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New Energy Vehicle Industry Chain Evaluation by Developing Decision-Making Methodology with HyperSoft Set and Neutrosophic Sets

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Abstract: The New Energy Vehicle (NEV) industry has emerged as a crucial sector in the global transition toward sustainable transportation. This study proposed a decision-making methodology for NEV industry chain evaluation. We used two decision making methods, such as SWARA method to compute the criteria weights and the MAIRCA method to rank the alternatives. These methods are used under the neutrosophic sets to deal with uncertainty data. Then we used the HyperSoft Set to show the relationship between the criteria and their values. This study proves the validation of the proposed approach by applying the proposed approach in case study. Four experts are invited in this study to evaluate six criteria and seven alternatives. Comparative analysis between our method and other methods shows the effectiveness of the proposed approach. Sensitivity analysis is conducted to show the stability of the ranks of the proposed approach.

Keywords: New Energy Vehicle (NEV); HyperSoft Set; Neutrosophic HyperSoft Set; Interval Valued Pythagorean Neutrosophic Set (IVPNS).

1. Introduction and Related Work

The New Energy Vehicle (NEV) industry has emerged as a crucial sector in the global transition toward sustainable transportation. With increasing concerns over climate change, energy security, and environmental degradation, governments and industries worldwide have invested heavily in electric vehicles (EVs), hybrid-electric vehicles (HEVs), and hydrogen fuel cell vehicles (HFCVs). The NEV industry chain consists of multiple interconnected segments, including battery production, vehicle manufacturing, charging infrastructure, supply chain logistics, policy regulation, and recycling technologies[1], [2]. Understanding and evaluating the performance and resilience of this industry chain is essential for sustainable development and long-term competitiveness.

Despite its rapid growth, the NEV industry faces several challenges, such as technological innovation constraints, supply chain vulnerabilities, high infrastructure costs, and regulatory uncertainties. These challenges necessitate a comprehensive evaluation framework that considers multiple criteria affecting the industry's overall efficiency and effectiveness[3], [4]. Multi-Criteria Decision-Making (MCDM) methodologies provide a structured approach for analyzing complex, multi-dimensional problems by integrating qualitative and quantitative factors. Among these methodologies, HyperSoft Set theory has gained attention due to its ability to handle uncertainties, overlapping attributes, and hierarchical decision structures.

To assess the NEV industry chain's performance, this study evaluates seven alternatives representing key stakeholders, including battery manufacturers, electric vehicle producers, charging infrastructure providers, supply chain firms, autonomous mobility companies, regulatory bodies, and sustainability-focused enterprises. The HyperSoft Set model allows for a nuanced evaluation by assigning lower-bound, middle-value, and upper-bound scores to each alternative under the selected criteria[5], [6].

The findings of this research will provide practical insights for policymakers, industry leaders, and investors, helping them identify strengths, weaknesses, and potential areas for improvement in the NEV industry chain. Additionally, the application of HyperSoft Set theory in this context will demonstrate its effectiveness in handling complex decision-making problems with uncertain and interrelated parameters. By offering a structured and data-driven evaluation framework, this study contributes to the sustainable growth and strategic development of the NEV industry, ensuring its resilience and competitiveness in the global market.

Due to their intrinsic ambiguity, the data used in many complex problems—including those in computer science, engineering, social and economic contexts, medical science, and more—may not always have clear, exact, and predictable characteristics. Most of these intricate issues have been approached using a range of ideas. To address these issues, Zadeh developed the notion of a fuzzy set, in which the concept of a membership function is represented by the symbol μ, providing the range [0,1] to signify the degree of belongingness to the set in question[7], [8].

Uncertainty and indeterminacy are crucial in a neutrosophic setting. First proposed by Smarandache in 1995, the idea of a neutrosophic set (NS) enables indeterminacy to be represented as three components: truth, indeterminacy, and false membership[9], [10].

To determine the shortest path in each network, the A* search technique is frequently used. On the other hand, the nodes in a conventional A* search algorithm are thought to have crisp values, or a single value. In many real-world situations when ambiguity or uncertainty are present, this assumption might not hold true. An interval-valued Neutrosophic Pythagorean (IVNP) environment can offer a more reliable and accurate representation in certain situations. Uncertain and imprecise data, which are common in executive issues, can be effectively modeled using interval-valued Neutrosophic Pythagorean sets (IVNPS). Because the values of the nodes in the graph can fluctuate within specific intervals rather than having fixed values, these sets offer a more adaptable method of capturing uncertainty.

The interval representation is a strong tool in executive processes and can manage vague or insufficient information with ease. Raut et al. [11] suggested an enhanced A* search method that makes use of the IVPN environment. This method seeks to determine a graph's shortest path in the presence of ambiguity and uncertainty. To deal with the uncertainty in node values and edge weights, their model integrated the IVNPS theory into the A* search framework. To determine the heuristic function and choose the best node to grow next, it makes use of the neutrosophic Pythagorean distance idea.

While neutrosophic sets, a more general concept that includes fuzzy sets and intuitionistic fuzzy sets, are designed to represent real-world data that is uncertain, imprecise, inconsistent, and incomplete, the interval-valued Pythagorean fuzzy set (IVPFS) offers a fresh method for dealing with vagueness and uncertainty. Furthermore, rather than concentrating just on one value, the creation of Interval Value Neutrosophic Sets (IVNS) improves accuracy when solving issues involving a range of integers inside the actual unit interval. Notwithstanding these developments, there is still a lack of study on issues related to actual implementation, comparisons with current approaches, and the application of these ideas in many domains.

By putting forth a unique idea based on the Interval Valued Pythagorean Neutrosophic Set (IVPNS), a generalization of the IVPFS and INS, Razak et al. [12] aimed to close this research gap. The creation of IVPNS offers a more thorough framework for dealing with ambiguity, uncertainty, and partial information in a variety of domains, which promotes stronger decision-making, enhanced problem-solving skills, and better complex system management. Additionally, their study compares IVPFS and IVNS and presents algebraic operations for IVPNS, such as addition, multiplication, scalar multiplication, and exponentiation. To show these procedures in action, their paper includes illustrated numerical examples. Furthermore, the algebraic features of IVPNS are presented and carefully proved in their paper, with particular attention paid to their commutative and associative characteristics.

The rest of this study is organized as follows: Section 2 presents the HyperSoft set definition and with the neutrosophic sets. Section 3 shows the definition of the IVPNS. Section 4 shows the steps of the proposed approach to computing the criteria weights and ranking the alternatives. Section 5 shows the results and discussion. Section 6 shows comparative analysis with four MCDM methods to show the effectiveness of the proposed approach. Section 7 shows the sensitivity analysis to show the stability of the ranks. Section 8 shows the conclusion of this study.

2. HyperSoft Set (HSS)

Let U be the universal set and P(U) is the power set of U. Let $A^1, A^2, C^3, \dots A^n$ be a set of attributes for $n \geq 1$and the corresponding values are $R^1, R^2, R^3, \dots R^n$, $R^i \cap R^j = \emptyset \; for \; i \neq j$.

A pair $(F, R^1 \times R^2 \times R^3 \ldots . R^n)$ is a HSS over U where F is a mapping with $F: R^1 \times R^2 \times R^3 \ldots R^n \rightarrow P(U)$ [13].

(Neutrosophic HyperSoft Set (NHSS))

Let U be the universal set and P(U) is the power set of U. Let $A^1, A^2, A^3, \ldots A^n$ be a set of attributes for $n \geq 1$and the corresponding values are $R^1, R^2, R^3, \ldots R^n$, $R^i \cap R^j = \emptyset\ for\ i \neq j$ and the relation $R^1 \times R^2 \times R^3 \ldots . R^n = S$

A pair (F, S) is a NHSS over U where $(F, R^1 \times R^2 \times R^3 \ldots . R^n) = R^1 \times R^2 \times R^3 \ldots . L^n \rightarrow P(U)$ with $F(R^1 \times R^2 \times R^3 \ldots . R^n) = \{T(F(S)), I(F(S)), F(F(S)), x \in U\}$ where T,I, and F refer to truth, indeterminacy, and falsity functions[14].

3. Interval Valued Pythagorean Neutrosophic Set (IVPNS)[12]

This section shows some definitions of the IVPNS:

Let two IVPNNs such as $N_1 = ([b^L_{N_1}, b^U_{N_1}], [I^L_{N_1}, I^U_{N_1}], [S^L_{N_1}, S^U_{N_1}],)$ and $N_2 = ([b^L_{N_2}, b^U_{N_2}], [I^L_{N_2}, I^U_{N_2}], [S^L_{N_2}, S^U_{N_2}],)$

$$N_1 \oplus N_2 = \begin{pmatrix} [b^L_{N_1} + b^L_{N_2} - b^L_{N_1} b^L_{N_2}, b^U_{N_1} + b^U_{N_2} - b^u_{N_1} b^U_{N_2}], \\ [I^L_{N_1} I^L_{N_2}, I^U_{N_1} I^U_{N_2}], \\ [S^L_{N_1} S^L_{N_2}, S^U_{N_1} S^U_{N_2}] \end{pmatrix} \tag{1}$$

$$N_1 \otimes N_2 = \begin{pmatrix} [b^L_{N_1} b^L_{N_2}, b^U_{N_1} b^U_{N_2}], \\ [I^L_{N_1} + I^L_{N_2} - I^L_{N_1} I^L_{N_2}, I^U_{N_1} + I^U_{N_2} - I^u_{N_1} I^U_{N_2}], \\ [S^L_{N_1} + S^L_{N_2} - S^L_{N_1} S^L_{N_2}, S^U_{N_1} + S^U_{N_2} - S^u_{N_1} S^U_{N_2}] \end{pmatrix} \tag{2}$$

$$\varphi N_1 = \begin{pmatrix} \left[1 - \left(1 - b^L_{N_1}\right)^{\varphi}, 1 - \left(1 - b^U_{N_1}\right)^{\varphi}\right], \\ \left[\left(I^L_{N_1}\right)^{\varphi}, \left(I^Y_{N_1}\right)^{\varphi}\right], \\ \left[\left(S^L_{N_1}\right)^{\varphi}, \left(S^Y_{N_1}\right)^{\varphi}\right] \end{pmatrix} \tag{3}$$

$$N_1^{\varphi} = \begin{pmatrix} \left[\left(b^L_{N_1}\right)^{\varphi}, \left(b^Y_{N_1}\right)^{\varphi}\right], \\ \left[1 - \left(1 - I^L_{N_1}\right)^{\varphi}, 1 - \left(1 - I^U_{N_1}\right)^{\varphi}\right], \\ \left[1 - \left(1 - S^L_{N_1}\right)^{\varphi}, 1 - \left(1 - S^U_{N_1}\right)^{\varphi}\right] \end{pmatrix} \tag{4}$$

$$0 \leq b^U_{N_1} + S^U_{N_1} \leq 1 \tag{5}$$

$$0 \leq b^U_{N_1} + I^U_{N_1} + S^U_{N_1} \leq 2 \tag{6}$$

$$0 \leq \left(b^U_{N_1}\right)^2 + \left(I^U_{N_1}\right)^2 + \left(S^U_{N_1}\right)^2 \leq 2 \tag{7}$$

Let $\pi_A(x) = [\pi^U_A(x), \pi^L_A(x)]$ is called IVPNS, where

$$\pi_A^U(x) = \sqrt{1 - \left(b_A^U(x)\right)^2 - \left(I_A^U(x)\right)^2 - \left(S_A^U(x)\right)^2} \tag{8}$$

$$\pi_A^L(x) = \sqrt{1 - \left(b_A^L(x)\right)^2 - \left(I_A^L(x)\right)^2 - \left(S_A^L(x)\right)^2} \tag{9}$$

4. Multi-Criteria Decision-Making Methods

This section uses the different MCDM methods to compute the criteria weights and rank the alternatives. Two MCDM methods are used in this study such as: SWARA method to compute the criteria weights and the MAIRCA method to rank the alternatives. MCDM methods are used under the neutrosophic sets.

IVPN-SWARA[15], [16]

1) Ranking the criteria in terms of relative importance

2) Compute the coefficient

$$F_j = \begin{cases} 1 & if\ j = 1 \\ S_j + 1 & if\ j > 1 \end{cases} \tag{10}$$

Where S_j refers to the initial value by experts.

3) Compute the initial weights of criteria

$$h_j = \begin{cases} 1 & if\ j = 1 \\ \frac{h_j}{F-j} & if\ j > 1 \end{cases} \tag{11}$$

4) Compute the relative wights of criteria.

$$W_j = \frac{h_j}{\sum_{j=1}^{n} h_j} \tag{12}$$

IVPN- MAIRCA[17], [18]

1) Build the decision matrix.

2) Compute the elements $t_{p_{ij}}$ of the theoretical rating matrix

$$t_{p_{ij}} = x_{ij} * w_j \tag{13}$$

3) Compute the elements of real rating matrix

$$u_{ij} = t_{p_{ij}} \left(\frac{x_{ij} - \min x_i}{\max x_i - \min x_i}\right) \text{ for positive criteria} \tag{14}$$

$$u_{ij} = t_{p_{ij}} \left(\frac{x_{ij} - \max x_i}{\min x_i - \max x_i}\right) \text{ for cost criteria} \tag{15}$$

4) Compute the total gap matrix

$$k_{ij} = t_{p_{ij}} - u_{ij} \tag{16}$$

5) Compute the final values of the criterion function

$$D_i = \sum_{i=1}^{m} k_{ij} \tag{17}$$

6) Rank the alternatives.

5. Results and Discussions

This section shows the results and discussion of the proposed approach by applying it on a case study to show the validation of the proposed approach. This section shows the preferences of experts and decision makers to evaluate the criteria and alternatives. Four experts are invited in this study to evaluate 6 criteria and seven alternatives. The criteria of this study are:

Technological Innovation: Level of R&D, battery technology, AI integration, and smart mobility advancements.

Supply Chain Stability: Efficiency of sourcing raw materials, battery production, and semiconductor supply.

Environmental Impact: Sustainability of materials, carbon footprint, and recycling processes.

Market Competitiveness: Market share, brand positioning, cost-effectiveness, and customer adoption rate

Infrastructure Readiness: Availability of charging stations, battery swapping networks, and government incentives.

Government Policies: Subsidies, regulations, and support for NEV adoption.

The alternatives of this study are organized as follows: Electric Vehicle Manufacturers, Supply Chain and Material Providers, Battery Manufacturers, Government and Regulatory Bodies, Autonomous and Smart Mobility Solutions, Recycling and Sustainability Companie, Charging Infrastructure Providers

IVPN-SWARA

1) We ranked the criteria in terms of relative importance

2) We Compute the coefficient using Eq. (10).

3) We compute the initial weights of the criteria using Eq. (11) as shown in Fig 1.

4) We compute the relative wights of criteria using Eq. (12) as shown in Fig 2.

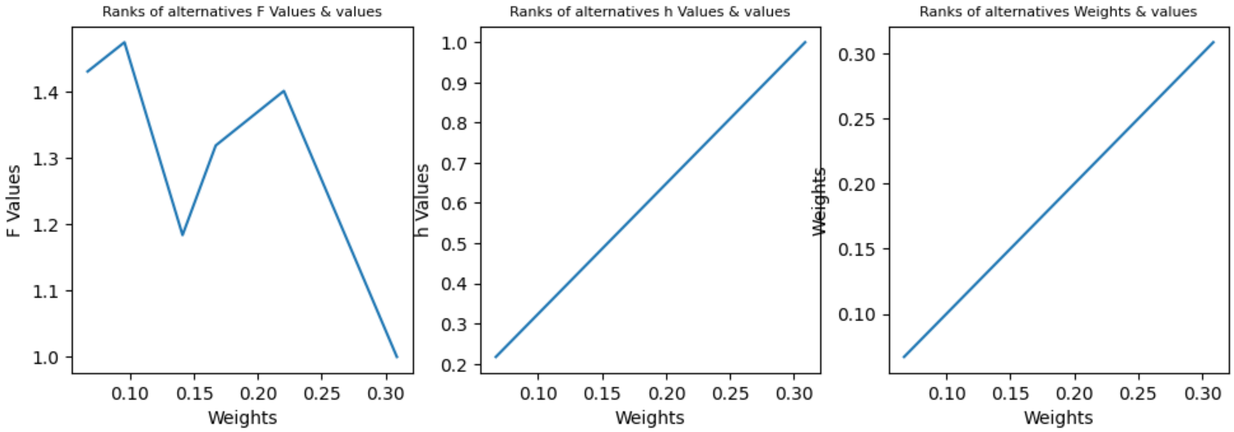

Fig 1. The SWARA results.

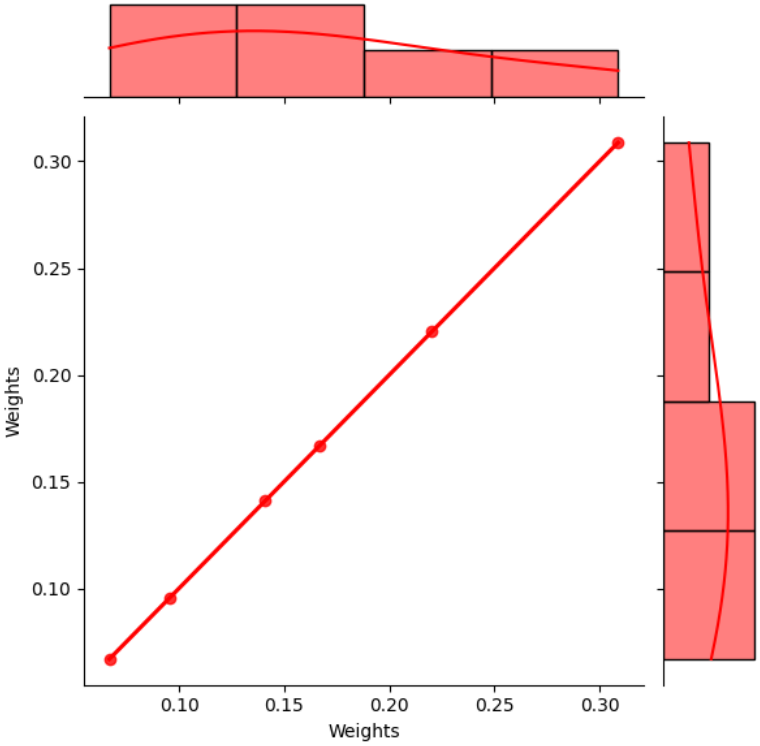

Fig 2. The relative wights of criteria.

IVPN- MAIRCA

After computing the criteria weights, we applied the NHSS to select the best values of each criterion. We select the best values such as: $R1-3\times R2-1\times R3-2\times R4-4\times R5-1\times R6-3$

1) We used the IVPNNs to build the decision matrix as shown in Table 1-4. Then we applied the score function to obtain crisp values. Then we combine the decision matrix.

2) Then we compute the elements $t_{p_{ij}}$ of the theoretical rating matrix using Eq. (13) as shown in Table 5.

3) We compute the elements of real rating matrix using Eq. (14) and Eq. (15) as shown in Table 6.

4) We compute the total gap matrix using Eq. (16) as shown in Table 7.

5) We compute the final values of the criterion function using Eq. (17).

6) Then we rank the alternatives as shown in Fig 3.

Table 1. The first IVPNNs

	R_{1-3}	R_{2-1}	R_{3-2}	R_{4-4}	R_{5-1}	R_{6-3}
A_1	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.5],[0.3,0.4],[0.3,0.5])	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.2,0.3])	([0.3,0.5],[0.4,0.5],[0.5,0.6])
A_2	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.3,0.5],[0.4,0.5],[0.5,0.6])	([0.4,0.6],[0.3,0.5],[0.2,0.3])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.5,0.6],[0.4,0.5],[0.3,0.4])
A_3	([0.4,0.5],[0.3,0.4],[0.3,0.5])	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.2,0.3])	([0.3,0.5],[0.4,0.5],[0.5,0.6])	([0.4,0.5],[0.3,0.4],[0.3,0.5])
A_4	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.4,0.5],[0.3,0.4],[0.3,0.5])	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.4,0.6],[0.3,0.5],[0.3,0.4])
A_5	([0.4,0.6],[0.3,0.5],[0.2,0.3])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.4,0.5],[0.3,0.4],[0.3,0.5])	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.3,0.4],[0.2,0.4],[0.3,0.5])
A_6	([0.4,0.6],[0.3,0.5],[0.2,0.3])	([0.4,0.6],[0.3,0.5],[0.2,0.3])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.2,0.3])	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.3,0.5],[0.4,0.5],[0.5,0.6])
A_7	([0.3,0.5],[0.4,0.5],[0.5,0.6])	([0.3,0.5],[0.4,0.5],[0.5,0.6])	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.3,0.5],[0.4,0.5],[0.5,0.6])	([0.3,0.5],[0.4,0.5],[0.5,0.6])	([0.4,0.6],[0.3,0.5],[0.2,0.3])

Table 2. The second IVPNNs

	R_{1-3}	R_{2-1}	R_{3-2}	R_{4-4}	R_{5-1}	R_{6-3}
A_1	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.5],[0.3,0.4],[0.3,0.5])	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.2,0.3])	([0.3,0.5],[0.4,0.5],[0.5,0.6])
A_2	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.3,0.5],[0.4,0.5],[0.5,0.6])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.5,0.6],[0.4,0.5],[0.3,0.4])
A_3	([0.4,0.5],[0.3,0.4],[0.3,0.5])	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.5],[0.3,0.4],[0.3,0.5])
A_4	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.4,0.5],[0.3,0.4],[0.3,0.5])	([0.4,0.5],[0.3,0.4],[0.3,0.5])	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.3,0.4])
A_5	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.5],[0.3,0.4],[0.3,0.5])	([0.3,0.4],[0.2,0.4],[0.3,0.5])
A_6	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.5,0.6],[0.3,0.5],[0.3,0.4])
A_7	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.3,0.5],[0.4,0.5],[0.5,0.6])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.5,0.6],[0.4,0.5],[0.3,0.4])

Table 3. The third IVPNNs

	R_{1-3}	R_{2-1}	R_{3-2}	R_{4-4}	R_{5-1}	R_{6-3}
A_1	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.5],[0.3,0.4],[0.3,0.5])	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.2,0.3])	([0.3,0.5],[0.4,0.5],[0.5,0.6])
A_2	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.3,0.5],[0.4,0.5],[0.5,0.6])	([0.4,0.6],[0.3,0.5],[0.2,0.3])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.5,0.6],[0.4,0.5],[0.3,0.4])
A_3	([0.3,0.5],[0.4,0.5],[0.5,0.6])	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.2,0.3])	([0.3,0.5],[0.4,0.5],[0.5,0.6])	([0.4,0.5],[0.3,0.4],[0.3,0.5])
A_4	([0.4,0.6],[0.3,0.5],[0.2,0.3])	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.3,0.4])
A_5	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.3,0.5],[0.4,0.5],[0.5,0.6])	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.4,0.6],[0.3,0.5],[0.3,0.4])
A_6	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.2,0.3])	([0.3,0.5],[0.4,0.5],[0.5,0.6])	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.3,0.5],[0.4,0.5],[0.5,0.6])	([0.3,0.4],[0.2,0.4],[0.3,0.5])
A_7	([0.4,0.5],[0.3,0.4],[0.3,0.5])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.2,0.3])	([0.3,0.5],[0.4,0.5],[0.5,0.6])	([0.4,0.6],[0.3,0.5],[0.2,0.3])	([0.3,0.5],[0.4,0.5],[0.5,0.6])

Table 4. The fourth IVPNNs

	R_{1-3}	R_{2-1}	R_{3-2}	R_{4-4}	R_{5-1}	R_{6-3}
A_1	([0.3,0.5],[0.4,0.5],[0.5,0.6])	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.4,0.5],[0.3,0.4],[0.3,0.5])	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.4,0.6],[0.3,0.5],[0.2,0.3])	([0.5,0.6],[0.3,0.5],[0.3,0.4])
A_2	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.5,0.6],[0.4,0.5],[0.3,0.4])
A_3	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.4,0.5],[0.3,0.4],[0.3,0.5])	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.4,0.5],[0.3,0.4],[0.3,0.5])	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.4,0.5],[0.3,0.4],[0.3,0.5])
A_4	([0.4,0.5],[0.3,0.4],[0.3,0.5])	([0.4,0.5],[0.3,0.4],[0.3,0.5])	([0.4,0.5],[0.3,0.4],[0.3,0.5])	([0.4,0.6],[0.3,0.5],[0.2,0.3])	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.4,0.5],[0.3,0.4],[0.3,0.5])
A_5	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.5],[0.3,0.4],[0.3,0.5])	([0.4,0.6],[0.3,0.5],[0.3,0.4])
A_6	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.3,0.4],[0.2,0.4],[0.3,0.5])	([0.4,0.5],[0.3,0.4],[0.3,0.5])	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.3,0.4],[0.2,0.4],[0.3,0.5])
A_7	([0.4,0.6],[0.3,0.5],[0.3,0.4])	([0.5,0.6],[0.4,0.5],[0.3,0.4])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.2,0.3])	([0.5,0.6],[0.3,0.5],[0.3,0.4])	([0.4,0.6],[0.3,0.5],[0.2,0.3])

Table 5. The values of $t_{p_{ij}}$

	R_{1-3}	R_{2-1}	R_{3-2}	R_{4-4}	R_{5-1}	R_{6-3}
A_1	0.123824457	0.050161	0.087296	0.06184	0.057046	0.014069
A_2	0.098423312	0.042129	0.032018	0.078408	0.052872	0.040561
A_3	0.056737177	0.108065	0.073205	0.073027	0.032327	0.01818
A_4	0.146472851	0.087005	0.054005	0.064341	0.042735	0.028533
A_5	0.132886438	0.092476	0.07459	0.060178	0.026729	0.019192
A_6	0.142777216	0.101346	0.054153	0.037361	0.027466	0.01405

A_7	0.112054264	0.102498	0.098594	0.031211	0.042999	0.03169

Table 6. The values of real rating matrix.

	R_{1-3}	R_{2-1}	R_{3-2}	R_{4-4}	R_{5-1}	R_{6-3}
A_1	0.092572	0.006110116	0.014815	0.021708	0.057046	1.02E-05
A_2	0.045722	0	0.032018	0	0.045592	0.040561
A_3	0	0.108065404	0.027917	0.008326	0.005969	0.002832
A_4	0.146473	0.059215961	0.03617	0.019176	0.022563	0.015588
A_5	0.112767	0.070612309	0.026894	0.023244	0	0.003722
A_6	0.136897	0.091018769	0.036148	0.032492	0.000668	0
A_7	0.069075	0.093842464	0	0.031211	0.023077	0.021086

Table 7. The total gap matrix.

	R_{1-3}	R_{2-1}	R_{3-2}	R_{4-4}	R_{5-1}	R_{6-3}
A_1	0.031252064	0.044051	0.072481	0.040133	0	0.014059
A_2	0.05270139	0.042129	0	0.078408	0.00728	0
A_3	0.056737177	0	0.045288	0.0647	0.026358	0.015348
A_4	0	0.02779	0.017835	0.045165	0.020172	0.012945
A_5	0.020119647	0.021864	0.047696	0.036934	0.026729	0.015469
A_6	0.005880075	0.010328	0.018004	0.004869	0.026798	0.01405
A_7	0.042978999	0.008655	0.098594	0	0.019922	0.010604

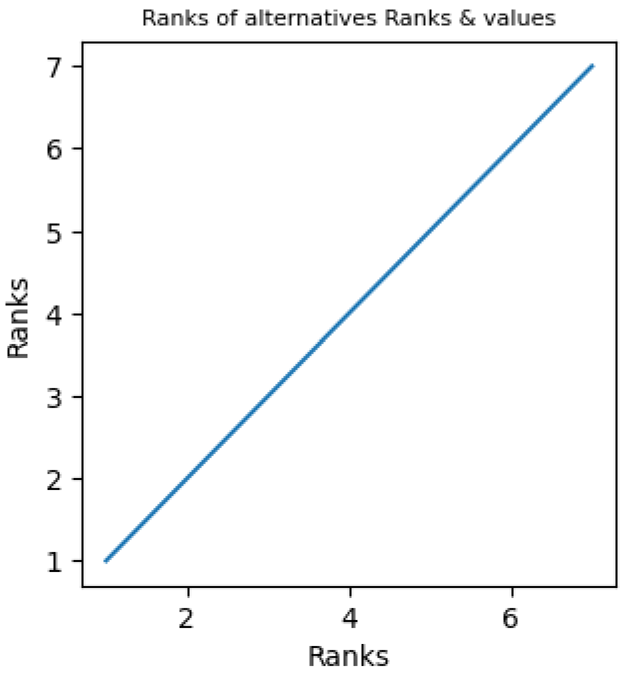

Fig 3. The rank of alternatives.

6. Comparative Analysis

This section shows the comparative analysis between the proposed approach and other MCDM methods. The aim of the comparative analysis is to show the effectiveness of the proposed approach compared to other MCDM methods. This section compares the proposed approach with four MCDM methods such as VIKOR, MOOSRA, MOORA, and MULTIMOORA methods. We used the same weights of the SWARA method in the comparison results.

Fig 4 shows the results of the comparative analysis. We show alternative 3 is the best and alternative 6 is the worst. We show our method is effective compared to other MCDM methods. Our method has relationships between other MCDM methods.

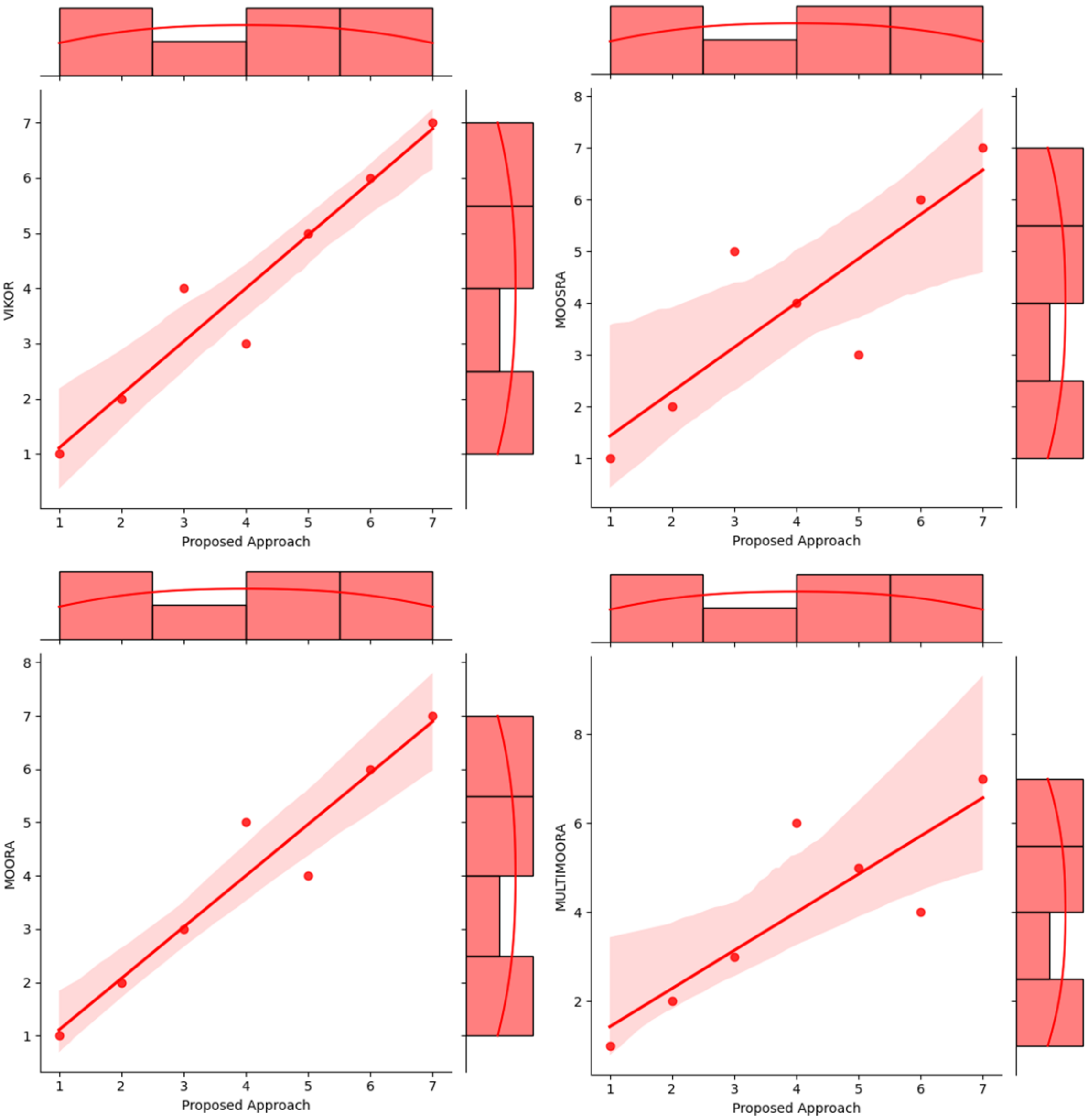

Fig 4. Comparative results.

7. Sensitivity Analysis

This section shows the sensitivity analysis results between the ranks of the alternatives. in this section we proposed seven cases in criteria weights to rank the alternatives under these cases to show the stability of the ranks. Fig 5 shows the different criteria weights. In the first case, we put all the criteria the same weights, then we rank the alternatives.

The results show alternative 3 is the best and alternative 6 is the worst. Fig 6 shows the different ranks of the alternatives. In the second case, we increase the first criterion by 25% weight and other criteria have the same weight. In this case, we show alternative 3 is the best and alternative 6 is the worst. In the third case, we increase the second criterion by 25% weight and other criteria have the same weight. In this case, we show alternative 3 is the best and alternative 6 is the worst. In the fourth case, we increase the third criterion by 25% weight and other criteria have the same weight. In this case, we show alternative 3 is the best and alternative 6 is the worst.

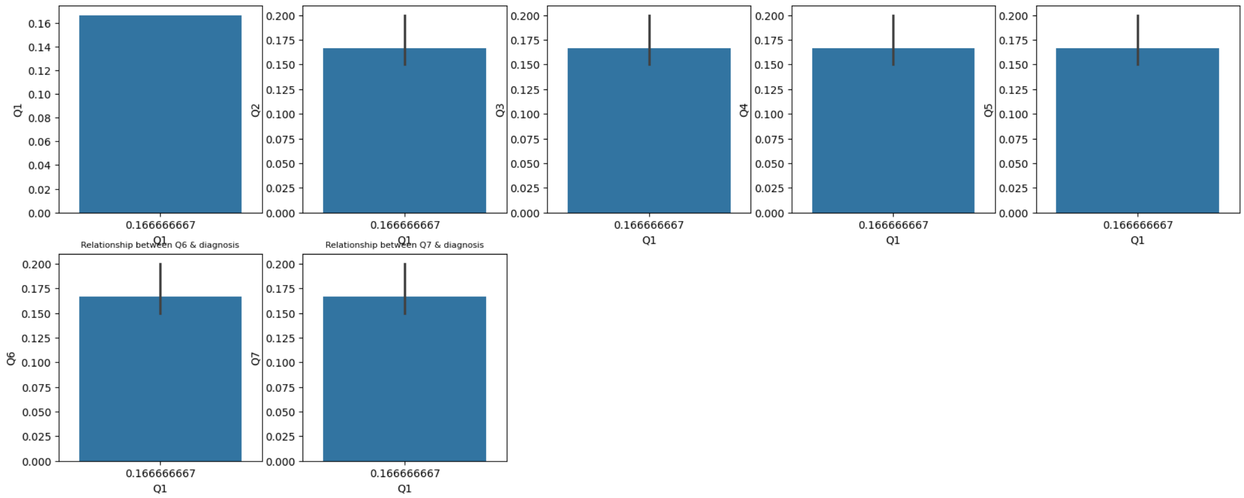

Fig 5. Seven criteria weights.

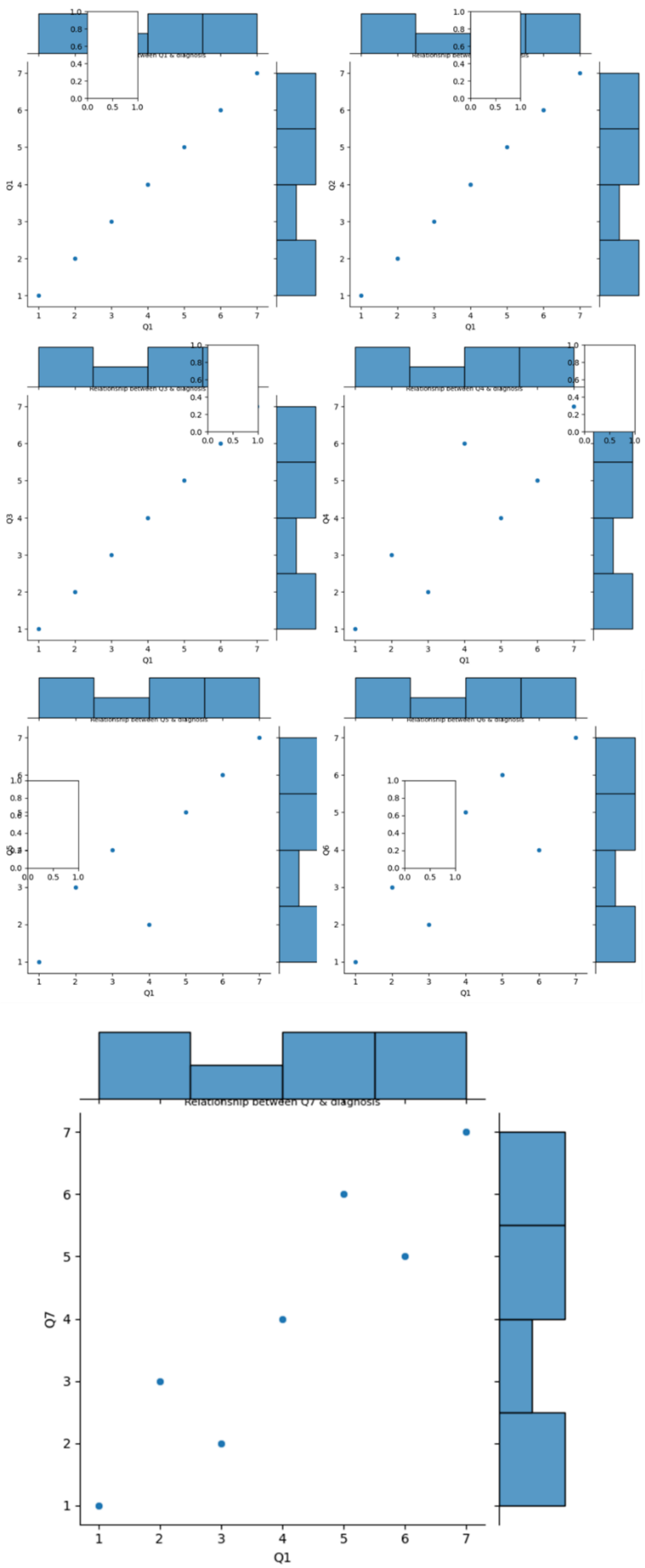

Fig 6. Analysis of ranks.

8. Conclusions and Future Works

This study proposed a MCDM approach for evaluation of New Energy Vehicle. We used two MCDM methods such as SWARA method to compute the criteria weights and MAIRCA method to rank the alternatives. These methods are used under the Interval Valued Pythagorean Neutrosophic Set (IVPNS) to deal with the vague data. The HyperSoft set is used to show the relationship between the criteria. We evaluated six criteria and seven alternatives in this study. The results show alternative 3 is the best and alternative 6 is the worst. We compared our model with the other four MCDM methods. The results show our method is effective compared to other methods. We applied the sensitivity analysis by seven cases. The results show our model is stable of ranks under different cases.

The future works, the Interval Valued Pythagorean Neutrosophic Set can be used in the MCDM problems to dela with uncertainty and vague information. The SWARA method can be used to compute the criteria weights. The MAIRCA can be used to rank the alternatives.

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