})_{m*n} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (9)$$

Where xij represents the evaluation score of alternative i with respect to criterion j.

- – Step 3 assign the weight for criteria and calculate the normalized weighted decision matrix by using equation 10.

$$V = (v_{ij})_{m*n} = w_j * r_{ij} \quad (10)$$

where w_j is the weight of each criterion.

- Step 4 involves employing the equations (11) through (14) to identify the positive ideal solution (PIS) and negative ideal solution (NIS).

$$A^+ = \left\{ v_1^+, v_2^+, \ldots, v_n^+ \right\} \quad (11)$$

$$v^+ = \{ \left(j \in J_b \right), (\min_i v_{ij} \mid J \in J_{nb}) | \in \left[1 \ldots m \right] \} \quad (12)$$

$$A^- = \left\{ v_1^-, v_2^-, \ldots, v_n^- \right\} \quad (13)$$

$$v^- = \{ \left(j \in J_b \right), (\max_i v_{ij} \mid J \in J_{nb}) | \in \left[1 \ldots m \right] \} \quad (14)$$

where J_{nb} is a set of beneficial criteria, and non-beneficial criteria.

- Step 5 The performance of alternative is computed by using equation 15 and 16, which are used to determine the Euclidian distance farthest from the negative ideal solution (NIS)and nearest from the positive ideal solution (PIS).

$$s_i^+ = \sqrt{\sum_{j=1}^{m} \left(V_i - V_j^+ \right) \wedge 2} \quad (15)$$

$$s_i^- = \sqrt{\sum_{j=1}^{m} \left(V_i - V_j^- \right) \wedge 2} \quad (16)$$

- Step 6 calculate the rank of alternative" by using equation 17.

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \tag{17}$$

3. Alternative Solution

Alternatives are essential to MCDM because they provide a range of options for decision-makers to consider according to factors like risk and cost. They can pick wisely by analyzing, choosing from and checking alternatives by comparing them on different aspects. Fuzzy MCDM allows you to look at several marketing initiatives using criteria that may sometimes conflict. Fuzzy logic helps change opinions based on experience into values that can be clearly measured. Because customer experience enhancement and flexibility are hard to measure precisely, MCDM methods using fuzzy numbers are usually applied.

Fuzzy MCDM is a way to evaluate each marketing plan alternative against every criterion, thanks to the use of fuzzy sets. Firms can pick their evaluation criteria, assess their importance and replicate decision-making on a computer. With Fuzzy MCDM, strategies are sorted by their effectiveness which allows a business to choose the best marketing option and reach its objectives in the market. This article looks at 15 strategies along with 13 criteria and introduces the use of MCDM and fuzzy decision making to help firms choose the most effective strategy.

4. Assessment of Criteria Weights

In determining the weights for assessing criteria in selecting effective marketing strategies through Multi-Criteria Decision Making (MCDM) methods, a thorough and systematic approach is indispensable [12]. Expert consultation plays a critical role in quantifying the importance of criteria, taking into account factors such as audience engagement potential, brand impact, cost-effectiveness, and return on investment. Data from consumer behavior studies and cost-benefit analyses further inform weight assignments, ensuring a comprehensive evaluation for informed decision-making in choosing marketing strategies that best align with business objectives. Sensitivity analysis considers weight ranges for non-normally distributed data, enhancing the robustness of the evaluation process in dynamic and diverse market contexts.

5. Multi Criteria Decision Making Process Case Study

In this section, professional experts conducted assessments for evaluation. In India, experts were selected from sectors including marketing, government, academia, and industry research to ensure credibility. Inputs were gathered from the Ministry of Commerce, digital marketing agencies, brand associations, consumer behavior committees, and marketing research institutions. Previous research data, such as audience engagement metrics and ROI statistics, informed the questionnaire content. The Delphi method was employed, where initial assessments were reviewed by experts in a second evaluation round, prompting them to reassess the performance values of each marketing strategy alternative. Seventeen valid questionnaires were collected, marking the conclusion of the evaluation process. Here, Plithogenic Neutrosophic set scale values are expressed as linguistic variables, as shown in Table 58.1 [13].

Table 58.1 Plithogenic neutrosophic set scale values

LINGUISTIC VARIABLES	PLITHOGENIC NEUTROSOPHIC SET
Extremely good (EG)	((1.00,0.01,0.01),(0.98,0.001,0.001),(0.97,0.002,0.002),(0.96,0.003,0.003),(0.95,0.004,0.004)) & ((1.00,0.00,0.00),(0.99,0.01,0.01),(0.98,0.02,0.02),(0.97,0.03,0.03),(0.96,0.04,0.04))
Very very good (VVG)	((0.92,0.115,0.115),(0.91,0.126,0.126),(0.90,0.107,0.107),(0.93,0.138,0.138),(0.93,0.149,0.149)) & ((0.92,0.11,0.11),(0.91,0.12,0.12),(0.90,0.10,0.010),(0.93,0.13,0.13),(0.94,0.14,0.14))
Very good (VG)	((0.82,0.175,0.225),(0.81,0.166,0.216),(0.80,0.157,0.207),(0.83,0.188,0.238),(0.84,0.199,0.249)) & ((0.82,0.17,0.22),(0.81,0.16,0.21),(0.80,0.15,0.20),(0.83,0.18,0.23),(0.84,0.19,0.24))
Good (G)	((0.72,0.278,0.328),(0.71,0.267,0.317),(0.70,0.256,0.306),(0.73,0.288,0.338),(0.74,0.299,0.349)) & ((0.72,0.27,0.32),(0.71,0.26,0.31),(0.70,0.25,0.30),(0.73,0.28,0.33),(0.74,0.29,0.34))
Medium good (MG)	((0.62,0.376,0.426),(0.61,0.366,0.416),(0.60,0.356,0.406),(0.63,0.387,0.437),(0.64,0.398,0.448)) & ((0.62,0.37,0.42),(0.61,0.36,0.41),(0.60,0.35,0.40),(0.63,0.38,0.43),(0.64,0.39,0.44))
Medium (M)	((0.50,0.50,0.50),(0.501,0.501,0.501),(0.502,0.502,0.502),(0.503,0.503,0.503),(0.504,0.504,0.504))
Medium bad (MB)	((0.42,0.67,0.62),(0.41,0.66,0.61),(0.40,0.65,0.60),(0.43,0.68,0.63),(0.44,0.69,0.64))
Bad (B)	((0.32,0.77,0.72),(0.31,0.76,0.71),(0.30,0.75,0.70),(0.33,0.78,0.73),(0.34,0.79,0.74))
Very bad (VB)	((0.22,0.87,0.82),(0.21,0.86,0.81),(0.20,0.85,0.80),(0.23,0.88,0.83),(0.24,0.89,0.84))
Very very bad (VVB)	((0.12,0.91,0.91),(0.11,0.92,0.92),(0.10,0.90,0.90),(0.13,0.93,0.93),(0.14,0.94,0.94))
Extremely bad (EB)	((0.02,0.0.99,0.99),(0.01,0.98,0.98),(0.00,1.00,1.00),(0.03,0.97,0.97),(0.04,0.96,0.96))

5.1 Multicriteria Ranking Results

As seen in Fig. 58.1, a comparative analysis is plotted on a radar graph, and Table 58.2 compares VIKOR with TOPSIS, from which ranks are obtained.

Table 58.2 Comparing VIKOR and TOPSIS ranks

Alternatives	VIKOR (Qi) V=0.5	Rank	TOSIS (Pi)	Rank
A1	0.935	12	0.4869	12
A2	0.916	10	0.4994	10
A3	0.918	9	0.5000	9
A4	0.896	6	0.5172	6
A5	0.918	8	0.5108	7
A6	1.000	15	0.4706	15
A7	0.942	13	0.4862	13
A8	0.918	11	0.4938	11
A9	0.903	7	0.5076	8
A10	0.980	14	0.4745	14
A11	0.857	5	0.5308	5
A12	0.000	1	0.8144	1
A13	0.290	3	0.7589	2
A14	0.288	2	0.7481	3
A15	0.348	4	0.7215	4

The radar graph in Fig. 58.1 shows the performance of each alternative depending on the analysis criteria. Values on each axis show how each choice performed against each criterion. The lines show VIKOR and TOPSIS performance rankings for each alternative. Lines closer to the graph center perform worse, whereas lines farther from the center perform better. This graph shows how alternatives perform using both strategies.

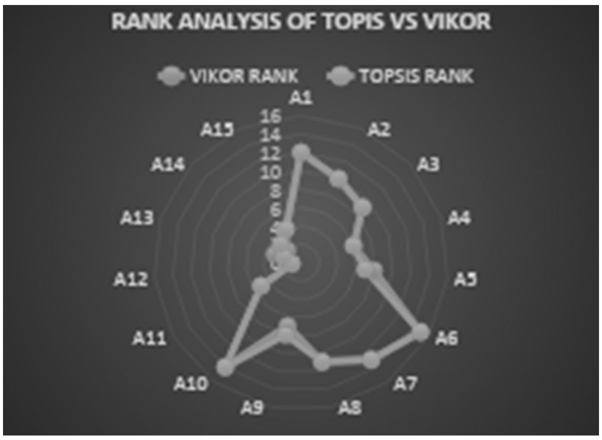

Fig. 58.1 The comparative study of VIKOR and TOPSIS rank

From the table above, "audience engagement" performs best for content marketing (0.814) and worst for traditional advertising (0.476). Social media marketing tops "cost-effectiveness," while influencer marketing falls short. Content marketing has strong brand impact and engagement potential but low results speed and platform adaptability. According to the data, content marketing performs well in audience engagement, brand impact, and long-term ROI, social media marketing performs well in adaptability and cost-effectiveness, and traditional advertising and influencer marketing perform "middle" across performance indicators. Content marketing is best for firms seeking high engagement and brand loyalty, according to this analysis. Social media marketing and influencer marketing complement each other due to their cost-effectiveness and reach, especially for quick engagement and brand awareness.

6. Conclusion

In conclusion, using Plithogenic Neutrosophic sets in Multi-Criteria Decision Making (MCDM) to evaluate marketing strategy alternatives has provided useful insights. We evaluated 15 marketing strategies—including Social Media Marketing, Content Marketing, Influencer Marketing, and Traditional Advertising—using 13 criteria to determine their practicality and effectiveness. With the help of the TOPSIS and VIKOR methods of MCDM, we discovered which strategies would give us the greatest results for boosting brand engagement, maintaining customer retention and enhancing ROI. Among the 15 approaches we looked at, Content Marketing offered the highest audience engagement, the most adaptability, the best potential for long-term benefits and the strongest effect on a brand. This strategy emphasizes providing meaningful, educational, and entertaining content to boost company reputation and consumer loyalty. Content marketing stands out as a strategic way to fostering brand loyalty, attaining sustainable growth, and establishing enduring relationships with customers as organizations continue to negotiate changing consumer expectations.

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