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Information for Authors and Subscribers

*"***Neutrosophic Systems with Applications***"* has been created for publications on advanced studies in neutrosophy, neutrosophic set, neutrosophic logic, neutrosophic probability, neutrosophic statistics that started in 1995 and their applications in any field, such as the neutrosophic structures developed in algebra, geometry, topology, etc.

The submitted papers should be professional, in good English, containing a brief review of a problem and obtained results.

Neutrosophy is a new branch of philosophy that studies the origin, nature, and scope of neutralities, as well as their interactions with different ideational spectra.

This theory considers every notion or idea <A> together with its opposite or negation <antiA> and with their spectrum of neutralities <neutA> in between them (i.e., notions or ideas supporting neither <A> nor <antiA>). The <neutA> and <antiA> ideas together are referred to as <nonA>.

Neutrosophy is a generalization of Hegel's dialectics (the last one is based on <A> and <antiA> only). According to this theory every idea <A> tends to be neutralized and balanced by <antiA> and <nonA> ideas - as a state of equilibrium.

In a classical way <A>, <neutA>, <antiA> are disjointed two by two. But, since in many cases the borders between notions are vague, imprecise, Sorites, it is possible that <A>, <neutA>, <antiA> (and <nonA> of course) have common parts two by two, or even all three of them as well.

Neutrosophic Set and Neutrosophic Logic are generalizations of the fuzzy set and respectively fuzzy logic (especially of intuitionistic fuzzy set and respectively intuitionistic fuzzy logic). In neutrosophic logic a proposition has a degree of truth (T), a degree of indeterminacy (I), and a degree of falsity (F), where T, I, F are standard or non-standard subsets of $]^-0, 1^+[$.

Neutrosophic Probability is a generalization of the classical probability and imprecise probability.

Neutrosophic Statistics is a generalization of classical statistics.

What distinguishes neutrosophic from other fields is the <neutA>, which means neither <A> nor <antiA>.

<neutA>, which of course depends on <A>, can be indeterminacy, neutrality, tie game, unknown, contradiction, ignorance, imprecision, etc.

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Transition Supply Chain 4.0 to Supply Chain 5.0: Innovations of Industry 5.0 Technologies Toward Smart Supply Chain Partners

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Abstract: Industry 4.0 provides businesses with the tools they need to meet difficulties such as fluctuating demand and unstable markets. Additionally, Industry 4.0 refers to the connectivity of computers, various materials, and artificial intelligence (AI) with minimum involvement from humans in the decision-making process. Although Industry 4.0 has a significant potential for the expansion of the industrial sector, it faces several hurdles, including integration of technology, problems with human resources, problems with supply chains, and data security concerns. The human-centered approach that Industry 5.0 took meant that many of the problems that plagued Industry 4.0 could finally be solved. In the previous generation, known as Industry 4.0, the emphasis was placed on scalability and volume of production; however, in the next generation, known as Industry 5.0, human centricity is the key focus. We have included a list of the different technical improvements that are part of Industry 5.0 as well as the technological advancements that are part of Industry 4.0. The problems that plagued Industry 4.0 have been addressed head-on in Industry 5.0, including concerns over data protection and the integration of new technologies. This study would serve as a foundation for academics and companies to learn about the technologies of Industry 4.0, their obstacles, the technical advancements, and the methods by that Industry 5.0 addressed the issues of Industry 4.0. Also, we constructed an appraiser model to appraise manufacturers as partner in supply chain. We selected manufacturers which are interested in deploying Industry 5.0 in their operation. Analytic Hierarchy Process (AHP) and Complex Proportional Assessment (COPRAS) are contributed to construct appraiser model under authority of uncertainty theory entailed in single value neutrosophic sets (SVNSs) to support AHP and COPRAS in ambiguity situations.

Keywords: Industry 5.0; Industry 4.0; Technical Improvements; Human Centricity; Data Security; AHP; COPRAS; Single Value Neutrosophic sets.

1. Introduction

Prior to the advent of the Industrial Revolution, production was conducted through traditional methods that may have been more optimal for large-scale production [1]. The advent of steam power and mechanized systems precipitated the onset of the First Industrial Revolution, a transformative period characterized by a significant augmentation in production, reaching an eightfold increase. The onset of the Second Industrial Revolution was marked by the introduction of novel technological innovations, such as electrical, mechanical, and electronic devices within the industrial sector. The implementation of partial automation within the context of industry and production marked the inception of what is commonly referred to as Industry 3.0. This enhancement resulted in increased reliability and efficiency in the production process [2]. The advent of computer numerical control brought about the implementation of a semi-automatic software system that effectively automates the process of machining parts. This technological advancement has proven to be instrumental in enhancing production volume. The advancement of Industry 3.0 necessitated substantial quantities of materials and diverse resources, coupled with the enhancement of prevailing methodologies, thereby giving rise to the emergence of Industry 4.0. The integration of manufacturing systems with Information and Communication Technology in Industry 4.0 has led to the automation of various processes. The advent of Industry 4.0 has significantly enhanced the efficacy of strategic decision-making processes by virtue of its real-time data analysis capabilities.

The advent of Industry 4.0 has brought forth a multitude of novel technologies, including but not limited to additive manufacturing, artificial intelligence, augmented reality, blockchain, and Cybersecurity [3]. Additionally, it aids in the mitigation of diverse obstacles, such as fluctuations in demand and volatility in the market. Industry 4.0 encompasses the integration of computer systems, materials, and artificial intelligence, aiming to minimize human involvement in decision-making processes. The impetus for the Industrial Revolution emerged from the necessity to transform conventional machinery into autonomous learning machines capable of enhancing performance, maintenance, and management through the utilization of contextual interactions. The advent of Industry 4.0 has also facilitated the implementation of digital food traceability systems, which have proven effective in mitigating instances of food fraud and enhancing the efficiency of food-related information dissemination. Amidst the Covid-19 pandemic, Industry 4.0 offered a diverse range of digital solutions to address pressing challenges.

Industry 5.0 is a paradigm that integrates the cognitive abilities of human beings with the accuracy and productivity of artificial intelligence in the context of industrial manufacturing processes. The emergence of Industrial 5.0 can be attributed to its potential to address the obstacles encountered in the context of Industry 4.0. This new paradigm places a strong emphasis on human-centricity and the fulfilment of societal requirements [4]. The implementation of this solution has the potential to effectively address the discrepancy that exists between manufacturing practices and the societal demands. The advancement of the Industrial Revolution to its fifth iteration necessitates the implementation of more advanced technological systems, including Network Sensor Data Interoperability, smart houses, Cobots, and other intelligent systems. Operators have the option to utilize collaborative robots, also known as Cobots, in order to enhance their efficiency and precision. Industry 5.0 prioritizes the integration of humans in manufacturing and industrial production processes, thereby offering workers more substantial and fulfilling employment opportunities.

1.1 Relevance of the study

Industry 5.0 has the potential to effectively address the obstacles encountered during the Industrial Revolution 4.0. Industry 4.0 paradigm does not offer the necessary framework for attaining Europe's objectives by 2030 due to its potential to establish a technological monopoly within the market. Industry 5.0 encompasses the anticipation of future disruptions that may be encountered by the industry, such as the COVID-19 pandemic, while also incorporating the principles of sustainability. In the context of industrial development, Industry 4.0 placed emphasis on sustainability, while Industry 5.0 shifts its focus towards human centricity.

1.2 Aims of the study

The objective of this study is to investigate the ways in which Industry 5.0 and its emerging innovations contribute to addressing the obstacles encountered in the context of Industry 4.0. Industry 5.0 has not only facilitated the implementation of diverse novel technologies, but it is also aiding in the resolution of the limitations encountered in Industry 4.0. Therefore, the primary objective is to examine the obstacles encountered by Industry 4.0 and subsequently investigate the diverse technologies associated with Industry 5.0 in order to assess their potential for implementation and integration within the industrial sector. This analysis aims to address the limitations and enhance the collaboration between these technologies and the human workforce. Another objective represents in evaluating manufacturers which embracing technologies of industry 5.0 in its operations and chain.

2. Obstacles Faced by Industry 4.0

Integration of technology is a big obstacle for Industry 4.0, among other important problems. The manufacturing of low-quality goods is a possible outcome of using technology that do not possess the capability to deal with the effects of digitalization. Additionally, additional effort is required in order to successfully deploy new information technology. In addition, standardized protocols will need to be developed so that machines can communicate with one another effectively.

Another significant obstacle that firms must overcome is keeping their data and information secure. The Internet of Things has the potential to make enterprises more susceptible to industrial espionage and unauthorized access.

The problem of human resources is just another difficulty that Industry 4.0 must overcome. To be able to operate in such an atmosphere, the staff members need the appropriate training.

Additionally, certain supply chain problems arose as a result of Industry 4.0. The process of digitizing and automating supply networks is gaining momentum. Both the accuracy of market forecasts and the capacity to track individual items have seen significant increases as a direct result of increased precision in both areas. This has resulted in a decrease in the number of planning cycles. The most difficult obstacle that must be overcome in supply chain management is the management of data integration and privacy.

3. Industry 5.0 as a solution to the problems that have been caused by Industry 4.0

There are several difficulties associated with Industry 4.0, all of which are effectively addressed by Industry 5.0.

3.1 Supply chain problem

Supply chain 4.0 takes into account a variety of issues, including its tactics, technologies that are disruptive to the industry, and numerous ramifications for the supply chain's performance [5]. Supply chain 4.0 is mostly focused on technological advancements, but supply chain 5.0 takes into account the interaction of people and technology. The new supply chain, known as version 4.0, is predicated on the concept of mass customization as well as improved supply chain performance attained via increased transparency, flexibility, and waste reduction. The objective of Industry 5.0 is to preserve these advantages while also generating additional value via mass personalization. The Internet of Things, artificial intelligence, and blockchain are the primary technologies used by supply chain 4.0. On the other hand, Industry 5.0 utilizes similar technologies but with more advanced characteristics in terms of technology, particularly AI and the utilization of cobots. The management of the supply chain for Industry 5.0 also has an emphasis on sustainability. Table 1 exhibits the positive impact of Industry 5.0 toward supply chain 5.0.

Table 1. Influence Industry 5.0 Technologies on Supply Chain.

Ref #	Utilized Industry 5.0 Technology	Technology's influence on the supply chain
Govindan etal [6], Al-Talib etal [7], Qader et al. [8]	Internet of Things (IoT)	• When a disruptive event is noticed, IoT can give precise information and enable quick treatment.

		• Reduced lead times. • Higher service rate. • Enhanced inventory velocity through improved inventory picking procedures
Govindan et al. [6]	Cyber-Physical Systems (Cyb-PSs)	• More transparent and traceable distribution. • Eliminate waste and practice lean manufacturing.
Zouari et al.[9]	Big Bata Analytics (BDAs)	•With the use of BDA, disturbances may be tracked back to their source and their spread can be observed. •Information sharing.
Karl et al. [10], Singh et al. [11]	Digital Twins (DIT)	• Improve client engagement to boost service rate. • Risk management.
Goel et al. [12]	Industrial Robotics (Ind R)	• A comprehensive change of the production and manufacturing phase is being brought about by Ind R. • Assist employees do their duty by utilizing various forms of cooperation. • Security
Ivanov et al. [13], Ding [14]	Additive Manufacturing (AM)	• Rapid and on-demand production. • Expedite the construction of multiple sophisticated prototypes that may be employed in the manufacturing process.

3.2 Human resource problem

The traditional methods of production were more easily automated as a result of Industry 4.0. Therefore, the employees have need for proper training to be supplied to them. Industry 5.0, on the other hand, places an emphasis on human centricity and is predicated on effective communication between people and robots. In this regard, the contributions made by cobots have been significant. In order to accomplish the goal at hand, these robots coordinate their efforts with human workers. As a result, they contribute to increased levels of productivity and efficiency in the workforce. In addition, the employees can participate in activities that add more value to the product without having to do duties that are boring or be engaged in professions that are hazardous. However, in order to safeguard these devices from future malfunctions, predictive maintenance has to be performed on them regularly.

Typically and according to [15] when investing in new technology, businesses now have many goals in mind. When a corporation, for instance, demands both improved information exchange and information security at the same time, the decision-making process may be complicated by the presence of numerous, sometimes at odds, criteria.

Thus, this study attempts to enhance the decision-making process by utilizing MCDM techniques as AHP [16] to evaluate the sustainability of the supply chain. Others benefited from the ability of fuzzy sets (FSs) to strengthen MCDM techniques in uncertain situations. For instance, [17] combined interval-valued intuitionistic Fuzzy (IVIF) Sets with AHP to appraise criteria weights and the IVIF Additive Ratio Assessment (ARAS) technique utilized for evaluating the alternatives. In a similar vein, [18] hesitant fuzzy AHP (HF-AHP) was employed for evaluating criteria and sub-criteria of BC in the supply chain, HF- Technique for Order Preference by Similarity to Ideal Solution (HF-TOPSIS) for ranking alternatives.

Although FS with its various versions has been widely used for supporting decision makers (DMs) in ambiguated decisions and situations through combination with MCDM methods. Another uncertainty theory is used as Neutrosophic theory with MCDM techniques in appraising the process for the supply chain.

Hence, this study serves as an appraiser for influencing Industry 5.0 in the supply chain especially the manufacturing sector as a partner in the supply chain. Also ranking, and appraising alternatives of manufacturers and recommend the most optimal one.

4. Evaluation Procedure Methodology

Herein, we are analyzing and evaluating the implications regarding employing digital technologies in the supply chain according to Industry 5.0's considerations. The process of analyzing and evaluating is conducted through a set of steps by various techniques.

4.1 Basic Industry 5.0’s Considerations

The initial and vital step in our study is determining the major considerations related to implementing Industry 5.0 technologies in supply chain.

Step 1: we identify considerations of Industry 5.0 technologies which contribute to analyzing and evaluating the manufacturers that embracing Industry 5.0 technologies in its operations and supply chain.

Step 2: we are selecting members of experts who are interested in our search scope and forming an expert panel. This panel is volunteering to rate manufacturers based on the identified considerations of Industry 5.0.

4.2 Judgement of Considerations

The initial and vital step in our study is determining the major considerations related to implementing Industry 5.0 technologies in supply chain.

Step 3: the confirmed panel is rating the identified considerations based on scale is listed in [19]. This scale is constructed based on interpreting crisp values into approximate values and considering measuring the degree of belonging (truth), non-belonging (falsity), and indeterminacy. This interpretation falls under the phenomenon of single-value neutrosophic sets (SVNSs). This phenomenon belongs to uncertainty theory is neutrosophic theory.

Step 4: decision matrices are produced by the previous step. These matrices are transformed into crisp matrices according to the score function represented in Eq. (1).

$$s(\mathrm{con}_{ij}) = \frac{(2+\mathrm{Tr}-\mathrm{In}-\mathrm{Fl})}{3} \tag{1}$$

Where:

$s(\text{con}_{ij})$ refers to score function. whilst $\text{Tr}, \text{Fl}, \text{In}$ refers to truth, false, and indeterminacy respectively.
Step 5: the produced crisp decision matrices are aggregated into aggregated decision matrix through calculating average of these matrices as in Eq. (2).

$$\text{New con}_{ij} = \frac{(\sum_{j=1}^{\text{Exp}} \text{con}_{ij})}{\text{Exp}s} \quad (2)$$

Where:
con_{ij} refers to value of Industry 5.0's consideration in decision matrices, where Exps refers to number of experts.

4.3 *Generalization of considerations' weights via AHP technique*

The initial and vital step in our study is determining the major considerations related to implementing Industry 5.0 technologies in supply chain.
Step 6: AHP technique is working under authority of SVNSs to compute weights of industry 5.0's considerations. Eq. (3) operate to normalize aggregated decision matrix after that normalized decision matrix is generated.

$$Q_{ij} = \frac{\text{con}_j}{\sum_{j=1}^{m}(\text{con}_j)}, j = 1,2, \ldots \ldots . n \quad (3)$$

Where:
Q_{ij} is a normalized decision matrix. Whilst con_j is element/consideration in aggregated decision matrix, and $\sum_{j=1}^{m}(\text{con}_j)$ is the sum of considerations per column in the aggregated matrix.
Step 7: Eq. (4) plays an important role in obtaining considerations' weights as:

$$\text{weig\_con}_i = \frac{\sum_{i=1} Q_i}{\text{N\_con}} \quad (4)$$

Where:
weig_con_i refers to consideration's weight, N_con indicates to number of considerations =8, $\sum_{i=1} Q_i$ sum of considerations per raw in normalized matrix.
Step 8: Check consistency ratio (Con R) through calculating consistency index (Con I) and a random consistency index (Ran I) based on following Eq. (5).

$$\text{Con R} = \frac{\text{Con I}}{\text{Ran I}} \quad (5)$$

4.4 *Recommending Optimal Alternative based on Ranker Technique*

Herein, subjective technique has been applied as COPRAS under authority of SVNSs to appraise set of alternatives which deploying Industry 5.0 based on determined considerations. Afterthat rank it and recommend best one through deploying the following steps:
Step 9: we are cooperating with the formed expert panel to appraise alternatives based on determined industry 5.0's considerations. Neutrosophic decision matrices have been constructed through rating alternatives via utilizing scale in [19].
Step 10: converting neutrosphic decision matrices into crisp matrices through Eq. (1) and aggregated it into single decision matrix. Based on Eq. (2).
Step 11: Eq. (6) plays an important role in normalizing single decision matrix.

$$\text{Norm}_{\text{Agg}} = [s_{ij}]_{m \times n} = \frac{p_{ij}}{\sum_{i=1}^{m} p_{ij}} \quad (6)$$

Where:
Norm_{Agg} is normalized of aggregated decision matrix. p_{ij} considers value of consideration for alternatives in aggregated decision matrix. $\sum_{i=1}^{m} p_{ij}$ refers to sum of consideration per column.
Step 12: weighted decision matrix is generated through Eq. (7).

$$\text{weig\_ dec}_{ij} = \text{weig\_con}_i * \text{Norm}_{\text{Agg}} \quad (7)$$

Step 13: Sum of weighted decision matrix calculated according to Eqs. (8) and (9).

$$\text{Sum\_weig}_{+i} = \sum_{j=1}^{n} \text{weig\_ dec}_{+ij}, \text{ for beneficial criteria} \quad (8)$$

$$\text{Sum\_weig}_{-i} = \sum_{j=1}^{n} \text{weig\_ dec}_{-ij}, \text{ for nonbeneficial criteria} \quad (9)$$

Step 14: the relative importance of alternatives is calculated through Eq. (10).

$$Q_i = Sum\_weigs_{+i} + \frac{Sum\_weig_{-min} \sum_{i=1}^{m} Sum\_weig_{-i}}{Sum\_weig_{-i} \sum_{i=1}^{m}(Sum\_weig_{-m}/Sum\_weig_{-i})} \tag{10}$$

Step 15: quantity utility U_i for each alternative is computed based on Eq. (11) to rank the alternatives.

$$U_i = \left[\frac{Q_i}{Q_{max}}\right] \times 100\% \tag{11}$$

5. Case Study: Empirical Evidence

In this study, we implemented our proposed model on real manufacturers on the 10th of Ramadan City, Egypt to prove model's validity. The candidates of manufacturers have different activities. Herein, we cooperate with four manufacturers (alternatives) that embrace the technologies of Industry 5.0 in their operations and its chain. These alternatives have been appraised through our proposed model based on determined Industry 5.0's considerations.

- Firstly, the considerations of industry 5.0 are determined.
  - In this study, eight considerations (Con(n)) have been determined to contribute to appraisal operation as in Figure 1.
  - The expert panel is formed to rate determined considerations which consists of three members.
- Secondly, considerations' valuation.
  - Neutrosophic decision matrices are constructed based on experts' rating.
  - Deneutrosopic these matrices into crisp values based on Eq. (1) and aggregated it into single aggregated matrix is listed in Table 2.
  - Table 3 represents normalization for aggregated decision matrix.
  - We leveraged normalized decision matrix to obtain considerations' weights based on Eq. (4) as in Figure 2.
  - According to Figure 2, Con 8 is highest weight value based on AHP and SVNSs otherwise, Con1 with least value.

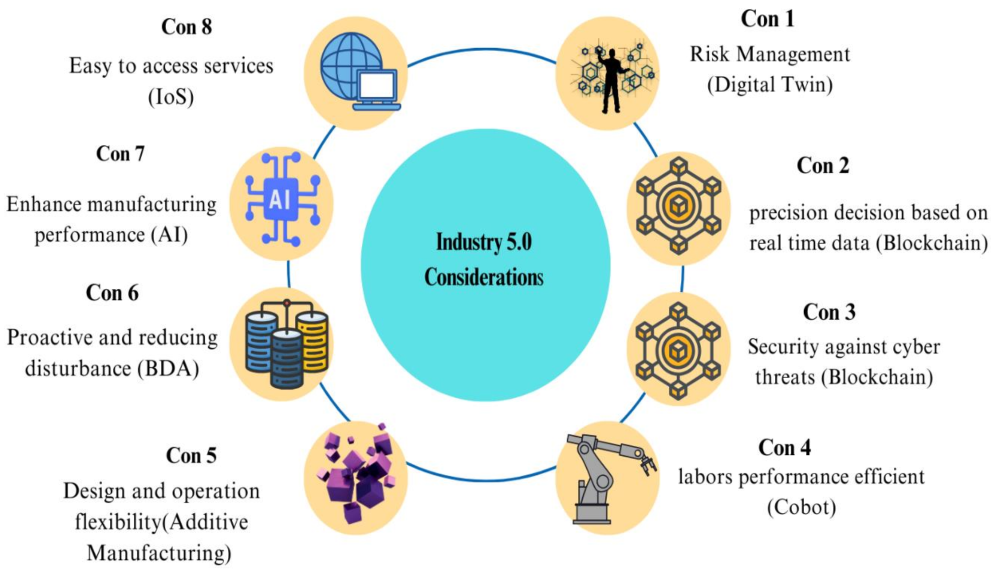

Figure 1. Determined Industry 5.0 considerations.

Table 2. Aggregated decision matrix AHP based on SVNSs.

	Con_1	Con_2	Con_3	Con_4	Con_5	Con_6	Con_7	Con_8
Con_1	0.5	0.761	0.728	0.428	0.667	0.69	0.61	0.46
Con_2	1.033	0.5	1	0.93	0.7	0.694	0.47	0.69
Con_3	2.533	1	0.5	0.967	0.87	0.521	0.87	0.73
Con_4	5.533	1.067	1.033	0.5	1	0.97	0.9	0.74
Con_5	4.033	4	1.2	1	0.5	0.97	0.7	0.97
Con_6	2.5667	2.567	3.067	1.033	1.03	0.5	0.94	0.97
Con_7	4.133	4.33	1.133	1.133	1.13	1.1	0.5	0.76
Con_8	4.867	2.567	2.533	1.367	1.03	1.033	1.57	0.5

Table 3. Normalized aggregated decision matrix AHP based on SVNSs.

	Con_1	Con_2	Con_3	Con_4	Con_5	Con_6	Con_7	Con_8
Con_1	0.019	0.045	0.065	0.058	0.096	0.108	0.092	0.079
Con_2	0.041	0.03	0.07	0.127	0.101	0.1072	0.072	0.119
Con_3	0.101	0.06	0.05	0.131	0.126	0.080	0.133	0.125
Con_4	0.219	0.06	0.09	0.068	0.144	0.149	0.137	0.128
Con_5	0.160	0.24	0.11	0.136	0.072	0.1493	0.107	0.166
Con_6	0.102	0.15	0.27	0.14	0.149	0.077	0.143	0.167
Con_7	0.164	0.26	0.101	0.154	0.163	0.169	0.076	0.131
Con_8	0.193	0.153	0.226	0.186	0.1489	0.159	0.238	0.086

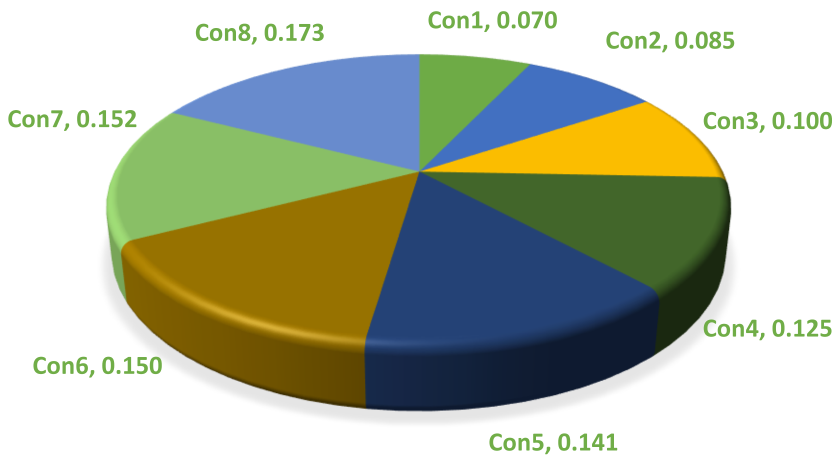

Figure 2. Considerations Weights AHP based on SVNSs.

- Thirdly, Recommending Optimal Alternative
  - According to preferences of expert panel for alternatives based on Industry 5.0, we constructed neutrosophic decision matrices.
  - Score function in Eq. (1) utilized to deneutrosophic the constructed matrices.
  - Then these matrices aggregated into decision matrix based on Eq. (2) as listed in Table 4.
  - According to Eq. (6) to normalize the aggregated decision matrix as in Table 5.

- Each element in generated normalized decision matrix is multiplied by weights of AHP based on SVNSs and produce weighted decision matrix as in Table 6.
- In this study, determined considerations are considered beneficial. Thus, Eq. (8) is utilized to get S_{+i} values. Thus, S_{-i} values= zero. Subsequently, the value of S-min/S-i is zero, where S-min is zero. So, the relative importance of alternatives (Q_i) based on Eq. (10), $Q_1 = 0.24533810603$. $Q_2 = 0.30649300022$. $Q_3 = 0.16555453$, $Q_4 = 0.209908098$.
- Eq. (11) is applied to calculate quantitative utility (U_i) for alternatives where its values are exhibiting in Figure 3. According to these values manufacturer 2 (A2) is optimal one. Otherwise, manufacturer 3 (A3) is the worst.

Table 4. Aggregated decision matrix COPRAS based on SVNSs.

	Con1	Con2	Con3	Con4	Con5	Con6	Con7	Con8
A1	0.81	0.65	0.33	0.62	0.39	0.37	0.72	0.84
A2	0.81	0.74	0.69	0.54	0.1	0.84	0.27	0.71
A3	0.72	0.62	0.81	0.1	0.81	0.81	0.51	0.81
A4	0.9	0.81	0.72	0.28	0.71	0.62	0.9	0.53

Table 5. Normalized aggregated decision matrix COPRAS based on SVNSs.

	Con1	Con2	Con3	Con4	Con5	Con6	Con7	Con8
A1	0.25	0.23	0.13	0.40	0.19	0.13	0.29	0.29
A2	0.33	0.34	0.31	0.58	0.06	0.37	0.16	0.34
A3	0.15	0.15	0.19	0.05	0.23	0.2	0.13	0.19
A4	0.22	0.22	0.22	0.16	0.26	0.19	0.27	0.16

Table 6. Weighted decision matrix COPRAS based on SVNSs.

	Con1	Con2	Con3	Con4	Con5	Con6	Con7	Con8
A1	0.016	0.019	0.013	0.05	0.028	0.021	0.045	0.051
A2	0.024	0.029	0.031	0.07	0.0083	0.056	0.025	0.060
A3	0.010	0.0125	0.019	0.01	0.033	0.030	0.020	0.033
A4	0.015	0.019	0.022	0.02	0.04	0.028	0.041	0.027

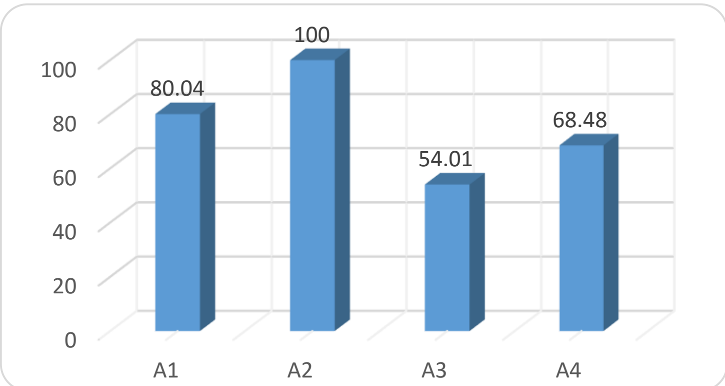

Figure 3. Alternatives' quantitative utility by COPRAS based on SVNSs.

6. Discussion

Industry 4.0 is characterized by a strong emphasis on technology, while Industry 5.0 seeks to enhance these technological advancements by incorporating human-centric elements. One such area where Industry 5.0 demonstrates this shift is in the supply chain. In this context, Industry 5.0 retains the advantages of Industry 4.0, such as mass customization, while also introducing the concept of collaborative robots, which ensures that humans remain an integral part of the supply chain process. The unauthorized access and manipulation of data through piracy represent a significant challenge within the context of Industry 4.0. However, the implementation of Blockchain Middleware offers a promising solution to effectively address this issue.

Hence, it is important for any supply chain and its participants to embrace the technologies of Industry 5.0 toward gain competitive advantages and to be sustainable in global markets. For this, the appraising process for manufacturers that deploy such technologies in their operations and throughout their chain.

Herein, we conducted a survey for these manufacturers which are interested in applied modern technologies. The results of the survey were represented by four manufacturers (alternatives) which contributed to the appraising process. These alternatives are considered the major factor in this process. Another factor is the considerations that are utilized to rate the alternatives.

These rates are treated as input for techniques of constructed appraisal models. AHP based on SVNSs is analyzing these rates and obtaining considerations' weights. The results of AHP based on SVNSs are exhibited in Figure 2 where con8 is best with the highest value, followed by con6 whilst con1 is worst with the least value. Implementation of COPRAS based on SVNSs to rank alternatives and recommend optimal ones. According to the results of these techniques which are showcased in Figure 3, A2 is optimal whilst A3 is the worst.

7. Conclusions

This work focuses on researching the problems that were encountered by Industry 4.0 and the solutions that were found for them in Industry 5.0. Industry 5.0 is still in the process of being developed, and there is only a small amount of material available. Therefore, Industry 5.0 presents a tremendous potential for research to be carried out, particularly in the fields of Data Security and Integration. This is because the integration of things with the Internet, also known as The Industrial Internet of Things, is often regarded as the most critical difficulty. Ideas that are more environmentally friendly may also be created for Industry 5.0. The era of automation and digitalization has made it simpler to examine the data created by sensors used in businesses. This has made it possible to eliminate the many hurdles that had been preventing companies from increasing their production and efficiency.

Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that there is no conflict of interest in the research.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

References

1. L. Alexa, M. Pîslaru, and S. Avasilcăi, "From Industry 4.0 to Industry 5.0—An Overview of European Union Enterprises BT - Sustainability and Innovation in Manufacturing Enterprises: Indicators, Models and Assessment for Industry 5.0," A. Draghici and L. Ivascu, Eds. Singapore: Springer Singapore, 2022, pp. 221–

231. doi: 10.1007/978-981-16-7365-8_8.
2. M.-C. Marica and N. Bizon, “Industry 5.0 vs. Industry 4.0 Reference Architectures, Challenges and Trends,” J. Electr. Eng. Electron. Control Comput. Sci., vol. 8, no. 30, pp. 33–38, 2022.
3. I. Gagnidze, “Industry 4.0 and industry 5.0: can clusters deal with the challenges? (A systemic approach),” Kybernetes, vol. ahead-of-p, no. ahead-of-print, Jan. 2022, doi: 10.1108/K-07-2022-1005.
4. A. Haruna et al., “Mitigating oil and gas pollutants for a sustainable environment – Critical review and prospects,” J. Clean. Prod., p. 137863, 2023, doi: https://doi.org/10.1016/j.jclepro.2023.137863.
5. L. Azevedo, D. Granato, V. G. Maltarollo, and J. E. Gonçalves, “A mosaic-structured framework applied in the healthy food design: insights from integrated in silico and in vitro approaches,” Curr. Opin. Food Sci., vol. 52, p. 101047, 2023, doi: https://doi.org/10.1016/j.cofs.2023.101047.
6. K. Govindan, D. Kannan, T. B. Jørgensen, and T. S. Nielsen, “Supply Chain 4.0 performance measurement: A systematic literature review, framework development, and empirical evidence,” Transp. Res. Part E Logist. Transp. Rev., vol. 164, p. 102725, 2022.
7. M. Al-Talib, W. Y. Melhem, A. I. Anosike, J. A. G. Reyes, and S. P. Nadeem, “Achieving resilience in the supply chain by applying IoT technology,” Procedia Cirp, vol. 91, pp. 752–757, 2020.
8. G. Qader, M. Junaid, Q. Abbas, and M. S. Mubarik, “Industry 4.0 enables supply chain resilience and supply chain performance,” Technol. Forecast. Soc. Change, vol. 185, p. 122026, 2022.
9. D. Zouari, S. Ruel, and L. Viale, “Does digitalising the supply chain contribute to its resilience?,” Int. J. Phys. Distrib. Logist. Manag., vol. 51, no. 2, pp. 149–180, 2021.
10. A. A. Karl, J. Micheluzzi, L. R. Leite, and C. R. Pereira, “Supply chain resilience and key performance indicators: a systematic literature review,” Production, vol. 28, 2018.
11. C. S. Singh, G. Soni, and G. K. Badhotiya, “Performance indicators for supply chain resilience: review and conceptual framework,” J. Ind. Eng. Int., vol. 15, pp. 105–117, 2019.
12. R. Goel and P. Gupta, “Robotics and industry 4.0,” A Roadmap to Ind. 4.0 Smart Prod. Sharp Bus. Sustain. Dev., pp. 157–169, 2020.
13. D. Ivanov, A. Dolgui, and B. Sokolov, “The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics,” Int. J. Prod. Res., vol. 57, no. 3, pp. 829–846, 2019.
14. B. Ding, “Pharma Industry 4.0: Literature review and research opportunities in sustainable pharmaceutical supply chains,” Process Saf. Environ. Prot., vol. 119, pp. 115–130, 2018.
15. G. Büyüközkan and M. Güler, “A combined hesitant fuzzy MCDM approach for supply chain analytics tool evaluation,” Appl. Soft Comput., vol. 112, p. 107812, 2021, doi: 10.1016/j.asoc.2021.107812.
16. C. H. Hsu, R. Y. Yu, A. Y. Chang, W. L. Liu, and A. C. Sun, “Applying Integrated QFD-MCDM Approach to Strengthen Supply Chain Agility for Mitigating Sustainable Risks,” Mathematics, vol. 10, no. 4, pp. 1–41, 2022, doi: 10.3390/math10040552.
17. G. Büyüközkan and F. Göçer, “An extension of ARAS methodology under interval valued intuitionistic fuzzy environment for digital supply chain,” Appl. Soft Comput., vol. 69, pp. 634–654, 2018.
18. M. Çolak, İ. Kaya, B. Özkan, A. Budak, and A. Karaşan, “A multi-criteria evaluation model based on hesitant fuzzy sets for blockchain technology in supply chain management,” J. Intell. Fuzzy Syst., vol. 38, no. 1, pp. 935–946, 2020.
19. M. Abdel-Basset, A. Gamal, N. Moustafa, A. Abdel-Monem, and N. El-Saber, “A Security-by-Design Decision-Making Model for Risk Management in Autonomous Vehicles,” IEEE Access, vol. 9, pp. 107657–107679, 2021, doi: 10.1109/ACCESS.2021.3098675.

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A Novel Method of Decision Making Based on Plithogenic Contradictions

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Abstract: Plithogenic decision-making models are evolved integrating the Plithogenic modelling approach with various methods of multi-criteria decision-making (MCDM). The earlier Plithogenic based decision methods are primarily based on the degrees of appurtenance. This paper introduces a novel Plithogenic ranking genre of decision-making paradigm based on degrees of contradiction. The method of Decision Making on Plithogenic Contradictions (DMPC) developed in this research work is indigenous and unique as the modeling procedure doesn't resemble any of the decision methods. This simple and logical approach proposed in this paper is applied in making optimal decisions on supplier selection. The proposed contradiction based Plithogenic model shall be integrated with other decision methods and this will certainly create a breakthrough in framing contradictions based combined Plithogenic decision-making models.

Keywords: Plithogenic Sets; Plithogenic Contradiction; MCDM; Decision Making on Plithogenic Contradictions.

1. Introduction

The everlasting conflict of choosing the optimal alternatives satisfying all the criteria to the expected extent is motivating the researchers to develop new methods. This has led to the expansion of the theoretical aspects of decision-making with the development of scientific and algorithmic approaches to decision-making methods. The construction of any decision-making problem comprises certainly an elementary decision-making matrix with values matching the alternatives and criteria. The two prime objectives of the decision methods are to find the criterion weights and ranking of the alternatives. The decision-making methods are classified based on information availability, decision timeline, domain, level, structure, outcome, approach, and process.

The circumstances of making decisions are influenced by several factors affecting the deterministic nature of decision-making. The representations using crisp sets are replaced with the extension of fuzzy sets developed by Zadeh [1] to handle impreciseness and uncertainty. These fuzzy sets are further extended to intuitionistic sets [2] and neutrosophic sets to deal the situations of decision-making with hesitancy and indeterminacy. The decision-making methods developed in crisp sense are discussed by the researchers in the extended version of sets. However, these different representations of set are unified under one roof of Plithogeny by Smarandache [3] in the year 2018. The origin and development of Plithogenic sets has made novel plithogenic decision-making methods to evolve. Smarandache has contributed a lot to the field of Plithogeny, especially to the development of fundamental concepts of the Plithogenic sets [4-6]. Smarandache has also contributed to Plithogenic algebraic structures [7-8]. Nivetha and Smarandache have together initialized the conceptualization of Plithogenic based hypergraphs and super hypergraphs [9-10].

A plithogenic set is basically a 5-tuple set that deals with attributes. This set comprises attribute values, degrees of appurtenance, and contradiction. The degrees of appurtenance decide the nature of the Plithogenic sets and it assumes any of the set representations such as crisp, fuzzy, intuitionistic, and neutrosophic. The Plithogenic decision-making methods primarily involve plithogenic operators to obtain a unified decision-making matrix based on the expert's opinion. The literature on Plithogenic based multi criteria decision making (MCDM) methods is limited. Some of the most commonly applied conventional decision-making methods are discussed in Plithogenic environment only with the inclusion of the Plithogenic operators of union and intersection and degrees of appurtenance. This has motivated the authors to develop a new genre of decision-making method based on the degrees of contradiction. The method of making decisions with a contradiction degree is proposed as a method of ranking the alternatives. This method is very simple in its formulation and the logical approach makes the method more rational.

The paper is organized as follows: section 2 sketches out the contributions in the domain of Plithogenic decision-making. Section 3 presents the proposed method of Decision Making on Plithogenic Contradictions. Section 4 applies the proposed method to the supplier selection problem. Section 5 discusses the results under different cases and section 6 concludes the work with future directions.

2. Literature review

The theory of Plithogeny is applied in MCDM integrating a wide range of different concepts of soft sets, Hypersoft sets, cognitive maps, hypergraphs, and many others. Plithogenic decision-making models are developed based on these concepts to design solutions to real-life problems. Plithogenic based MCDM are either the extensions or the generalizations of the existing mathematical concepts. The Plithogenic logic, probability statistics, and optimization assist in obtaining optimal solutions to decision-making problems. The contributions of researchers towards the formulation of Plithogenic decision-making models are presented in Table 1.

Table 1. Contributions of Plithogenic based decision making.

Authors & Year	Plithogenic Decision Making Method	Domain of Application	Highlights of the contribution
Ozcil et al. [11]	MAIRCA	Green Supplier selection	• Minimization of the gap between ideal and empirical values • Plithogenic aggregation operators
Abdel-Basset et al. 12]	VIKOR	Hospital medical care systems	• Plithogenic contradiction degree for dominant attribute
Abdel-Basset et al. [13]	QFD	Selecting supply chain sustainability	• Plithogenic aggregation operators
Rana et al. [14]	Plithogenic Hypersoft set, Plithogenic Whole Hypersoft set	Selecting faculty for the Engineering department	• Frequency matrix for final ranking

Abdel-Basset, & Mohamed, [15]	TOPSIS-CRITIC	Sustainable supply chain risk management	• Plithogenic aggregation operators
Abdel-Basset et al. [16]	BWM	Supply chain problem	• Plithogenic aggregation operators
Abdel-Basset et al. [17]	AHP,VIKOR, TOPSIS	Financial performance evaluation in manufacturing industries	• Plithogenic aggregation operators
Gómez et al. [18]	VIKOR	Pedagogical performance.	• Plithogenic aggregation operators
Grida et al. [19]	VIKOR,BWM	IoT based supply chain	• Plithogenic aggregation operators
Abdel-Basset et al. [20]	MABAC; BWM	Supplier selection	• Plithogenic aggregation
Ahmad et al. [21]	PHSS based TOPSIS	Parking spot choice problem	• Plithogenic aggregation
Smarandache, &Martin [22]	Plithogenic n-super hypergraph, Dominant enveloping vertex	E-learning system of education (Work from Home During Covid-19)	• Classification of Dominant Enveloping Vertex • Plithogenic Connectors
Gomathy et al. [23]	Plithogenic operator laws (fuzzy tnorm & tconorm)	Medical field	• Plithogenic aggregate operators
Martin et al. [24]	Plithogenic sociogram & Plithogenic number	Food processing industry	• Preferential ordering based on attributes
Öztaş et al. [25]	Plirhogeny, DEA	Tourist travelers performance (Accommodation for touristic travelers)	• Plithogenic aggregation operations
Korucuk et al. [26]	CRITIC	logistics sector	• Plithogenic aggregation operations
Sujatha, et al. [27]	FCM, Plithogenic operators	Corona virus (Covid-19)	• Plithogenic aggregation of weights
Martin et al. [28]	PHS,DM	Covid- 19	• Extended combined plithogenic hypersoft sets

Hernández et al. [29]	Plithogenic logic, SWOT	Entrepreneurship competence in university students	• Plithogenic aggregation operators
Martin et al. [30]	PSCM	Factors in COVID-19 diagnostic model	• Degree of contradiction with respect to the factors
Ulutaş et al. [31]	PIPRECIA	Prioritization of logistics sector	• Plithogenic aggregation operators
Ulutaş et al. [32]	SWARA	Logistics sector	• Plithogenic aggregation operators
Singh. [33]	Plithogenic graph; Plithogenic set	Olympic Players performance	• Plithogenic aggregation operators
Ansari & Kant. [34]	AHP	Supply chain	• Plithogenic aggregation operators
Martin et al. [35]	PROMTHEE	Smart materials selection	• Plithogenic aggregation operators
Singh [36]	Plithogenic graphs	Dark data analysis (Performance of players in crickets)	• Conflict situation
Singh [37]	Plithogenic graphs	Air Quality Index Analysis(Impact on human health)	• Single-valued Neutrosophic Plithogenic data visualization
Priyadharshini & Irudayam [38]	MCDM	Agriculture field	• Plithogenic aggregate operators
Rodríguez et al. [39]	Plithogenic number, MCDM	Education and Society	• Representations using Plithogenic number
Priya & Martin [40]	PCM, IPCM, CCM	online learning system	• Plithogenic sets in determining the association between the factors
Fernández et al. [41]	AHP, TOPSIS	Selection of Investment Projects	• Plithogenic aggregate operators
Castro Sánchez et al. [42]	Plithogenic logics	Educational Development	• Plithogenic aggregate operators
Priyadharshini & Irudayam [43]	RPNS	Candidate's selection in interview.	• RPNS Operators • Correlation measures and its properties
Bharathi & Leo [44]	PPfuzzy graph	Social Network	• To discover the network's most outgoing, gregarious, powerful, and key figures.

Villacrés et al. [45]	AHP	Ergonomic Occupational Health Risks for teachers	• Instant solutions
Moncayo et al. [46]	SWOT, Plithogeny	Ecuadorian Hospital environment	• Plithogenic operators
Pai & Prabhu Gaonkar [47]	Plithogenic set	Risk Assessment due to accident	• Assessing risk and ranking of the criteria in a complex system
Romero et al. [48]	AHP,TOPSIS	Investment Projects selection problem	• Plithogenic aggregate operators
Antonio et al. [49]	Plithogenic logic	Electronic payment methods/Mechanism	• Plithogenic aggregate operators
Sultana et al. [50]	Plithogenic graphs	Spreading coronavirus disease (COVID-19)	• Plithogenic aggregate operators
Ahmad & Afzal [51]	PDM,PHSS,PSM	Mathematical modeling and AI (COVID-19 suspect)	• Plithogenic aggregate operators
Martin, N [52]	SWARA-TOPSIS	Food Processing Methods	• Plithogenic operators
Liang et al. [53]	CRITIC, Game theory, TOPSIS-GRA	Air traffic flow problem	• Plithogenic aggregation
Abdelfattah, W. [54]	DEA	University in Saudi Arabia	• Plithogenic aggregation
Wang et al. [55]	COPRAS, PNRN	Sustainable Financing Enterprise selection	• Extended Similarity Measures
Sudha & Martin [56]	BWM	Teaching methods	• Plithogenic Pythagorean set.
Sudha., Martin, &Broumi [57]	CRITIC-MAIRCA	Livestock Feeding Stuff problem	• Plithogenic aggregation
Ulutaş, & Topal [58]	PIPRECIA	Renewable energy industry	• Plithogenic aggregation
Seby, & Ravi [59]	Plithogeny	Supply chain	• Plithogenic aggregation
Priya,, Martin, & Kishore [60]	Plithogeny	Human's cognitive domain	• Contradiction degree in PCM
Zuñiga et al. [61]	Plithogenic number	Classifications of clays	• Representations using Plithogenic numbers
Tayal et al. [62]	TOPSIS, WSM	Business	• Plithogenic aggregation

Wang et al. [63]	VIKOR	Supply Chain Financial risk evaluation	• Probabilistic Linguistic MAGDM
Sudha, & Martin [64]	PIPRECIA, AHP	Logistics selection sector	• Plithogenic Operators

In the above mentioned Plithogeny based decision-making methods, the following research gaps are identified.

- The plithogenic operators based on degree of appurtenance are widely applied and only in few instances the contradiction degree is used.
- The plithogenic oriented decision-making methods lack the use of the aspect of contradiction degree in handling the alternatives and criteria.

Hence this research work designs a decision-making method purely based on the contradiction degrees with respect to the dominant attribute value of the alternatives. The novel attributes of this paper are as follows:

- A distinctive decision making approach based on contradictions degree.
- Simple and compatible method of finding the optimal alternatives.
- Flexible method which accommodates several alternatives and criteria.

3. Proposed Method of Decision making based on Plithogenic Contradictions

This section consists of the steps involved in the method of Decision Making on Plithogenic Contradictions (DMPC). The elementary steps of this method are similar to the general working principle of an MCDM method. Figure 1 presents the overall framework of the proposed method of DMPC.

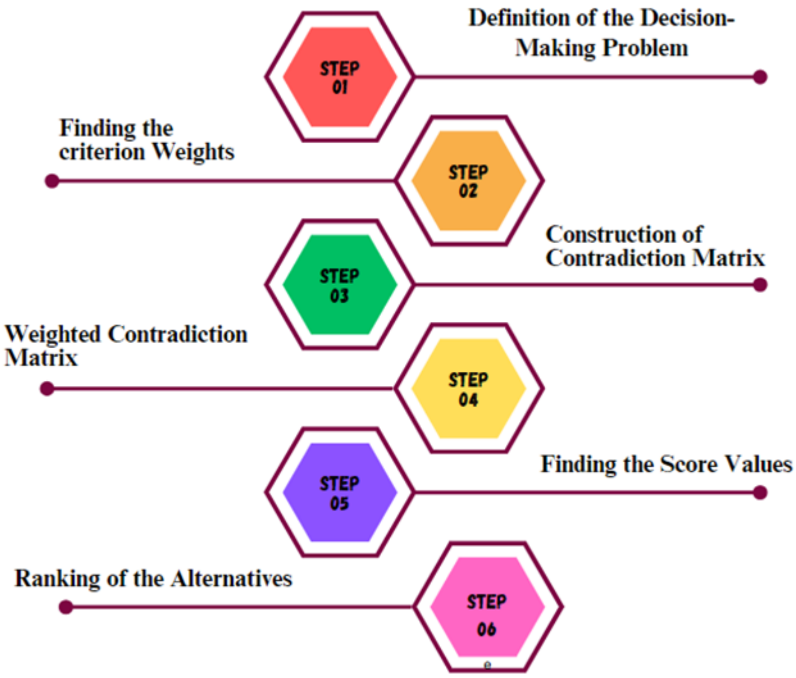

Figure 1. Overall framework of DMPC.

Step 1: *Definition of the decision-making problem*

It is the initial step in which the problem is well defined with alternatives and criteria. The criteria are classified into benefit and non-benefit based on the nature of the problem. Each of the criterion has sub-values. The decision making matrix with initial values is constructed especially with linguistic variables.

$$D_L = \begin{bmatrix} x_{L11} & \cdots & x_{L1n} \\ \vdots & \ddots & \vdots \\ x_{Lm1} & \cdots & x_{Lmn} \end{bmatrix}$$

The decision making matrix is with m alternatives and n criteria.

Step 2: *Finding the Criterion Weights*

The criterion weights say Wk are determined using any of the methods. Each of the criterion has criterion values say Cki.

Step 3: *Construction of contradiction matrix*

The dominant criterion value say CkD among the criterion values of each criteria is identified. The contradiction degree among the criterion values is determined. Based on the contradiction degree, the contradiction matrix is constructed with contradiction degrees pertaining to the dominant criterion value with respect to the values assumed by each alternative with respect to the criterion value in the initial matrix.

$$C_D = \begin{bmatrix} c_{D11} & \cdots & c_{D1n} \\ \vdots & \ddots & \vdots \\ c_{Dm1} & \cdots & c_{Dmn} \end{bmatrix}$$

Step 4: *Weighted contradiction matrix*

The weighted contradiction matrix $[WC_D]$is obtained by multiplying the criterion weights with the values of contradiction matrix.

Step 5: *Finding the score values*

The score values of each of the alternative with respect to both benefit and cost criteria say BSj and CSh is first calculated. The difference between the values is determined, say BSj - CSh = Df

Step 6: *Ranking of the alternatives*

The alternatives are ranked based on the difference values Df. The alternative with maximum difference value is ranked first and so on.

4. Application of DMPC in supplier selection

In this section, a decision-making problem is solved using the proposed method of DMPC. Let us consider a logistic supplier selection problem with five alternatives and four criteria say C1 – Price, C2 – Time span of delivery, C3 – Flexibility, and C4 – Reliability.

The criteria C1 and C2 are considered to be cost criteria and the criteria C3 and C4 are considered as benefit criteria.

Each criteria presumed to be the attribute possess the attribute values of {L, M, H} i.e. {Low, Moderate, High}.

For the cost criteria, the dominant attribute value is certainly LOW & for the benefit criteria it is HIGH.

Contradiction degree with respect to dominant attribute value (LOW) of the cost criteria (C1 & C2).

C(L,L) = 0
C(L,M) = 1/3
C(L,H) = 2/3

Contradiction degree with respect to dominant attribute value (HIGH) of the benefit criteria.

C(H,H) = 0
C(H,M) = 1/3
C(H,L) = 2/3
C(M,M) =0

The initial decision making matrix with linguistic values is presented in Table 2.

Table 2. Initial decision making matrix.

Alternatives /Criteria	**C1**	**C2**	**C3**	**C4**
	Cost Criteria		**Benefit Criteria**	
A1	L	H	L	M
A2	H	M	L	M
A3	M	L	H	M
A4	L	L	M	H
A5	L	H	M	L

The assumed criterion weights and the dominant attribute value with respect to each of criterion are presented as follows in Table 3.

Table 3. Decision matrix with criterion description.

Alternatives/ Criteria	**C1**	**C2**	**C3**	**C4**
	Cost Criteria		**Benefit Criteria**	
	0.35	0.25	0.20	0.20
A1	L	H	L	M
A2	H	M	L	M
A3	M	L	H	M
A4	L	L	M	H
A5	L	H	M	L
Dominant Value	L	L	H	H

The contradiction matrix with the contradiction degree of each criterion values with respect to the dominant criterion value is presented as follows in Table 4 using step 3.

Table 4. Contradiction matrix.

Alternatives/ Criteria	**C1**	**C2**	**C3**	**C4**
	Cost Criteria		**Benefit Criteria**	
	0.35	0.25	0.20	0.20
A1	0	2/3	2/3	1/3
A2	2/3	1/3	2/3	1/3
A3	1/3	0	0	1/3
A4	0	0	1/3	0
A5	0	2/3	1/3	2/3

The weighted contradiction matrix is computed using step 4 as follows in Table 5.

Table 5. Weighted contradiction matrix.

Alternatives /Criteria	**C1**	**C2**	**C3**	**C4**
	Cost Criteria		**Benefit Criteria**	
A1	0.00	0.17	0.13	0.07
A2	0.23	0.08	0.13	0.07
A3	0.12	0.00	0.00	0.07
A4	0.00	0.00	0.07	0.00
A5	0.00	0.17	0.07	0.13

The score values of the benefit and cost criteria with respect to each alternative are calculated as presented in Table 6.

Table 6. Score values of criteria.

Alternatives	Cost Criteria	Benefit Criteria
A1	0.17	0.20
A2	0.31	0.20
A3	0.12	0.07
A4	0.00	0.07
A5	0.17	0.20

The differences between the benefit and the cost criteria score values are presented in Table 7.

Table 7. Difference in score values.

Alternatives	Differences in the score values
A1	0.03
A2	-0.11
A3	-0.05
A4	0.07
A5	0.03

Based on the difference values the alternatives are ranked as follows as in Table 8.

Table 8. Ranking of the alternatives.

Alternatives	Ranking
A1	2
A2	4
A3	3
A4	1
A5	2

5. Discussion

The above ranking of the alternatives is obtained with assumed criterion weights. The same ranking procedure based on contradictions is repeated with different criterion weights obtained using various methods such as the Analytical Hierarchy Process (AHP), Entropy, and the method of CRITIC (CRiteria Importance through Intercriteria Correlation). Table 9 and Figure 2 represent the rankings of the alternatives using different criterion weights.

Table 9. Ranking of alternatives based on different criterion weights.

Alternatives	Rankings based on diverse criterion weights		
	AHP	CRITIC	Entropy
A1	2	2	2
A2	5	4	5
A3	4	5	4
A4	1	1	1
A5	3	3	3

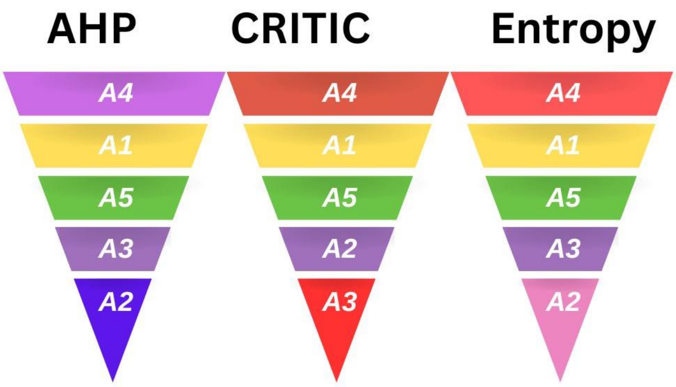

Figure 2. Graphical representation of diverse ranking of the alternatives.

6. Conclusions

This research work proposes a new genre of Plithogenic based decision-making method based on contradictions. The proposed method stands distinct in comparison with other methods as it streamlines a new modality of making optimal decisions. This method will definitely lessen the hurdles in choosing the alternatives based on cost and benefit criteria. The ranking obtained using the Plithogenic method based on contradictions is compared with different criterion weights. This method shall be dealt with extended Plithogenic sets. Also, the method of Plithogenic Cognitive Maps shall be associated with the proposed method as a means of developing several hybrid decision-making methods. This method is highly adaptable and flexible in nature and hence it shall be blended with other decision-making models to evolve new hybrid decision-making systems.

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Data availability
The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflict of interest
The authors declare that there is no conflict of interest in the research.

Ethical approval
This article does not contain any studies with human participants or animals performed by any of the authors.

References

1. Zadeh L. A.; Fuzzy sets, *Information and Control,* 1965, 8,338-353.
2. Atanassov, K. T.; Intuitionistic fuzzy sets. *Fuzzy Sets and Systems,* 1986, 20(1), 87–96. https://doi.org/10.1016/S0165-0114(86)80034-3
3. Florentin Smarandache.; Plithogenic Set, an Extension of Crisp, Fuzzy, Intuitionistic Fuzzy, and Neutrosophic Sets – Revisited. *Neutrosophic Sets and Systems*, 2018, vol. 21, pp. 153-166. https://doi.org/10.5281/zenodo.1408740
4. Florentin Smarandache: Plithogenic Set, an Extension of Crisp, Fuzzy, Intuitionistic Fuzzy, and Neutrosophic Sets - Revisited. *Neutrosophic Sets and Systems*, Vol. 21, 2018, 153-166.

5. Florentin Smarandache: Extension of Soft Set to Hypersoft Set, and then to Plithogenic Hypersoft Set. *Neutrosophic Sets and Systems*, Vol. 22, 2018, 168-170.
6. Florentin Smarandache: Conjunto plitogenico, una extension de los conjuntos crisp, difusos, conjuntos difusos intuicionistas y neutrosoficos revisitado. *Neutrosophic Computing and Machine Learning*, Vol. 3, 2018, 1-19.
7. Florentin Smarandache, Introduction to the Symbolic Plithogenic Algebraic Structures (revisited), *Neutrosophic Sets and Systems*2022., Vol. 53,
8. Florentin Smarandache, An Overview of Plithogenic Set and Symbolic Plithogenic Algebraic Structures (Review Paper), J. *Fuzzy. Ext.Appl.* Vol. 4, No. 1 (2023) 48–55, http://fs.unm.edu/P/Plithogeny-JFEA.pdf
9. Nivetha Martin, Florentin Smarandache: Concentric Plithogenic Hypergraph based on Plithogenic Hypersoft sets - A Novel Outlook. Neutrosophic Sets and Systems, Vol. 33, 2020, 78-91.
10. Florentin Smarandache, Nivetha Martin: Plithogenic n-Super Hypergraph in Novel Multi-Attribute Decision Making. *International Journal of Neutrosophic Science* (IJNS) Vol. 7, No. 1, 2020, 8-30.
11. Özçil, A., Tuş, A., Öztaş, G. Z., Adalı, E. A., & Öztaş, T. The novel integrated model of plithogenic sets and MAIRCA method for MCDM problems. *In International conference on intelligent and fuzzy systems* (pp. 733-741). (2020, July). Cham: Springer International Publishing.
12. Abdel-Basset, M., El-Hoseny, M., Gamal, A., & Smarandache, F. A novel model for evaluation Hospital medical care systems based on plithogenic sets. *Artificial intelligence in medicine*, (2019), 100, 101710.
13. Abdel-Basset, M., Mohamed, R., Zaied, A. E. N. H., & Smarandache, F. A hybrid plithogenic decision-making approach with quality function deployment for selecting supply chain sustainability metrics. *Symmetry*, (2019). 11(7), 903.
14. Rana, S., Qayyum, M., Saeed, M., Smarandache, F., & Khan, B. A. Plithogenic fuzzy whole hypersoft set, construction of operators and their application in frequency matrix multi attribute decision making technique. *Infinite Study*. (2019).
15. Abdel-Basset, M., & Mohamed, R. A novel plithogenic TOPSIS-CRITIC model for sustainable supply chain risk management. *Journal of Cleaner Production*, (2020). 247, 119586.
16. Abdel-Basset, M., Mohamed, R., Zaied, A. E. N. H., Gamal, A., & Smarandache, F. Solving the supply chain problem using the best-worst method based on a novel Plithogenic model. *In Optimization theory based on neutrosophic and plithogenic sets* (pp. 1-19). (2020). Academic Press.
17. Abdel-Basset, M., Ding, W., Mohamed, R., & Metawa, N. An integrated plithogenic MCDM approach for financial performance evaluation of manufacturing industries. *Risk management*, (2020). 22, 192-218.
18. Gómez, G. Á., Moya, J. V., Ricardo, J. E., & Sánchez, C. B. V. Evaluating Strategies of Continuing Education for Academics Supported in the Pedagogical Model and Based on Plithogenic Sets (Vol. 37). (2020). *Infinite Study.*
19. Grida, M., Mohamed, R., & Zaid, A. H. A novel plithogenic MCDM framework for evaluating the performance of IoT based supply chain. *Neutrosophic sets and systems*, (2020). 33(1), 323-341.
20. Abdel-Basset, M., Mohamed, R., Smarandache, F., & Elhoseny, M. A new decision-making model based on plithogenic set for supplier selection. *Infinite Study*. (2020).
21. Ahmad, M. R., Saeed, M., Afzal, U., & Yang, M. S. A novel MCDM method based on plithogenic hypersoft sets under fuzzy neutrosophic environment. *Symmetry*, (2020). 12(11), 1855
22. Smarandache, F., & Martin, N. Plithogenic n-super hypergraph in novel multi-attribute decision making. *Infinite Study*. (2020).
23. Gomathy, S., Nagarajan, D., Broumi, S., & Lathamaheswari, M. Plithogenic sets and their application in decision making. *Infinite Study*. (2020).
24. Martin, N., Smarandache, F., & Priya, R. Introduction to Plithogenic Sociogram with preference representations by Plithogenic Number. *Infinite Study*. (2020).
25. Öztaş, G. Z., Adalı, E. A., Tuş, A., Öztaş, T., & Özçil, A. An Alternative Approach for Performance Evaluation: Plithogenic Sets and DEA. *In International Conference on Intelligent and Fuzzy Systems* (pp. 742-749). (2020, July).Cham: Springer International Publishing.
26. Korucuk, S., Demir, E., Karamasa, C., & Stević, Ž. Determining the dimensions of the innovation ability in logistics sector by using plithogenic-critic method: An application in Sakarya Province. *International Review,* (1-2), (2020). 119-127

27. Sujatha, R., Poomagal, S., Kuppuswami, G., & Broumi, S. An Analysis on Novel Corona Virus by a Plithogenic Approach to Fuzzy Cognitive Map. *Infinite Study*. (2020).
28. Martin, N., Smarandache, F., & Broumi, S. Covid-19 decision-making model using extended plithogenic hypersoft sets with dual dominant attributes. *International journal of neutrosophic science*, 13(2), (2021). 75-86.
29. Hernández, N. B., Vázquez, M. Y. L., Caballero, E. G., Cruzaty, L. E. V., Chávez, W. O., & Smarandache, F. A new method to assess entrepreneurship competence in university students using based on plithogenic numbers and SWOT analysis. *International Journal of Fuzzy Logic and Intelligent Systems*, 21(3), (2021). 280-292.
30. Martin, N., Priya, R., & Smarandache, F. New Plithogenic sub cognitive maps approach with mediating effects of factors in COVID-19 diagnostic model. *Infinite Study.* (2021).
31. Ulutaş, A., Topal, A., Karabasevic, D., Stanujkic, D., Popovic, G., & Smarandache, F. Prioritization of logistics risks with plithogenic PIPRECIA method. *In International Conference on Intelligent and Fuzzy Systems* (pp. 663-670). (2021, August). Cham: Springer International Publishing
32. Ulutaş, A., Meidute-Kavaliauskiene, I., Topal, A., & Demir, E. Assessment of collaboration-based and non-collaboration-based logistics risks with plithogenic SWARA method. *Logistics*, (2021). 5(4), 82.
33. Singh, P. K. Single-valued Plithogenic graph for handling multi-valued attribute data and its context. *Int. J. Neutrosophic Sci*, 15, (2021). 98-112.
34. Ansari, Z. N., & Kant, R. A plithogenic based neutrosophic analytic hierarchy process framework to analyse the barriers hindering adoption of eco-innovation practices in supply chain. *International Journal of Sustainable Engineering,* 14(6), (2021). 1509-1524
35. Martin, N., Smarandache, F., & Broumi, S. PROMTHEE plithogenic pythagorean hypergraphic approach in smart materials selection. *Int J Neutrosophic Sci*, 13, (2021). 52-60.
36. Singh, P. K. Dark data analysis using intuitionistic plithogenic graphs. *International Journal of Neutrosophic Sciences,* 16(2), (2021). 80-100.
37. Singh, P. K. Air Quality Index Analysis Using Single-Valued Neutrosophic Plithogenic Graph for Multi-Decision Process. *International Journal of Neutrosophic Science* (IJNS), 16(1). (2021).
38. Priyadharshini, S. P., & Irudayam, F. N. A New Approach of Multi-Dimensional Single Valued Plithogenic Neutrosophic Set in Multi Criteria Decision Making. *Infinite Study*. (2021).
39. Rodríguez, R. C., Gómez, S. D. Á., Domínguez, E. R. A., Villanueva, L. K. B., & Terue, K. P. A Novel Evaluative Method of the Subject "Education and Society" of the Autonomous University of the Andes, Ecuador, based on Plithogenic Numbers. *Infinite Study*. (2021).
40. Priya, R., & Martin, N. Induced Plithogenic Cognitive Maps with Combined Connection Matrix to investigate the glitches of online learning system. *Infinite Study*. (2021).
41. Fernández, A. R., Gómez, G. Á., Hernández, S. D. R. Á., Arboleda, W. R. Á., & García, A. R. R. Selection of Investment Projects in a Plithogenic Environment. *Infinite Study.* (2021).
42. Castro Sánchez, F., Almeida Blacio, J. H., Flores Bracho, M. G., Andrade Santamaria, D. R., & Sánchez Casanova, R. Neutrosophic and Plithogenic Statistical Analysis in Educational Development. *Neutrosophic Sets and Systems*, 44(1), (2021). 26.
43. Priyadharshini, S. P., & Irudayam, F. N. A novel approach of refined plithogenic neutrosophic sets in multi criteria decision making. *Infinite Study*. (2021).
44. Bharathi, T., & Leo, S. A Study on Plithogenic Product Fuzzy Graphs with Application in Social network. *Indian Journal of Science and Technology*, 14(40), (2021). 3051-3063
45. Villacrés, G. E. F., Naranjo, F. A. V., & López, R. R. L. Plithogenic Logic for Determination of Strategic Solutions for Ergonomic Occupational Health Risks. *Infinite Study*. (2021).
46. Moncayo, M. F. C., Freire, L. E., Flores, L. C. G., & Delgado, J. L. G. Definition of Strategies in Ecuadorian Hospitals in a Plithogenic Environment. *Infinite Study*. (2021).
47. Pai, S. P., & Prabhu Gaonkar, R. S. Risk Assessment Using Evidential Reasoning in Plithogenic Environment. In Current Advances in Mechanical Engineering: *Select Proceedings of ICRAMERD* 2020 (2021). (pp. 949-962). Springer Singapore.

48. Romero Fernández, A., Álvarez Gómez, G., Álvarez Hernández, S. D. R., Álvarez Arboleda, W. R., & Rosales García, A. R. Selection of Investment Projects in a Plithogenic Environment. *Neutrosophic Sets and Systems*, 44(1), (2021). 30.
49. Antonio, L. O. L., Alberto, V. N. F., Toapanta, C., Vinicio, W., Naranjo, B., & Patricio, F. Electronic Payments in Decentralized Autonomous Municipal Governments of Ecuador. Decision Making through Plithogenic Logic. *Infinite Study*. (2021).
50. Sultana, F., Gulistan, M., Ali, M., Yaqoob, N., Khan, M., Rashid, T., & Ahmed, T. A study of plithogenic graphs: applications in spreading coronavirus disease (COVID-19) globally. *Journal of ambient intelligence and humanized computing*, 1-21(2022).
51. Ahmad, M. R., & Afzal, U. Mathematical modeling and AI based decision making for COVID-19 suspects backed by novel distance and similarity measures on plithogenic hypersoft sets. *Artificial Intelligence in Medicine*, 132, (2022). 102390
52. Martin, N. Plithogenic SWARA-TOPSIS Decision Making on Food Processing Methods with Different Normalization Techniques. *Advances in Decision Making, 69*-78. (2022).
53. Liang, B., Han, S., Li, W., Han, Y., Liu, F., Zhang, Y., & Lin, C. Plithogenic multi-criteria decision making approach on airspace planning scheme evaluation based on ATC-flight real-time simulation. IET *Intelligent Transport Systems*, 16(11), (2022). 1471-1488.
54. Abdelfattah, W. Variables Selection Procedure for the DEA Overall Efficiency Assessment Based Plithogenic Sets and Mathematical Programming. (2022).
55. Wang, P., Lin, Y., & Wang, Z. An Integrated Decision-Making Model Based on Plithogenic-Neutrosophic Rough Number for Sustainable Financing Enterprise Selection. *Sustainability*, 14(19), (2022). 12473.
56. Sudha, S., & Martin, N. Comparison of plithogenic and neutrosophic approaches in decision making via best–worst method. *In AIP Conference Proceedings* (Vol. 2516, No. 1). (2022, November). *AIP Publishing*
57. Sudha, S., Martin, N., & Broumi, S. Plithogenic CRITIC-MAIRCA Ranking of Feasible Livestock Feeding Stuffs. *International Journal of Neutrosophic Science* (IJNS), 18(4). (2022).
58. Ulutaş, A., & Topal, AEvaluation of the criteria used in the selection of renewable energy sources with the plithogenic PIPRECIA method. In Optimization and Decision-Making in the Renewable Energy Industry (pp. 109-125). (2022). *IGI Global*.
59. Seby, A., & Ravi, V. A plithogenic model for determining the best hotel chain in the Indian context. *International Journal of Hospitality and Event Management,* 2(3-4), (2022). 202-222.
60. Priya, R., Martin, N., & Kishore, T. E. Plithogenic cognitive analysis on instigating spiritual intelligence in smart age youth for humanity redemption. *In AIP Conference Proceedings* (Vol. 2393, No. 1). (2022, May). *AIP Publishing.*
61. Zuñiga, E. J. D., Jáuregui, G. M., Estrada, D. M. D., Masaya, N., & Tenazoa, P. STUDY OF MINERALOGY IN THE CLAY FRACTION IN REPRESENTATIVE SOILS OF PUCALLPA, PERU, BASED ON PLITHOGENIC NUMBERS.
62. Tayal, D. K., Yadav, S. K., & Arora, D. Personalized ranking of products using aspect-based sentiment analysis and Plithogenic sets. *Multimedia Tools and Applications*, 82(1), 1261-1287 (2023).
63. Wang, P., Lin, Y., Fu, M., & Wang, Z. VIKOR Method for Plithogenic Probabilistic Linguistic MAGDM and Application to Sustainable Supply Chain Financial Risk Evaluation. *International Journal of Fuzzy Systems*, 25(2), (2023). 780-793.
64. Sudha, S., & Martin, N. Comparative analysis of Plithogenic neutrosophic PIPRECIA over neutrosophic AHP in criteria ordering of logistics selection. *In AIP Conference Proceedings* (Vol. 2649, No. 1). (2023, June). *AIP Publishing.*

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Neutrosophic Bicubic B-spline Surface Interpolation Model for Uncertainty Data

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Abstract: Dealing with the uncertainty data problem using neutrosophic data is difficult since certain data are wasted due to noise. To address this issue, this work proposes a neutrosophic set (NS) strategy for interpolating the B-spline surface. The purpose of this study is to visualize the neutrosophic bicubic B-spline surface (NBB-sS) interpolation model. Thus, the principal results of this study introduce the NBB-sS interpolation method for neutrosophic data based on the NS notion. The neutrosophic control net relation (NCNR) is specified first using the NS notion. The B-spline basis function is then coupled to the NCNR to produce the NBB-sS. This surface is then displayed using an interpolation method that comprises surfaces representing truth, indeterminacy, and false membership. There is a numerical example for constructing the NBB-sS using interpolation and will use quantitative data in the form of discrete numerical cases, particularly in neutrosophic numbers. The major conclusion of this study is a mathematical representation of NBB-sS by using the interpolation method was introduced and visualized for a neutrosophic data problem. The scientific value contributed to this study is an acceptance of uncertainty. Therefore, since it incorporates geometric modeling, this work can make a significant contribution to the neutrosophic decision model.

Keywords: Neutrosophic Set Theory; Neutrosophic Control Net Relation; B-spline Surface; Interpolation Method; Uncertainty Data.

1. Introduction

The foundational concept of fuzzy set theory was introduced by Zadeh [1] in order to tackle the complexities associated with uncertainty in complex systems. Several years later, Atanassov [2] introduced the concept of the intuitionistic fuzzy set (IFS), which is an extension of fuzzy set theory that incorporates membership grade, non-membership, and uncertainty. Addressing a complex problem that possesses intuitive and fuzzy characteristics is a challenging task, and it is seldom explored within the realm of spline modeling. Multiple studies have been conducted in the field of datasets and splines, as seen by the references [3-11]. The neutrosophic technique was created by Florentin Smarandache [12] as a mathematical framework for handling ambiguous data by using the concept of neutrality. The concept of neutrosophic set (NS) is characterized by membership degrees, non-membership, and indeterminacy. In the present context, the term "neutrosophic set" pertains to the process of resolving and representing complex problems that encompass numerous domains. Neutrosophic set theory allows for the simultaneous assignment of true, false, and indeterminate membership degrees to an element. This facilitates the representation of complex forms of uncertainty and indeterminacy, such as scenarios when a proposition can possess both truth and falsehood simultaneously. Academics have also utilized geometric modeling to implement neutrosophic set approaches [13, 14,19].

The objective of this research is to provide a geometric framework that can effectively handle uncertain data, specifically emphasizing the neutrosophic bicubic B-spline surface (NBB-sS) interpolation model. Before constructing the NBB-sS, it is necessary to define the neutrosophic control point relation (NCPR) using the properties of the NS. The control points are employed in conjunction with the B-spline basis function to construct the NBB-sS model, which is subsequently visualized by interpolation. The structure of this document is outlined as follows. The introductory component of this investigation presented relevant contextual information. Section 2 provides an overview of the neutrosophic fundamental notion, NCPR and neutrosophic control net relation (NCNR). Section 3 illustrates the application of the NCPR method for the purpose of interpolating the NBB-sS. Section 4 includes both a mathematical illustration and a graphic depicting NBB-sS. The investigation includes a review of the characteristics of the surface, together with the methodology employed for its construction. The inquiry will be concluded in Part 5.

2. Preliminaries

This part describes the NS, including the core concept of NS and the NCPR. The IFS can handle limited data but not paraconsistent data [12]. "There are three memberships: a truth membership function, T, an indeterminacy membership function, I, and a falsity membership function, F, with the parameter 'indeterminacy' added by the NS specification" [12].

Definition 1: [12] Let Y be the main of conversation, with element in Y denoted as y . The Neutrosophic set is an object in the form.

$$\hat{B} = \{\left\langle y : T_{\hat{B}(y)}, I_{\hat{B}(y)}, F_{\hat{B}(y)} \right\rangle \mid y \in Y\} \tag{1}$$

where, the functions $T, I, F : Y \to]^{-}0,1^{+}[$ define, respectively, the degree of truth membership, the degree of indeterminacy, and the degree of false membership of the element $y \in Y$ to the set $\hat{B}$ with the condition;

$$0^{-} \leq T_{\hat{B}}(y) + I_{\hat{B}}(y) + F_{\hat{B}}(y) \leq 3^{+} \tag{2}$$

There is no limit to the amount of $T_{\hat{B}}(y), I_{\hat{B}}(y)$ and $F_{\hat{B}}(y)$

A value is chosen by NS from one of the real standard subsets or one of the non-standard subsets of $]^{-}0,1^{+}[$. The actual value of the interval $[0,1]$, on the other hand, $]^{-}0,1^{+}[$ will be utilized in technical applications since its utilization in real data such as the resolution of scientific challenges, will be physically impossible. As a direct consequence of this, membership value utilization is increased.

$$\hat{B} = \{\left\langle y : T_{\hat{B}(y)}, I_{\hat{B}(y)}, F_{\hat{B}(y)} \right\rangle \mid y \in Y\} \text{ and } T_{\hat{B}}(y), I_{\hat{B}}(y), F_{\hat{B}}(y) \in [0,1] \tag{3}$$

There is no restriction on the sum of $T_{\hat{B}}(y), I_{\hat{B}}(y), F_{\hat{B}}(y)$ .Therefore,

$$0 \leq T_{\hat{B}}(y) + I_{\hat{B}}(y) + F_{\hat{B}}(y) \leq 3 \tag{4}$$

Definition 2: [13, 14] Let $\hat{B} = \{\left\langle y : T_{\hat{B}(y)}, I_{\hat{B}(y)}, F_{\hat{B}(y)} \right\rangle \mid y \in Y\}$ and $\hat{C} = \{\left\langle z : T_{\hat{C}(z)}, I_{\hat{C}(z)}, F_{\hat{C}(z)} \right\rangle \mid z \in Z\}$ be neutrosophic elements. Thus, $NR = \{\left\langle (y,z) : T_{(y,z)}, I_{(y,z)}, F_{(y,z)} \right\rangle \mid y \in \hat{B}, z \in \hat{C}\}$ is a neutrosophic relation on $\hat{B}$ and $\hat{C}$.

Definition 3: [13,14] Neutrosophic set of $\hat{B}$ in space Y is Neutrosophic Point (NP) and $\hat{B}=\{\hat{B}_i\}$ where $i=0,...,n$ is a set of NPs where there exists $T_{\hat{B}}:Y\rightarrow[0,1]$ as truth membership, $I_{\hat{B}}:Y\rightarrow[0,1]$ as indeterminacy membership and $F_{\hat{B}}:\hat{Y}\rightarrow[0,1]$ as false membership with

$$T_{\hat{B}}(\hat{B})=\begin{cases}0 & if\ \hat{B}_i\notin\hat{B}\\ a\in(0,1) & if\ \hat{B}_i\hat{\in}\hat{B}\\ 1 & if\ \hat{B}_i\in\hat{B}\end{cases}$$

$$I_{\hat{B}}(\hat{B})=\begin{cases}0 & if\ \hat{B}_i\notin\hat{B}\\ b\in(0,1) & if\ \hat{B}_i\hat{\in}\hat{B}\\ 1 & if\ \hat{B}_i\in\hat{B}\end{cases} \quad (5)$$

$$F_{\hat{B}}(\hat{B})=\begin{cases}0 & if\ \hat{B}_i\notin\hat{B}\\ c\in(0,1) & if\ \hat{B}_i\hat{\in}\hat{B}\\ 1 & if\ \hat{B}_i\in\hat{B}\end{cases}$$

2.1 *Neutrosophic Point Relation*

Neutrosophic point relation (NPR) depends on the NS notion, which was addressed in the previous section. If P,Q is a group of Euclidean universal space points and $P,Q\in\mathbf{R}^2$ then NPR is defined as follows:

Definition 4 [19]
Let X,Y be collection of universal space points with non-empty set and $P,Q,I\in\mathbf{R}\times\mathbf{R}\times\mathbf{R}$, then NPR is defined as

$$\hat{R}=\left\{\left\langle\left(p_i,q_j\right),T_R(p_i,q_j),I_R(p_i,q_j),F_R(p_i,q_j)\right\rangle \mid T_R(p_i,q_j),I_R(p_i,q_j),F_R(p_i,q_j)\in I\right\} \quad (6)$$

where $\left(p_i,q_j\right)$ is an ordered pair of coordinates and $\left(p_i,q_j\right)\in P\times Q$ while $T_R(p_i,q_j),I_R(p_i,q_j),F_R(p_i,q_j)$ are the truth membership, indeterminacy membership and false membership that follows the condition of neutrosophic set which is $0\le T_{\hat{B}}(\hat{y})+I_{\hat{B}}(\hat{y})+F_{\hat{B}}(\hat{y})\le 3$.

2.2 *Neutrosophic Control Net Relation*

A spline surface's geometry can only be specified by all of the points required to construct the surface and this is what the term "control net" refers to [18]. The control net is critical in the development, control, and manufacturing of smooth surfaces [18]. In this part, the NCPR is defined by first using the control point concept from the research reported in [15-17] in the following way:

Definition 5: [19] Let $\hat{R}$ be a NPR, then NCPR is defined as set of point $n+1$ that indicates the positions and coordinates of a location and is used to describe the curve and is denoted by

$$\begin{aligned}\hat{P}_i^T&=\left\{\hat{p}_0^T,\hat{p}_1^T,...,\hat{p}_n^T\right\}\\ \hat{P}_i^I&=\left\{\hat{p}_0^I,\hat{p}_1^I,...,\hat{p}_n^I\right\}\\ \hat{P}_i^F&=\left\{\hat{p}_0^F,\hat{p}_1^F,...,\hat{p}_n^F\right\}\end{aligned} \quad (7)$$

where $\hat{P}_i^T$, $\hat{P}_i^I$ and $\hat{P}_i^F$ are neutrosophic control point for membership truth, indeterminacy and i is one less than n.

This study primarily focuses on surface modelling. Consequently, it is essential to present the concept of neutrosophic control net relation. In the context of surface modelling, the net control relation is formed by combining the relations of each control point [18]. In contrast to the curve model that simply requires control points [18]. Thus, the NCNR can be defined as follows.

Definition 6: Let $\hat{P}$ be an NCPR, and then define an NCNR as points $n+1$ and $m+1$ for $\hat{P}$ in their direction, and it can be denoted by $\hat{P}_{i,j}$ that represents the locations of points used to describe the surface and may be written as

$$\hat{P}_{i,j} = \begin{bmatrix} \hat{P}_{0,0} & \hat{P}_{0,1} & \cdots & \hat{P}_{0,j} \\ \hat{P}_{1,0} & \hat{P}_{1,1} & \cdots & \hat{P}_{1,j} \\ \vdots & \vdots & \ddots & \vdots \\ \hat{P}_{i,0} & \hat{P}_{i,1} & \cdots & \hat{P}_{i,j} \end{bmatrix} \quad (8)$$

where $\hat{P}_{i,j}$ are also the points that make up a polygon's control net.

3. Neutrosophic Bicubic B-spline Surface Interpolation

Piegl and Tiller [18] introduced the B-spline basis function will be mixed with NCNR as stated in the previous section. The NCNR and Definition 1 of the neutrosophic set are used to build the NBB-sS, which is then used to incorporate the B-spline blending function in a geometric model. The interpolation approach model is mathematically stated as follows:

Definition 7: Let $\hat{P}_i^T = \{\hat{p}_0^T, \hat{p}_1^T, ..., \hat{p}_n^T\}, \hat{P}_i^I = \{\hat{p}_0^I, \hat{p}_1^I, ..., \hat{p}_n^I\}, \hat{P}_i^F = \{\hat{p}_0^F, \hat{p}_1^F, ..., \hat{p}_n^F\}$ where $i = 0,1,...,n$ is NCPR. The Cartesian product B-spline surface determined by is the obvious expansion of the Bezier surface. $BsS(u,w)$ denoted as neutrosophic B-spline surface approximation as follows:

$$BsS(u,w) = \sum_{i=0}^{n}\sum_{j=0}^{m} \hat{P}_{i,j} N_i^k(u) M_j^l(w) \quad (9)$$

where $N_i^k(u)$ and $M_j^l(w)$ are the B-spline basis function in the u and w parametric directions.

$$\begin{aligned} N_i^1(u) &= \begin{cases} 1 & if \quad \mathrm{u}_i \le u < u_{i+1} \\ 0 & otherwise \end{cases} \\ N_i^1(u) &= \frac{(u-u_i)}{u_{i+k-1}-u_i} N_i^{k-1}(u) + (7)\frac{(u_{i+k}-u)}{u_{i+k}-u_{i+1}} N_{i+1}^{k-1}(u) \end{aligned} \quad (10)$$

$$\begin{aligned} M_j^1(w) &= \begin{cases} 1 & if \quad \mathrm{w}_j \le w < w_{j+1} \\ 0 & otherwise \end{cases} \\ M_j^1(w) &= \frac{(w-w_j)}{w_{j+l-1}-u_i} M_i^{l-1}(w) + (8)\frac{(w_{j+l}-w)}{w_{j+l}-w_{j+1}} M_{j+1}^{l-1}(w) \end{aligned} \quad (11)$$

The parametric function neutrosophic B-spline surface in Eq. (9) is defined as follows and is made up of three surfaces: a member surface, a non-member surface, and an indeterminacy surface.

$$BsS^T(u,w) = \sum_{i=0}^{n}\sum_{j=0}^{m} \hat{P}_{i,j}{}^T N_i^k(u) M_j^l(w) \quad (12)$$

$$BsS^{F}(u,w)=\sum_{i=0}^{n}\sum_{j=0}^{m}\hat{P}_{i,j}{}^{F}N_i^k(u)M_j^l(w) \tag{13}$$

$$BsS^{I}(u,w)=\sum_{i=0}^{n}\sum_{j=0}^{m}\hat{P}_{i,j}{}^{I}N_i^k(u)M_j^l(w) \tag{14}$$

The surface for the neutrosophic B-spline will be lie in the NCPR since NBB-sS using interpolation method. Suppose $\hat{F}_{i,j}$ as data point matrix. Thus, the interpolation procedure is as follows:

$$\begin{bmatrix} \hat{F}_{0,0} & \hat{F}_{0,1} & \cdots & \hat{F}_{0,j} \\ \hat{F}_{1,0} & \hat{F}_{1,1} & \cdots & \hat{F}_{1,j} \\ \vdots & \vdots & \ddots & \vdots \\ \hat{F}_{i,0} & \hat{F}_{i,1} & \cdots & \hat{F}_{i,j} \end{bmatrix} = \begin{bmatrix} BsS(u_0,w_0) & BsS(u_0,w_1) & \cdots & BsS(u_0,w_j) \\ BsS(u_1,w_0) & BsS(u_1,w_1) & \cdots & BsS(u_1,w_j) \\ \vdots & \vdots & \ddots & \vdots \\ BsS(u_i,w_0) & BsS(u_i,w_1) & \cdots & BsS(u_i,w_j) \end{bmatrix} \tag{15}$$

Each $BsS(u,w)$ can be expressed as a matrix product as follows:

$$BsS(u_i,w_j)=\begin{bmatrix} N_0^k(u_i) & N_1^k(u_i) & \cdots & N_i^k(u_i) \end{bmatrix} \times \begin{bmatrix} \hat{P}_{0,0} & \hat{P}_{0,1} & \cdots & \hat{P}_{0,j} \\ \hat{P}_{1,0} & \hat{P}_{1,1} & \cdots & \hat{P}_{1,j} \\ \vdots & \vdots & \ddots & \vdots \\ \hat{P}_{i,0} & \hat{P}_{i,1} & \cdots & \hat{P}_{i,j} \end{bmatrix} \times \begin{bmatrix} M_0^l(w_j) \\ M_1^l(w_j) \\ \vdots \\ M_i^l(w_j) \end{bmatrix} \tag{16}$$

All the separate equations can be combined into a single matrix equation:

$$\hat{F}=N^T\hat{P}M \tag{17}$$

where $\hat{F}$ denotes the data points from Eq. (15), and $\hat{P}$ denotes the matrix containing the unknown control points $\hat{P}_{i,j}$. The values of the B-spline polynomials at the given parameters are contained in the matrix M^T and N:

$$N^T=\begin{bmatrix} N_0^k(u_0) & N_1^k(u_0) & \cdots & N_i^k(u_0) \\ N_0^k(u_1) & N_1^k(u_1) & \cdots & N_i^k(u_1) \\ \vdots & \vdots & \ddots & \vdots \\ N_0^k(u_i) & N_1^k(u_i) & \cdots & N_i^k(u_i) \end{bmatrix} \tag{18}$$

$$M=\begin{bmatrix} M_0^l(w_0) & M_0^l(w_0) & \cdots & M_0^l(w_j) \\ M_1^l(w_1) & M_1^l(w_1) & \cdots & M_1^l(w_j) \\ \vdots & \vdots & \ddots & \vdots \\ M_j^l(w_j) & C_j^l(w_j) & \cdots & C_j^l(w_j) \end{bmatrix} \tag{19}$$

To find the control point $\hat{P}_{i,j}$, Eq. (17) can be easily simplified as follows since this study is an interpolation method. Therefore, the matrices should be inverse to find the interpolate data.

$$\hat{P}=\left(N^T\right)^{-1}\hat{F}\left(M\right)^{-1} \tag{17}$$

To demonstrate the neutrosophic bicubic B-spline surface, consider the following $\hat{P}_{i,j}$ to find NBB-sS with degrees of truth membership, false membership, and indeterminacy with $i=3, j=3$ for bicubic case.

$$\begin{bmatrix} \hat{P}_{0,0} & \hat{P}_{0,1} & \hat{P}_{0,2} & \hat{P}_{0,3} \\ \hat{P}_{1,0} & \hat{P}_{1,1} & \hat{P}_{1,2} & \hat{P}_{1,3} \\ \hat{P}_{2,0} & \hat{P}_{2,1} & \hat{P}_{2,2} & \hat{P}_{2,3} \\ \hat{P}_{3,0} & \hat{P}_{3,1} & \hat{P}_{3,2} & \hat{P}_{3,3} \end{bmatrix} \tag{18}$$

4. Applications of Neutrosophic Bicubic B-spline Surface Interpolation

To illustrate the neutrosophic B-spline surface interpolation, let considered a neutrosophic B-spline surface for 4×4 NCNR with the degree of truth membership, indeterminacy membership and false membership as follow in Table 1. The example given below shows that each NCPR follow the condition $0^- \leq T_{\hat{B}}(y)+I_{\hat{B}}(y)+F_{\hat{B}}(y)\leq 3^+$. Therefore, it is satisfying the neutrosophic set problem.

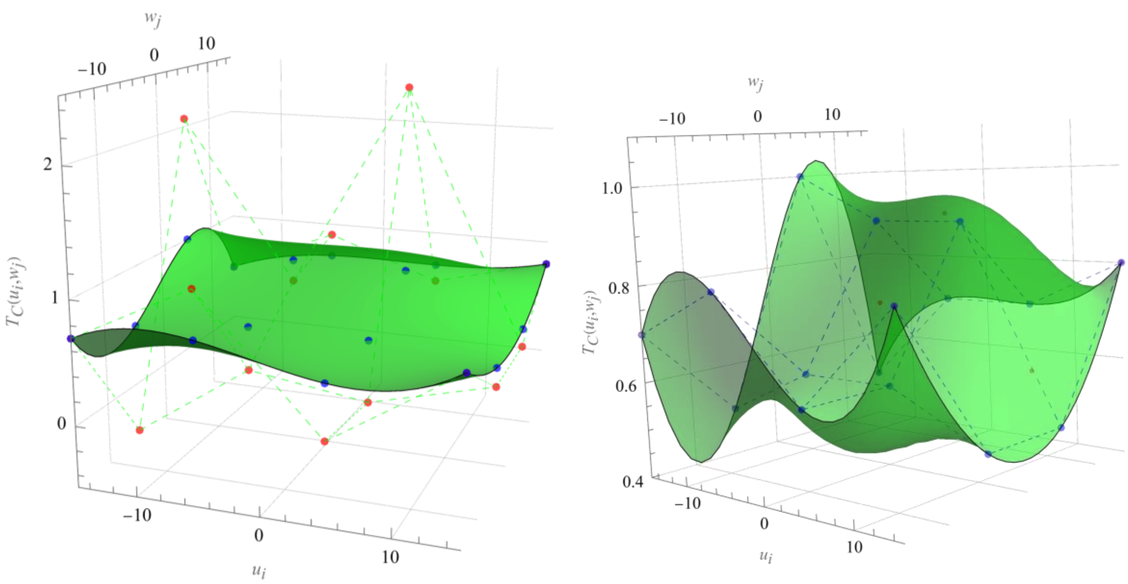
Table 1. NCPR with its respective degrees.

NCPR $\hat{P}_{i,j}$	Truth Membership $\hat{P}^T_{i,j}$	False Membership $\hat{P}^F_{i,j}$	Indeterminacy Membership $\hat{P}^I_{i,j}$
$\hat{P}_{0,0}=(-15,15)$	0.5	0.8	0.3
$\hat{P}_{0,1}=(-15,5)$	1.0	0.4	0.2
$\hat{P}_{0,2}=(-15,-5)$	0.5	0.5	0.6
$\hat{P}_{0,3}=(-15,-15)$	0.7	0.6	0.3
$\hat{P}_{1,0}=(-5,15)$	0.7	0.5	0.4
$\hat{P}_{1,1}=(-5,5)$	0.9	0.3	0.4
$\hat{P}_{1,2}=(-5,-5)$	0.6	0.6	0.4
$\hat{P}_{1,3}=(-5,-15)$	0.8	0.5	0.3
$\hat{P}_{2,0}=(5,15)$	0.7	0.3	0.6
$\hat{P}_{2,1}=(5,5)$	0.9	0.5	0.2
$\hat{P}_{2,2}=(5,-5)$	0.6	0.8	0.2
$\hat{P}_{2,3}=(5,-15)$	0.6	0.4	0.6
$\hat{P}_{3,0}=(15,15)$	0.8	0.4	0.5
$\hat{P}_{3,1}=(15,5)$	0.5	0.7	0.4
$\hat{P}_{3,2}=(15,-5)$	0.5	0.7	0.4
$\hat{P}_{3,3}=(15,-15)$	0.8	0.5	0.3

Table 1 is also can represented in matrix form. $\langle t, f, i\rangle$ denoted as truth, false and indeterminacy membership.

$$\hat{P}_{3,3}=\begin{bmatrix}\langle(-15,15);0.5,0.8,0.3\rangle & \langle(-15,5);1.0,0.4,0.2\rangle & \langle(-15,-5);0.5,0.5,0.6\rangle & \langle(-15,-15);0.7,0.6,0.3\rangle\\ \langle(-5,15);0.7,0.5,0.4\rangle & \langle(-5,5);0.9,0.3,0.4\rangle & \langle(-5,-5);0.6,0.6,0.4\rangle & \langle(-5,-15);0.8,0.5,0.3\rangle\\ \langle(5,15);0.7,0.3,0.6\rangle & \langle(5,5);0.9,0.5,0.2\rangle & \langle(5,-5);0.6,0.8,0.2\rangle & \langle(5,-15);0.6,0.4,0.6\rangle\\ \langle(15,15);0.8,0.4,0.4\rangle & \langle(15,5);0.5,0.7,0.4\rangle & \langle(15,-5);0.5,0.7,0.4\rangle & \langle(15,-15);0.8,0.5,0.3\rangle\end{bmatrix}$$

Thus, by using Definition 7, the respective surface is visualized in Figure 1 until Figure 3 for truth, false and indeterminacy degrees. Since this study focuses on interpolation, each surface will interpolate its respective NCNR. The NCNR has been shown in Figure 1(b), 2(b) and 3(b), the dashed line represents as control net while the dot point denoted as control points. For Figure 1(a), 2(a) and 3(a), the dashed line represents as control net for data point, while the data point denoted as red dot that obtained by utilizing Equation (17). The surface capacity for Figures (a) and (b) has been reduced from 0.7 to 0.5 in order to observe the NCNR phenomenon across the spline in Figure (b). Additionally, the graphics in Figure (b) also appear larger due to adjustments in the range of the graphic.



(**a**) (**b**)

Figure 1. NBB-sS interpolation for truth membership: **(a)** NBB-sS and its control net for data points with 0.7 capacity of surface; **(b)** NBB-sS and its control net for control points with 0.5 capacity of surface.

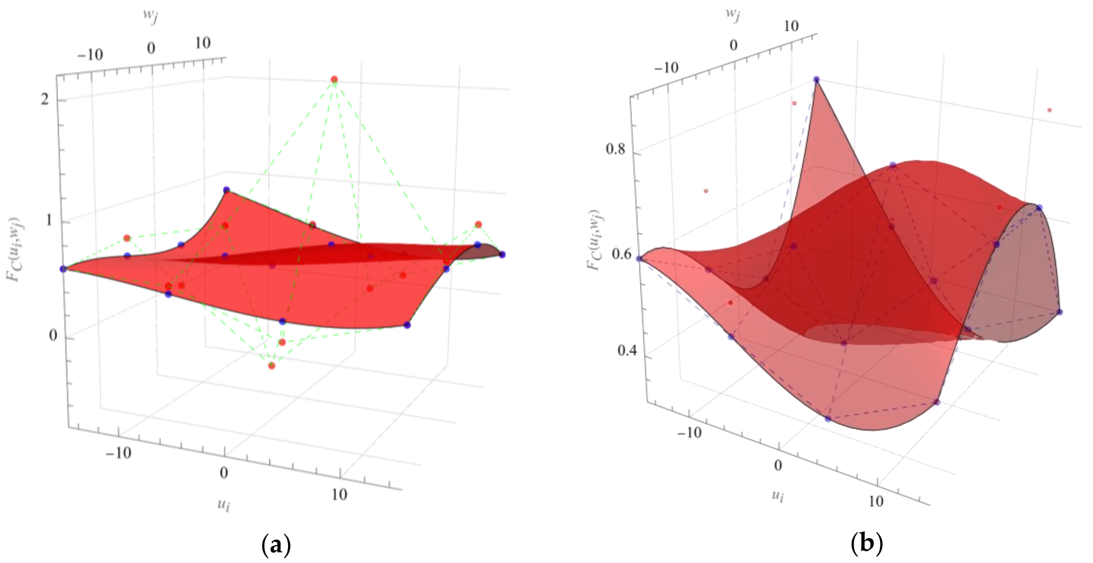


Figure 2. NBB-sS interpolation for false membership: **(a)** NBB-sS and its control net for data points with 0.7 capacity of surface; **(b)** NBB-sS and its control net for control points with 0.5 capacity of surface.

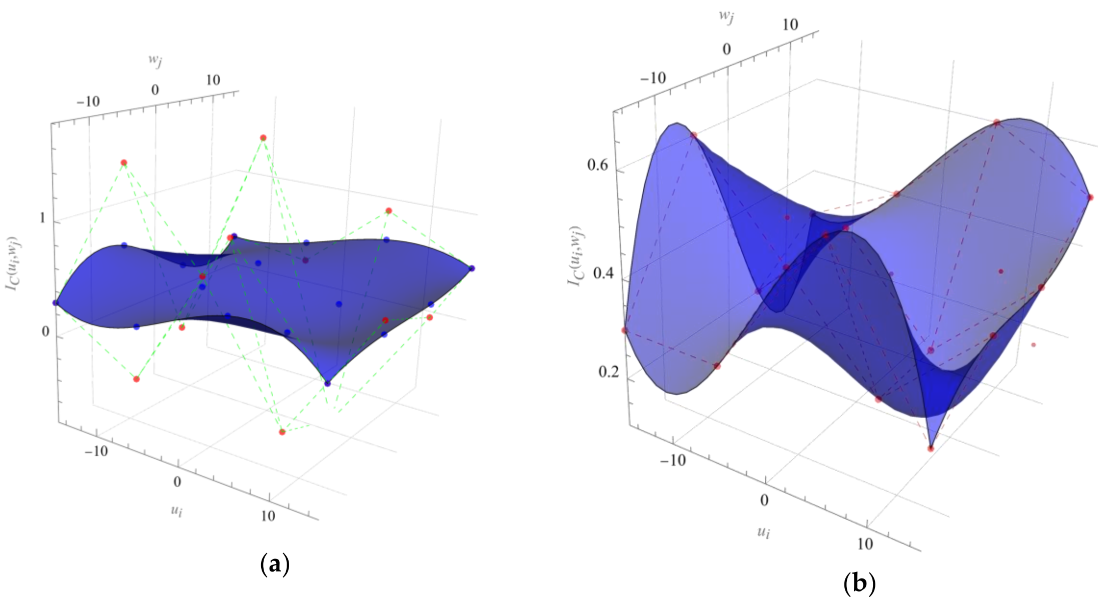


Figure 3. NBB-sS interpolation for indeterminacy membership: **(a)** NBB-sS and its control net for data points with 0.7 capacity of surface; **(b)** NBB-sS and its control net for control points with 0.5 capacity of surface. Since the surface is blue in this case, the control point and control net change to red, which is different from the other surface.

As a results, the novelty of this study as follows:

- The definition of NCNR for NBB-sS based on previous work for NCPR, NPR, NCP, NR, NP, and fundamental notion of NS.
- The mathematical representation of NBB-sS was found after some simplification from Eq. (9) to Eq. (18).

- The visualization of NBB-sS for truth, false and indeterminacy membership degrees.

5. Conclusions

This paper introduced the NCNR-based for creating NBB-sS model. The Bezier and non-uniform rational B-splines (NURBS) functions for surfaces and curves can be used to improve the findings in future study. Aside from that, by utilizing type-2 NS theory as a case of study. Surface data visualization can be utilized in a variety of applications, including geographic information system (GIS) modeling of spatial regions with uncertain borders, remote sensing, object reconstruction from an aerial laser scanner, bathymetric data visualization, and many more. The NBB-sS model can be used to address and solve difficulties characterized by uncertainty. Therefore, the applicability of this study is this study can treat and visualizing the uncertainty data as indeterminacy degree by using geometric modelling for B-spline surface and NS features while the scientific valued is there will be no data wasted during data collection process since all data will be examined and processes. As a result, the NCNR and NBB-sS models may provide a comprehensive analysis and description of a modeling issue that includes for any bicubic surface.

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Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that there is no conflict of interest in the research.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

References

1. Zadeh, L. A. Fuzzy Set, Information and Control, 1965. Volume 8, pp. 338-353.
2. Atanassov, K. T. Intuitionistic Fuzzy Sets, VII ITKR's Session, Sofia, Bulgarian, 1983.
3. Anile, A. M., Falcidieno, B., Gallo, G., Spagnuolo M., Spinello S., Fuzzy Sets and Systems, 2000. Volume 113(3), pp. 397-410.
4. Kaleva, O. Fuzzy Sets and Systems, 1994. Volume 61(1), pp. 63-70.
5. Wahab, A. F., Zakaria, R. and Ali, J. M. Fuzzy Interpolation Rational Bezier Curve in Imaging and Visualization, 7th International Conference on Computer Graphics, Sydney, NSW, 2010, pp. 63-67.
6. Wahab A. F. and Zakaria, R. Fuzzy interpolation rational cubic Bezier curves modelling of blurring offline handwriting signature with different degrees of blurring, Applied Mathematical Sciences, 2012. Volume 6(81), pp. 4005-4016.
7. Zakaria R. and Wahab, A.F. Bezier curve modelling for intuitionistic fuzzy data problem, Applied Mathematical Sciences, 2013. Volume 7 (45), pp. 2229-2238.
8. Abbas, S., Hussain M. Z. and Irshad, M. Image Interpolation by Rational Ball Cubic B-spline Representation and Genetic Algorithm, Alexandria Engineering Journal, 2017.
9. Bica A. M. and Popescu, C. Note on Fuzzy Monotonic Interpolating Splines of Odd Degree, Fuzzy Sets and Systems, 2017. Volume 310, pp. 60-73.
10. Cheng, K.-H. Adaptive B-spline-based Fuzzy Sliding-mode Control for an Auto-warehousing Crane System, Applied Soft Computing, 2016. Volume 48, pp. 476-490.

11. Gaeta, M., Loia V. and Tomasiello, S. Cubic B – Spline Fuzzy Transforms for an Efficient and Secure Compression in Wireless Sensor Networks, Information Sciences, 2016. Volume 339, pp. 19-30.
12. Smarandache, F. A Unifying Field in Logics: Neutrosophic Logic. Neutrosophy, Neutrosophic Set, Neutrosophic Probability: Neutrosophic Logic. Neutrosophy, Neutrosophic Set, Neutrosophic Probability. Infinite Study, 2005.
13. Tas, F. and Topal, S. Bezier Curve Modelling for Neutrosophic Data Problem. Neutrosophic set and system. University of New Mexico, 2017.
14. Topal, S. and Tas, F. Bézier Surface Modelling for Neutrosophic Data Problems. Neutrosophic set and system. University of New Mexico, 2018. Volume 19, pp. 19-23.
15. Wahab, A. F., Ali, J. M., Majid, A. A. and Tap, A. O. M. Fuzzy Set in Geometric Modeling, Proceedings International Conference on Computer Graphics, Imaging and Visualization, CGIV, Penang, 2004, pp. 227–232.
16. Wahab, A. F., Ali, J. M., Majid, A. A. and Tap, A. O. M. Penyelesaian Masalah Data Ketakpastian Menggunakan Splin-B Kabur, Sains Malaysiana, 2010, Volume 39(4), pp. 661-670.
17. Wahab, A. F., Ali, J. M. and Majid, A. A. Fuzzy geometric modeling, Sixth International Conference on Computer Graphics, Imaging and Visualization, (2009), pp 276-280.
18. Piegl, L. and Tiller, W. The NURBS Book (Springer-Verlag Berlin Heidelberg, Germany), 1995.
19. Binti Rosli, S. N. I., & Bin Zulkifly, M. I. E. A Neutrosophic Approach for B-Spline Curve by Using Interpolation Method. Neutrosophic Systems with Applications, **2023**. 9, 29–40. https://doi.org/10.61356/j.nswa.2023.43.

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Heart Disease Prediction under Machine Learning and Association Rules under Neutrosophic Environment

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Abstract: Early identification and precise prediction of heart disease have important implications for preventative measures and better patient outcomes since cardiovascular disease is a leading cause of death globally. By analyzing massive amounts of data and seeing patterns that might aid in risk stratification and individualized treatment planning, machine learning algorithms have emerged as valuable tools for heart disease prediction. Predictive modeling is considered for many forms of heart illness, such as coronary artery disease, myocardial infarction, heart failure, arrhythmias, and valvar heart disease. Resource allocation, preventative care planning, workflow optimization, patient involvement, quality improvement, risk-based contracting, and research progress are all discussed as management implications of heart disease prediction. The effective application of machine learning-based cardiac disease prediction models requires collaboration between healthcare organizations, providers, and data scientists. This paper used three tools such as the neutrosophic analytical hierarchy process (AHP) as a feature selection, association rules, and machine learning models to predict heart disease. The neutrosophic AHP method is used to compute the weights of features and select the highest features. The association rules are used to give rules between values in all datasets. Then, we used the neutrosophic AHP as feature selection to select the best feature to input in machine learning models. We used nine machine learning models to predict heart disease. We obtained the random forest (RF) and decision tree (DT) have the highest accuracy with 100%, followed by Bagging, k-nearest neighbors (KNN), and gradient boosting have 99%, 98%, and 97%, then AdaBoosting has 89%, then logistic regression and Naïve Bayes have 84%, then the least accuracy is support vector machine (SVM) has 68%.

Keywords: Machine Learning; Heart Disease Prediction; Association Rules; Neutrosophic AHP; Feature Selection; Accuracy.

1. Introduction

The worldwide burden of morbidity and death due to cardiovascular disease continues to be high. Preventative measures, optimal therapeutic approaches, and a decrease in adverse cardiovascular events may all benefit greatly from the early identification and precise prediction of persons at risk for heart disease. The early identification of people at risk for cardiovascular disease has been the subject of a great deal of study over the years, leading to the development of prediction models and risk assessment approaches. This study examines the state of the art in predicting cardiovascular illness and discusses the obstacles, opportunities, and future paths that lie ahead [1, 2].

Heart disease, which includes coronary artery disease, myocardial infarction, and heart failure, is a complicated multifactorial ailment impacted by a wide range of hereditary, environmental, and behavioral variables. Understanding these characteristics and how they interact is crucial for accurately predicting an individual's risk of developing heart disease [3, 4]. The risk of cardiovascular disease may be estimated using conventional risk assessment models like the Framingham Risk Score, which takes into account variables including age, gender, blood pressure, cholesterol levels, and smoking status. Despite their usefulness, these models often employ a small number of variables and may fail to capture important interplays between potential dangers.

Novel methodologies using machine learning, artificial intelligence, and big data analytics have emerged as powerful instruments for cardiac disease prediction thanks to the development of technology and the availability of large-scale healthcare data. These methods may one day be able to analyze massive volumes of data, unearth previously unknown patterns, and provide unique risk assessments for each individual user. Predictive models for cardiovascular illness have been progressively developed using machine learning methods such as logistic regression (LR), decision trees, random forests, support vector machines (SVMs), and neural networks. Clinical, genetic, lifestyle, and imaging data may all be included in these algorithms to provide solid models for precise risk assessment [3, 5].

There has been a lot of interest in incorporating genetic data into heart disease prediction algorithms. Individual vulnerability to heart disease is heavily influenced by genetic variables, and the addition of genetic markers may improve the accuracy and precision of prediction algorithms.

Wearable technology, such as activity trackers and smartwatches, may provide new information for predicting cardiovascular disease. For risk assessment and early diagnosis of cardiac disorders, these devices can constantly monitor physiological indicators including heart rate, activity levels, and sleep patterns [6, 7].

Electronic health records (EHRs) are increasingly being used as a reliable tool for predicting cardiovascular issues. EHRs are an invaluable resource for building accurate risk assessment models because they include so much information about patients. Although there have been improvements in heart disease prediction, there are still certain issues that require fixing. There are a number of obstacles that must be removed before predictive models can be widely used in clinical settings. These include data quality and standardization, interpretability of machine learning models, privacy concerns, and bias and fairness in predictive algorithms [8, 9].

Predicting cardiovascular illness raises important ethical questions. To keep patients confident in their healthcare professionals, it is critical that they respect their privacy, get their agreement before using predictive models, and share their results openly. In order to enhance patient outcomes and lessen the burden of cardiovascular illness, heart disease prognosis is a fast-developing subject with enormous promise. This study aims to improve cardiovascular care by fostering the creation of more precise, accessible, and individually tailored risk assessment tools by critically examining existing predictive models, addressing challenges, and exploring emerging technologies [10, 11].

This paper used three tools to predict heart disease, first step we used the neutrosophic analytical hierarchy process (AHP) as a feature section to select the best feature [12]. Then in the second step, we used the association rules to fined rules between variables in the data set. In the third step, we used machine learning models to predict the disease. Figure 1 shows the overall three steps to predict heart disease.

The rest of this paper is organized as follows: Section 2 introduces the challenges in heart disease prediction. Section 3 introduces the methodology of this paper and has three layers including neutrosophic AHP as a feature selection, association rules, and machine learning models. Section 4 presents the results and analysis of the dataset. Section 5 introduces the managerial implications of heart disease prediction. Finally, Section 6 presents the conclusion of this paper.

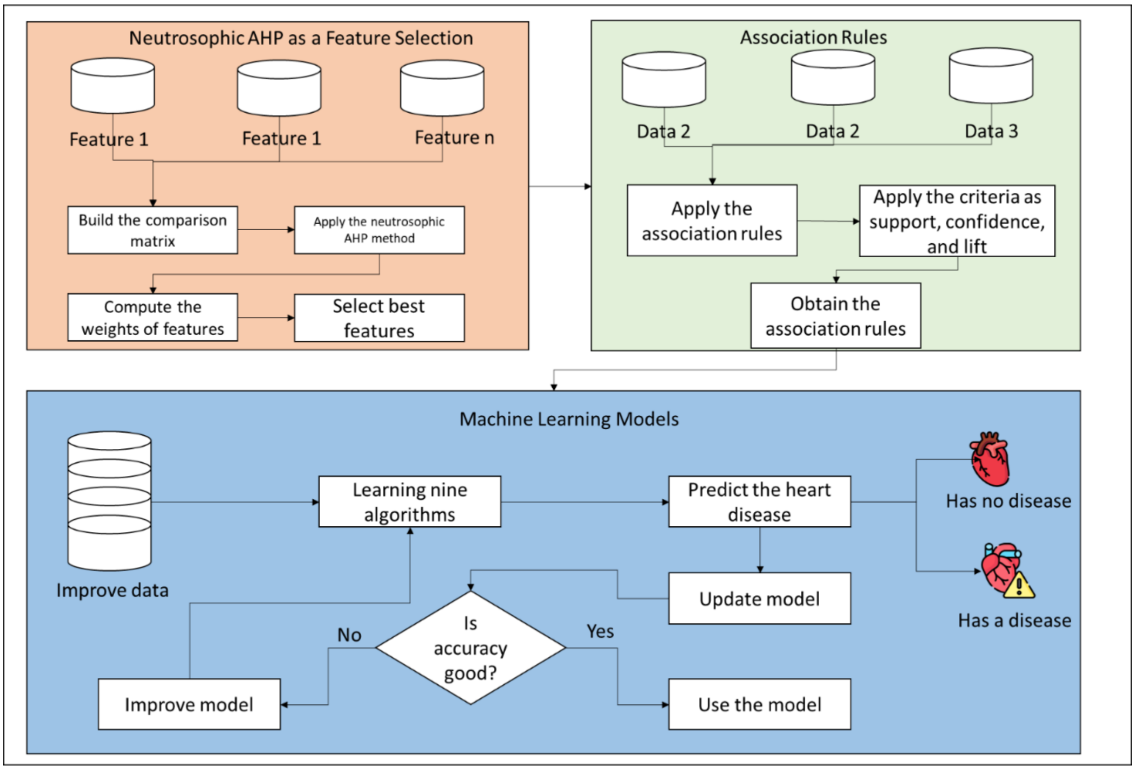

Figure 1. The overall steps of the proposed model to predict heart disease.

2. Heart Disease Prediction

Public health systems face substantial difficulties from cardiovascular disease, which remains a primary cause of morbidity and death globally. In order to adopt preventative measures, optimize treatment options, and reduce the burden of cardiovascular events, early identification and precise prediction of those at risk is critical. Predictive models and risk assessment approaches that help in the early detection of heart disease susceptibility have been the subject of intensive research and development in recent years. The purpose of this study is to present an in-depth analysis of the current status of cardiac disease prediction, including its successes, failures, and prospective future developments [13, 14].

Integration of demographics, medical history, lifestyle choices, and clinical biomarkers allows for more accurate prediction of cardiovascular disease. To calculate an individual's risk of cardiovascular disease, doctors have traditionally used risk assessment models like the Framingham Risk Score. The advent of technology and the availability of massive quantities of healthcare data, however, has led to the development of creative methodologies that use machine learning algorithms, artificial intelligence, and big data analytics to provide more precise and individual predictions.

Researchers and medical practitioners encounter a number of obstacles while attempting to foresee cases of heart disease. Among these difficulties are:

The accuracy and quality of the data used in heart disease prediction models are crucial. However, the accuracy, consistency, and completeness of data might vary widely depending on the source. To maintain the consistency and accuracy of prediction models, it is important to take data quality and standardization into account when integrating data from several sources, such as electronic health records, wearable devices, and genetic databases [15, 16].

While machine learning algorithms are useful for making predictions, they are not always easy to understand. Some models have a black box quality that makes it hard to decipher what is really driving forecasts. Gaining an understanding of the prediction process, fostering confidence among healthcare professionals, and aiding sound decision-making all depend on having access to interpretable models.

Prediction algorithms for cardiovascular disease depend on highly private medical information. It is critical that personal information about patients be kept private and that data be kept secure. Predicting cardiovascular illness is complicated by the need to protect individual privacy while yet providing researchers with access to necessary data [17, 18].

Fairness and Bias: Predictive methods may unwittingly amplify existing biases in the training data. Predicting cardiac disease may be difficult because of racial, ethnic, socioeconomic, and gender biases in healthcare. To guarantee fair and objective forecasts for everyone, it is essential to address and mitigate these biases.

External validation and generalizability Predictive models built for one population or healthcare system may not be applicable to another. To evaluate the efficacy and applicability of models, it is essential to conduct external validation in a variety of populations. The issue of designing models that work well for a wide range of users and contexts persists.

Dynamic variables that change over time have an impact on heart disease, as shown by longitudinal studies. Changes in risk variables, illness progression, and response to therapy are all important to account for in predictive models. Predicting the onset of cardiac disease is difficult since it requires taking into account both static and dynamic factors.

Including Genetic Data: Many people's predisposition to developing heart disease is determined by their genes. The precision and accuracy of prediction models may be improved by including genetic information in their construction. However, there are obstacles such as the difficulty in analyzing genetic data, the need for big genetic databases, and the ethical concerns with genetic testing and privacy [17, 19].

Fewer people from underrepresented groups have been included in heart disease research and data collection, for example, people of color. This underrepresentation may impair the development of specific risk assessment models for different groups and lead to discrepancies in forecast accuracy. Important steps towards a solution include filling up data gaps and ensuring research is inclusive [20, 21].

Improving the precision, fairness, and practicality of heart disease prediction algorithms depends on resolving these issues. We want to overcome these obstacles by creating highly accurate prognostic tools for the effective prevention and treatment of cardiovascular disease.

3. Methodology

This section has three layers. First, the neutrosophic AHP used as a feature selection is used to select the best feature in the dataset. Then, we used the association rules to find the rules between data. Finally, we applied nine machine learning models to predict heart disease.

3.1 Neutrosophic AHP as a Feature Selection

In order to choose which characteristics should be included in a model for predicting heart disease, neutrosophic AHP feature selection is used. The goal of neutrosophic feature selection is to deal with data uncertainty and imprecision by giving each feature a degree of membership [22]. This permits the characteristics most helpful to the model's prediction ability to be chosen, with their neutrosophic nature taken into account. By zeroing in on the most relevant characteristics, the accuracy and interpretability of heart disease prediction models may be increased by utilizing neutrosophic AHP feature selection approaches. We used the neutrosophic AHP method as a feature selection [23-25].

Each input layer is given due consideration using the AHP technique as a means of producing a well-informed choice. When employing the AHP, you may use both quantitative and qualitative data because of the hierarchical structure provided by comparing each criterion. The AHP technique allows for a rating scale from 1 to 9 for any given set of data.

When thinking about the first issue, the AHP method works well. This is due to the fact that AHP approaches may rank competing criteria in order of preference based on contextual factors. Indicators used in selecting choices may also be affected by the structure of the regional forwarding network [26]. The optimal size of a collection of cooperative candidates for a relay is the second open question. Cooperative candidate relay sets may include groups of nearby nodes with varying data redundancy rates, cooperative relay delays, and delivery ratios. One of the sets of a certain size is deemed the cooperative candidate relay set after being evaluated based on its characteristics, compatibility with the vehicular environment, and good trade-off among the necessary aspects.

Step 1. The hierarchical analysis between features in dataset is performed.
The hierarchal used to define the goal from the problem, and define the features.
Step 2. Build pairwise comparison matrix.
We used the triangular neutrosophic scale to evaluate the features [27].

$$A_{ij}^{t} = \begin{bmatrix} a_{11}^{t} & \cdots & a_{1n}^{t} \\ \vdots & \ddots & \vdots \\ a_{n1}^{t} & \cdots & a_{nn}^{t} \end{bmatrix} \quad (1)$$

Where a_{1n}^{t} refers to the triangular neutrosophic number, n refers to the number of criteria, t refers the decision makers.
Step 3. Obtain the crisp value.
We used the score function to obtain the crisp value [27].
Step 4. Combine the opinions of experts.
We used the average method to combine the different pairwise comparison matrix into one matrix.
Step 5. Compute the row average.

$$w_i = \frac{\sum_{j=1}^{n}\left(a_{ij}^{t}\right)}{n} \quad (2)$$

Step 6. Normalize the crisp values.

$$w_i^{m} = \frac{w_i}{\sum_{i=1}^{m} w_i} \quad (3)$$

Step 7. Compute the consistency ratio (CR).

$$CR = \frac{CI}{RI} \quad (4)$$

$$CI = \frac{\lambda\_max - n}{n-1} \quad (5)$$

Where λ_max refers to the weighted sum vector.

3.2 Association Rules

In order to model and uncover the interdependencies between database entries, association rules are used. Support, confidence, and lift are criteria to show the importance of associations [28-31].

3.2.1 Support

This metric provides insight into how often a certain collection of products appears in all trades. Let's pretend that Set1 is bread and Set2 is shampoo. There will be a lot more bread purchases than shampoo purchases. You correctly predicted that the support for set1 would be greater than that for set2. Let's say set1 is "bread and butter" and set2 is "bread and shampoo." Bread and butter are common cart items, but how often do you see bread and shampoo? Not really. In this situation, set1 is more likely to be preferred than set2 in terms of popularity. In mathematical terms, the amount of backing for an item set is the share of all transactions that include those objects.

$$\text{Support}\{\{x\} \rightarrow \{y\}\} = \frac{\text{Transactions containing both x and y}}{\text{total number of transactions}} \quad (6)$$

Using support value, we can determine which rules are worth investigating further. If there are 10,000 transactions, for instance, it may be useful to focus on the subset of item sets that appears at least 50 times, or has support = 0.005. Without further data, we cannot make any firm conclusions about the nature of the relationships among the items in a very poorly supported item set.

3.2.2 Confidence

This metric describes the probability that the consequent will be present on the cart, assuming that the antecedents are present. That is to say, of all the purchases that included the term "Captain Crunch," how many also included the word "Milk?" It's well known that the "Captain Crunch" vs. "Milk" guideline should be taken very seriously. Confidence, in technical terms, is the chance that the consequent will occur given the antecedent.

$$\text{Confidence } (\{x\} \rightarrow \{y\}) = \frac{\text{transactions containing both x and y}}{\text{transaction containing x}} \quad (7)$$

First, let's take a moment to think about a few additional situations. How sure are you that "Butter" and "Bread" are synonymous? To clarify, what percentage of purchases included both butter and bread? Extremely high, or very near to 1? Yeah, you nailed it. What about milk and yogurt? Back on top of the world. Milk for your toothbrush? Still unsure? Since "Milk" is such a common commodity, it is safe to assume that this rule will always hold true.

3.2.3 Lift

When determining the conditional probability of occurrence of Y given X, Lift accounts for the support (frequency) of consequent. The word "lift" is used to describe this metric rather literally. Imagine this as the *boost* to our self-assurance that comes from having Y in the shopping basket thanks to the presence of X. To restate, lift is the increase in the chance of Y being on the cart due to the knowledge of X's existence relative to the probability of Y being on the cart due to ignorance of X's presence.

$$\text{Lift } (\{x\} \rightarrow \{y\}) = \frac{(\text{transactions containing both x and y})/\ (\text{Transaction containing x})}{\text{Fraction of transactions containing y}} \quad (8)$$

3.3 Machine Learning Algorithms

Classification is a supervised learning technique in machine learning; it also denotes a predictive modelling challenge in which a class label is predicted for an input sample. Specifically, it is a mathematical function (f) that maps input variables (X) to target variables (Y), where Y might be a label or category. It may be performed on either structured or unstructured data to make predictions about the class of provided data items. Examples of classification the heart disease.

Classification problems with just two possible answers (true or false) are known as "binary classification." For example, in a job requiring binary classification, "normal" may be one class and "abnormal" another. As an example, if the work at hand includes a medical test, and the result is "cancer not detected," then "cancer detected" may be seen as the aberrant condition. In the same way, the "spam" and "not spam" categories used by email service providers are also regarded to be binary [23, 33].

The machine learning and data science field is rife with suggested categorization methods. The most widely-used approaches to predicting heart disease are summed up here.

3.3.1 Naïve Bayes

By using Bayes' theorem under the premise of feature independence, the naïve Bayes (NB) algorithm is developed. In many practical applications, such as document or text categorization, spam filtering, etc., it performs admirably and may be used for both binary and multi-class categories. The NB classifier may be used to efficiently categorize the data's noisy examples and build a solid prediction model. The main advantage is that it just requires a minimal amount of training data to rapidly and accurately estimate the required parameters, in contrast to more complex methods.

However, it makes very strong assumptions about the independence of characteristics, which might reduce its performance. Common NB classifier versions include the Gaussian, Multinomial, Complement, Bernoulli, and Categorical distributions [34, 35].

3.3.2 Logistic Regression

LR is another popular probabilistic-based statistical model used to address classification problems in machine learning. A logistic function, often known as the sigmoid function from its mathematical definition, is commonly used in LR to assess probabilities. Overfitting is possible with high-dimensional data, and it performs best when the data can be linearly partitioned. In these cases, regularization (L1 and L2) methods may be employed to prevent over-fitting. The linearity assumption between the dependent and independent variables is seen as a fundamental limitation of LR. Although it is more typically employed for classification difficulties, it may also be used for regression issues [36].

$$\mathrm{LR}(\mathrm{r}) = \frac{1}{1+\exp(-\mathrm{r})} \quad (9)$$

3.3.3 K-Nearest Neighbors

Known as a "lazy learning" method, k-nearest neighbors (KNN) is a kind of "instance-based learning" or non-generalizing learning. Rather than concentrating on building a single, overarching model, it maintains an n-dimensional database of all occurrences that correlate to training data. Similarity metrics (such as the Euclidean distance function) are used by KNN to classify fresh data points. Each point is assigned to a category based on a majority decision of its k closest neighbors. The accuracy is data-dependent, however, it is quite tolerant to noisy training data. Choosing the right number of neighbors to use might be challenging when using KNN. KNN is versatile, since it may be used for both classification and regression [37].

3.3.4 Support Vector Machine

SVMs are another prominent machine learning technology that may be used for classification, regression, and other applications. A SVM builds a hyper-plane or series of hyper-planes in high or infinite dimensional space. Since, in general, the larger the margin, the smaller the classifier's generalization error, it stands to reason that the hyper-plane, which has the largest distance from the closest training data points in each class, achieves a strong separation. It works well in high-dimensional spaces and exhibits varying behaviors depending on the kernel function used. Common kernel functions used in SVM classifiers include linear, polynomial, radial basis function (RBF), sigmoid, etc. SVM operates poorly, however, when there is more noise in the data set, such as when the target classes overlap [38, 39].

3.3.5 Decision Tree

One popular kind of supervised learning that does not rely on parameters is the decision tree (DT). Both the classification and regression jobs employ DT learning techniques. Popular DT algorithms include ID3, C4.5, and CART. And in the relevant application fields, such as user behavior analytics and Cybersecurity analytics, the newly suggested BehavDT and IntrudTree by Sarker et al. are successful. In order to categorize the instances, DT sorts the tree from its root node to a subset of its leaf nodes. Classifying instances involves traversing a tree from its root node to the leaf nodes along the branches that correspond to the attributes being checked. The Gini impurity and the entropy gain are two of the most often used metrics for partitioning [40].

We can define entropy and Gini as:

$$\mathrm{H}(\mathrm{x}) = -\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{p}(\mathrm{x_i}) \log_2 \mathrm{p}(\mathrm{x_i}) \quad (10)$$

$$\mathrm{E} = 1 - \sum_{\mathrm{i}=1}^{\mathrm{c}} \mathrm{p_i^2} \quad (11)$$

3.3.6 Random Forest

Well-known in the fields of machine learning and data science, random forest classifiers are employed as an ensemble classification approach. In this technique, "parallel ensemble" is used to simultaneously train several decision tree classifiers on independent subsamples of the data set, with the final result being determined by a vote or an average of the results. As a result, it improves prediction accuracy and regulates the issue of over-fitting. That's why it's more common for the random forest (RF) learning model to outperform those using a single decision tree. It uses a hybrid of bootstrap aggregation (bagging) and random feature selection to construct several decision trees with intentional variety. It works well with both categorical and continuous data and may be used for classification and regression issues [41, 42].

3.3.7 AdaBoost

Adaptive Boosting (AdaBoost) is an iterative ensemble learning procedure that uses error feedback to improve underperforming classifiers. This concept, dubbed "meta-learning" after its creators Yoav Freund et al. AdaBoost employs a "sequential ensemble," in contrast to the random forest's parallel ensemble. In order to achieve a decent classifier with high accuracy, it combines multiple underperforming classifiers to produce a powerful classifier. AdaBoost is an adaptive classifier since it greatly improves the classifier's efficiency; yet, it might lead to overfits in certain situations. AdaBoost is sensitive to noisy data and outliers, making it best utilized to improve the performance of decision trees, the basis estimator, for binary classification tasks [43].

3.3.8 Gradient Boosting

Similar to the RFs example up top, Gradient Boosting is a kind of ensemble learning method that builds a final model from a collection of smaller models (usually decision trees). Like how neural networks employ gradient descent to optimize weights, we use the gradient to minimize the loss function [44].

3.3.9 Bagging

The model is comprised of homogenous weak learners, who acquire knowledge in isolation and in parallel, and then average their results. Bagging, or Bootstrap Aggregating, is a meta-algorithm for machine learning ensembles that increases the reliability and precision of statistical classification and regression models. The variance is reduced and overfitting is prevented. Typically, this is used in decision tree techniques. The method of bagging is a variant of the model-averaging strategy [45].

4. Results and analysis

This section summarizes the analysis of heart disease data and the obtained results from the various machine learning algorithms.

4.1 Description of Dataset

The information may be accessed by the general public on the Kaggle website. It was collected as part of an ongoing cardiovascular research on people living in the town of Framingham, which is located in the state of Massachusetts. The information about the patients may be found in the dataset. It consists of nearly 4,000 rows and fifteen different qualities. In furthermore, the different statistical results for the dataset's input parameters are displayed in Table 1, including the count, mean, standard deviation, minimum, 25%, 50%, 75%, and maximum values.

Table 1. The statistics values of the attributes in heart disease data.

Statistics	sex	cp	trestbps	chol	fbs	restecg	thalach
count	1025.000	1025.000	1025.000	1025.000	1025.000	1025.000	1025.000
mean	54.434	0.696	0.942	131.612	246.000	0.149	0.530
Std.	9.072	0.460	1.030	17.517	51.593	0.357	0.528
Min	29.000	0.000	0.000	94.000	126.000	0.000	0.000
25%	48.000	0.000	0.000	120.000	211.000	0.000	0.000
50%	56.000	1.000	1.000	130.000	240.000	0.000	1.000
75%	61.000	1.000	2.000	140.000	275.000	0.000	1.000
Max	77.000	1.000	3.000	200.000	564.000	1.000	2.000

Statistics	exang	oldpeak	slope	ca	thal	Target
count	1025.000	1025.000	1025.000	1025.000	1025.000	1025.000
mean	149.114	0.337	1.072	1.385	0.754	2.324
Std.	23.006	0.473	1.175	0.618	1.031	0.621
Min	71.000	0.000	0.000	0.000	0.000	0.000
25%	132.000	0.000	0.000	1.000	0.000	2.000
50%	152.000	0.000	0.800	1.000	0.000	2.000
75%	166.000	1.000	1.800	2.000	1.000	3.000
Max	202.000	1.000	6.200	2.000	4.000	3.000

Figure 2 shows the data of sex and target columns. Where red color refers to the female and blue color refers to male. 0 refer to the target class no disease and 1 refers to the target class 1 has a disease. The number persons of male greater than female in 0 class. Also in 1 class the number rows in male greater than female.

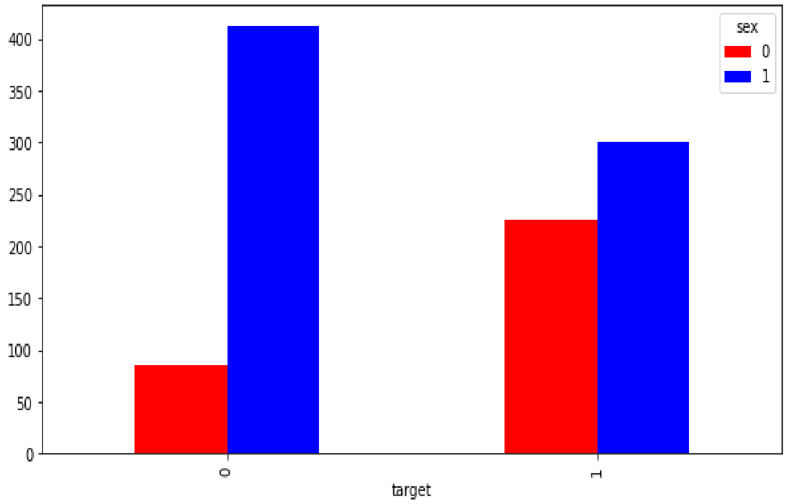

Figure 2. The sex and target columns.

Figure 3 shows the scatter diagram of data in age and cholesterol columns. Where the red color refers to the disease and blue color refers to no disease. The age between 30 and 40 years old have disease more than no disease.

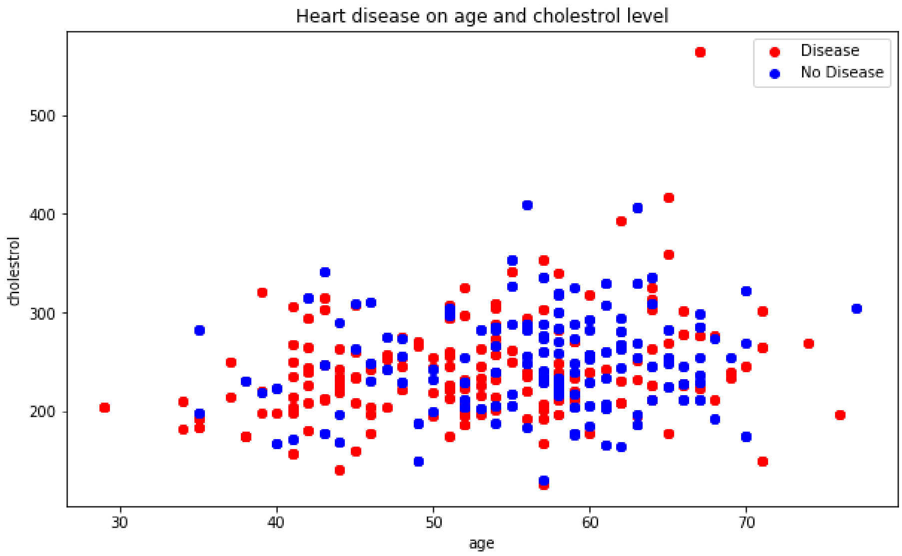

Figure 3. The scatter diagram of age and cholesterol.

Figure 4 shows the heatmap and correlation in dataset. In the age row, there are six criteria are negative correlation and other are positive correlation. The ca criterion is the highly positive correlated with the age criterion. The age criterion has a negative correlation with the target variable. In the sex criterion, there are 8 negative correlation criteria and 5 positive correlation criteria. The sex criterion has a negative correlation with the target variable. The thal is the highly correlated with the sex variable. In cp variable, there are six variables positive correlated and other are negative correlated. The cp has a positive correlation with the target variable. The cp variable is the most correlated variable with the target variable. In the trestbps, there are 7 positive correlated variables and other are negative correlated variable. Trestbps has a negative correlation with the target variable. In the chol, there are 7 positive correlated variables and other are negative correlated variable. Chol has a negative correlation with the target variable. In the fbs, there are 8 positive correlated variables and other are negative correlated variable. fbs has a negative correlation with the target variable. In the restecg, there are 4 positive correlated variables and other are negative correlated variable. restecg has a positive correlation with the target variable. In the thalach, there are 4 positive correlated variables and other are p correlated variable. thalach has a positive correlation with the target variable. In the exang, there are 8 positive correlated variables and other are negative correlated variable. exang has a negative correlation with the target variable in the oldpeak, there are 8 positive correlated variables and other are negative correlated variable. oldpeak has a negative correlation with the target variable. In the slope, there are 4 positive correlated variables and other are negative correlated variable. Slope has a positive correlation with the target variable. In the ca, there are 8 positive correlated variables and other are negative correlated variable. ca has a negative correlation with the target variable. In the thal, there are 7 positive correlated variables and other are negative correlated variable. thal has a negative correlation with the target variable.

In all variables there are four variables are positive correlated with the target variable and all other variables are negative correlated. The variables have positive correlation with the target variable are (cp, restecg, thalach, and slope). Between four variables, the cp is the largest positive correlated with the target variable. So, the cp, restecg, thalach, and slope have an association correlation with the target variable.

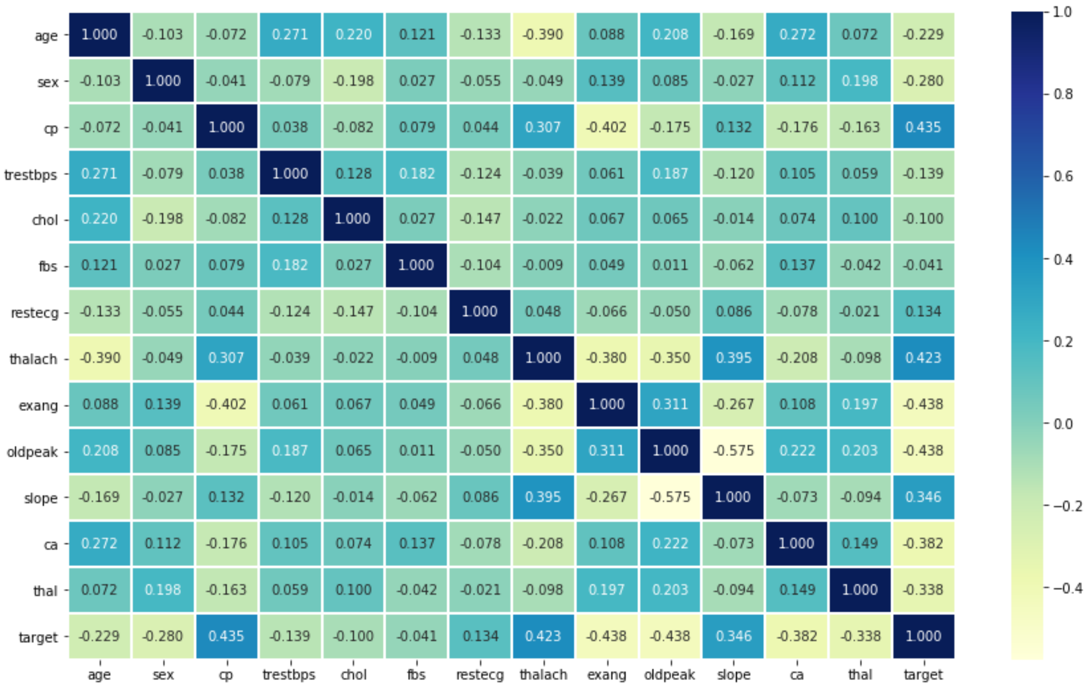

Figure 4. The heatmap in the dataset.

4.2 Neutrosophic AHP as a Feature Selection

We build the comparison matrix between 13 features. This matrix contains the triangular neutrosophic number. Table 2 shows the triangular neutrosophic numbers for 13 features. Then replace these numbers with the crisp values [27]. Then compute the normalization matrix. Then compute the weights of features as shown in Figure 5.

Table 2. Comparison matrix between 13 features.

	HDF_1	**HDF_2**	**HDF_3**
HDF_1	1	((1,1,1) ;0.50,0.50,0.50)	((6,7,8) ;0.90,0.10,0.10)
HDF_2	1/((1,1,1) ;0.50,0.50,0.50)	1	((4,5,6) ;0.80,0.15,0.20)
HDF_3	1/((6,7,8) ;0.90,0.10,0.10)	1/((4,5,6) ;0.80,0.15,0.20)	1
HDF_4	1/((1,2,3) ;0.40,0.65,0.60)	1/((6,7,8) ;0.90,0.10,0.10)	1((2,3,4) ;0.30,0.75,0.70)
HDF_5	1/((2,3,4) ;0.30,0.75,0.70)	1/((9,9,9) ;0.100,0.00,0.00)	1/((4,5,6) ;0.80,0.15,0.20)
HDF_6	1/((2,3,4) ;0.30,0.75,0.70)	1/((3,4,5) ;0.60,0.35,0.40)	1/((1,1,1) ;0.50,0.50,0.50)
HDF_7	1/((1,2,3) ;0.40,0.65,0.60)	1/((3,4,5) ;0.60,0.35,0.40)	1/((1,2,3) ;0.40,0.65,0.60)
HDF_8	1/((9,9,9) ;0.100,0.00,0.00)	1/((9,9,9) ;0.100,0.00,0.00)	1/((5,6,7) ;0.70,0.25,0.30)
HDF_9	1/((7,8,9) ;0.85,0.10,0.15)	1/((6,7,8) ;0.90,0.10,0.10)	1/((7,8,9) ;0.85,0.10,0.15)
HDF_{10}	1/((3,4,5) ;0.60,0.35,0.40)	1/((4,5,6) ;0.80,0.15,0.20)	1/((3,4,5) ;0.60,0.35,0.40)
HDF_{11}	1/((5,6,7) ;0.70,0.25,0.30)	1/((2,3,4) ;0.30,0.75,0.70)	1/((9,9,9) ;0.100,0.00,0.00)
HDF_{12}	1/((4,5,6) ;0.80,0.15,0.20)	1/((4,5,6) ;0.80,0.15,0.20)	1/((1,2,3) ;0.40,0.65,0.60)
HDF_{13}	1/((4,5,6) ;0.80,0.15,0.20)	1/((1,1,1) ;0.50,0.50,0.50)	1/((1,1,1) ;0.50,0.50,0.50)

	HDF_4	**HDF_5**	**HDF_6**
HDF_1	((1,2,3) ;0.40,0.65,0.60)	((2,3,4) ;0.30,0.75,0.70)	((2,3,4) ;0.30,0.75,0.70)
HDF_2	((6,7,8) ;0.90,0.10,0.10)	((9,9,9) ;0.100,0.00,0.00)	((3,4,5) ;0.60,0.35,0.40)
HDF_3	((2,3,4) ;0.30,0.75,0.70)	((4,5,6) ;0.80,0.15,0.20)	((1,1,1) ;0.50,0.50,0.50)
HDF_4	1	((5,6,7) ;0.70,0.25,0.30)	((3,4,5) ;0.60,0.35,0.40)
HDF_5	1/((5,6,7) ;0.70,0.25,0.30)	1	((3,4,5) ;0.60,0.35,0.40)
HDF_6	1/((3,4,5) ;0.60,0.35,0.40)	1/((3,4,5) ;0.60,0.35,0.40)	1
HDF_7	1/((1,2,3) ;0.40,0.65,0.60)	1/((5,6,7) ;0.70,0.25,0.30)	1/((7,8,9) ;0.85,0.10,0.15)
HDF_8	1/((1,2,3) ;0.40,0.65,0.60)	1/((7,8,9) ;0.85,0.10,0.15)	1/((5,6,7) ;0.70,0.25,0.30)
HDF_9	1/((1,1,1) ;0.50,0.50,0.50)	1/((6,7,8) ;0.90,0.10,0.10)	1/((6,7,8) ;0.90,0.10,0.10)
HDF_{10}	1/((1,2,3) ;0.40,0.65,0.60)	1/((1,1,1) ;0.50,0.50,0.50)	1/((4,5,6) ;0.80,0.15,0.20)
HDF_{11}	1/((5,6,7) ;0.70,0.25,0.30)	1/((3,4,5) ;0.60,0.35,0.40)	1/((9,9,9) ;0.100,0.00,0.00)
HDF_{12}	1/((1,1,1) ;0.50,0.50,0.50)	1/((7,8,9) ;0.85,0.10,0.15)	1/((5,6,7) ;0.70,0.25,0.30)
HDF_{13}	1/((1,2,3) ;0.40,0.65,0.60)	1/((2,3,4) ;0.30,0.75,0.70)	1/((3,4,5) ;0.60,0.35,0.40)

	HDF_7	**HDF_8**	**HDF_9**
HDF_1	((1,2,3) ;0.40,0.65,0.60)	((9,9,9) ;0.100,0.00,0.00)	((7,8,9) ;0.85,0.10,0.15)
HDF_2	((3,4,5) ;0.60,0.35,0.40)	((9,9,9) ;0.100,0.00,0.00)	((6,7,8) ;0.90,0.10,0.10)
HDF_3	((1,2,3) ;0.40,0.65,0.60)	((5,6,7) ;0.70,0.25,0.30)	((7,8,9) ;0.85,0.10,0.15)
HDF_4	((1,2,3) ;0.40,0.65,0.60)	((1,2,3) ;0.40,0.65,0.60)	((1,1,1) ;0.50,0.50,0.50)
HDF_5	((5,6,7) ;0.70,0.25,0.30)	((7,8,9) ;0.85,0.10,0.15)	((6,7,8) ;0.90,0.10,0.10)
HDF_6	((7,8,9) ;0.85,0.10,0.15)	((5,6,7) ;0.70,0.25,0.30)	((6,7,8) ;0.90,0.10,0.10)

HDF_7	1	((3,4,5) ;0.60,0.35,0.40)	((5,6,7) ;0.70,0.25,0.30)
HDF_8	1/((3,4,5) ;0.60,0.35,0.40)	1	((3,4,5) ;0.60,0.35,0.40)
HDF_9	1/((5,6,7) ;0.70,0.25,0.30)	1/((3,4,5) ;0.60,0.35,0.40)	1
HDF_{10}	1/((2,3,4) ;0.30,0.75,0.70)	1/((6,7,8) ;0.90,0.10,0.10)	1/((9,9,9) ;0.100,0.00,0.00)
HDF_{11}	1/((6,7,8) ;0.90,0.10,0.10)	1/((1,1,1) ;0.50,0.50,0.50)	1/((1,2,3) ;0.40,0.65,0.60)
HDF_{12}	1/((3,4,5) ;0.60,0.35,0.40)	1/((9,9,9) ;0.100,0.00,0.00)	1/((6,7,8) ;0.90,0.10,0.10)
HDF_{13}	1/((5,6,7) ;0.70,0.25,0.30)	1/((7,8,9) ;0.85,0.10,0.15)	1/((3,4,5) ;0.60,0.35,0.40)
	HDF_{10}	**HDF_{11}**	**HDF_{12}**
HDF_1	((3,4,5) ;0.60,0.35,0.40)	((5,6,7) ;0.70,0.25,0.30)	((4,5,6) ;0.80,0.15,0.20)
HDF_2	((4,5,6) ;0.80,0.15,0.20)	((2,3,4) ;0.30,0.75,0.70)	((4,5,6) ;0.80,0.15,0.20)
HDF_3	((3,4,5) ;0.60,0.35,0.40)	((9,9,9) ;0.100,0.00,0.00)	((1,2,3) ;0.40,0.65,0.60)
HDF_4	((1,2,3) ;0.40,0.65,0.60)	((5,6,7) ;0.70,0.25,0.30)	((1,1,1) ;0.50,0.50,0.50)
HDF_5	((1,1,1) ;0.50,0.50,0.50)	((3,4,5) ;0.60,0.35,0.40)	((7,8,9) ;0.85,0.10,0.15)
HDF_6	((4,5,6) ;0.80,0.15,0.20)	((9,9,9) ;0.100,0.00,0.00)	((5,6,7) ;0.70,0.25,0.30)
HDF_7	((2,3,4) ;0.30,0.75,0.70)	((6,7,8) ;0.90,0.10,0.10)	((3,4,5) ;0.60,0.35,0.40)
HDF_8	((6,7,8) ;0.90,0.10,0.10)	((1,1,1) ;0.50,0.50,0.50)	((9,9,9) ;0.100,0.00,0.00)
HDF_9	((9,9,9) ;0.100,0.00,0.00)	((1,2,3) ;0.40,0.65,0.60)	((6,7,8) ;0.90,0.10,0.10)
HDF_{10}	1	((1,1,1) ;0.50,0.50,0.50)	((4,5,6) ;0.80,0.15,0.20)
HDF_{11}	1/((1,1,1) ;0.50,0.50,0.50)	1	((2,3,4) ;0.30,0.75,0.70)
HDF_{12}	1/((4,5,6) ;0.80,0.15,0.20)	1/((2,3,4) ;0.30,0.75,0.70)	1
HDF_{13}	1/((3,4,5) ;0.60,0.35,0.40)	1/((1,1,1) ;0.50,0.50,0.50)	1/((1,2,3) ;0.40,0.65,0.60)
		HDF_{13}	
HDF_1		((4,5,6) ;0.80,0.15,0.20)	
HDF_2		((1,1,1) ;0.50,0.50,0.50)	
HDF_3		((1,1,1) ;0.50,0.50,0.50)	
HDF_4		((1,2,3) ;0.40,0.65,0.60)	
HDF_5		((2,3,4) ;0.30,0.75,0.70)	
HDF_6		((3,4,5) ;0.60,0.35,0.40)	
HDF_7		((5,6,7) ;0.70,0.25,0.30)	
HDF_8		((7,8,9) ;0.85,0.10,0.15)	
HDF_9		((3,4,5) ;0.60,0.35,0.40)	
HDF_{10}		((3,4,5) ;0.60,0.35,0.40)	
HDF_{11}		((1,1,1) ;0.50,0.50,0.50)	
HDF_{12}		((1,2,3) ;0.40,0.65,0.60)	
HDF_{13}		1	

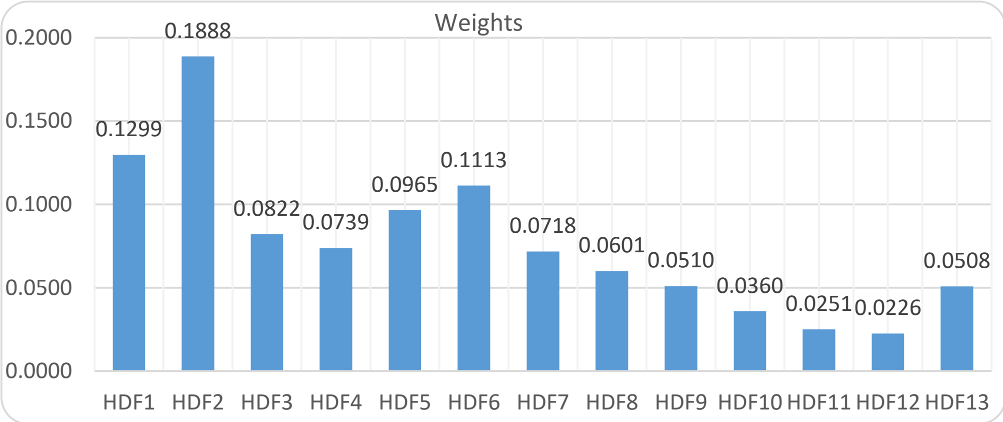

Figure 5. Weights of 13 features.

4.3 Association Rules

Table 3 shows the association rules between the target and other variables. Table 3 presents the support, confidence, and lift values.

Table 3. Comparison matrix between 13 features.

Column name in dataset	Target class	antecedent support	consequent support	Support	confidence	lift	leverage	Conviction
Age	0	0.8537	0.9756	0.8293	0.9714	0.9957	-0.0036	0.8537
	1	0.9756	0.8537	0.8293	0.8500	0.9957	-0.0036	0.9756
Sex	0	1.0	1.0	1.0	1.0	1.0	0.0	Inf
	1	1.0	1.0	1.0	1.0	1.0	0.0	Inf
CP	0	1.0	1.0	1.0	1.0	1.0	0.0	Inf
	1	1.0	1.0	1.0	1.0	1.0	0.0	Inf
trestbps	0	0.7755	0.7959	0.5714	0.7368	0.9258	-0.0458	0.7755
	1	0.7959	0.7755	0.5714	0.7179	0.9258	-0.0458	0.7959
fbs	0	1.0	1.0	1.0	1.0	1.0	0.0	Inf
	1	1.0	1.0	1.0	1.0	1.0	0.0	Inf
restecg	0	1.0	1.0	1.0	1.0	1.0	0.0	Inf
	1	1.0	1.0	1.0	1.0	1.0	0.0	Inf
thalach	0	0.7363	0.7802	0.5165	0.7015	0.8991	-0.058	0.7363
	1	0.7802	0.7363	0.5165	0.6620	0.8991	-0.058	0.7802
exang	0	1.0	1.0	1.0	1.0	1.0	0.0	Inf
	1	1.0	1.0	1.0	1.0	1.0	0.0	Inf
oldpeak	0	0.650	0.875	0.525	0.8077	0.9231	-0.0437	0.650
	1	0.875	0.650	0.525	0.6000	0.9231	-0.0437	0.875
slope	0	1.0	1.0	1.0	1.0	1.0	0.0	Inf
	1	1.0	1.0	1.0	1.0	1.0	0.0	Inf
ca	0	1.0	1.0	1.0	1.0	1.0	0.0	Inf
	1	1.0	1.0	1.0	1.0	1.0	0.0	Inf
thal	0	1.0	1.0	1.0	1.0	1.0	0.0	Inf
	1	1.0	1.0	1.0	1.0	1.0	0.0	Inf

4.4 Performance Measurements

Every confusion matrix provides a description of the operation of a classification algorithm on a set of test data for which the measured values are completely understood. The confusion matrix was used in the computation of the parameters stated in Table 4, which may be seen below. From Table 4 the random forest and decision tree have the best accuracy with 100% accuracy. We divide the dataset into train and test, the train set has 80% and the test set has 20% data. Figure 6 shows the confusion matrices.

Table 4. The results of machine learning algorithms.

	Logistic Regression	Random Forest	KNN	SVM	AdaBoosting	Bagging	Gradient Boosting	NB	Decision Tree
Accuracy	0.8439	1.0000	0.9805	0.6780	0.8927	0.9902	0.9756	0.8390	1.0000
Precision	0.8155	1.0000	0.9604	0.6165	0.9121	1.0000	0.9894	0.8333	1.0000
Recall	0.8660	1.0000	1.0000	0.8454	0.8557	0.9794	0.9588	0.8247	1.0000
F1-score	0.8400	1.0000	0.9798	0.7130	0.8830	0.9896	0.9738	0.8290	1.0000

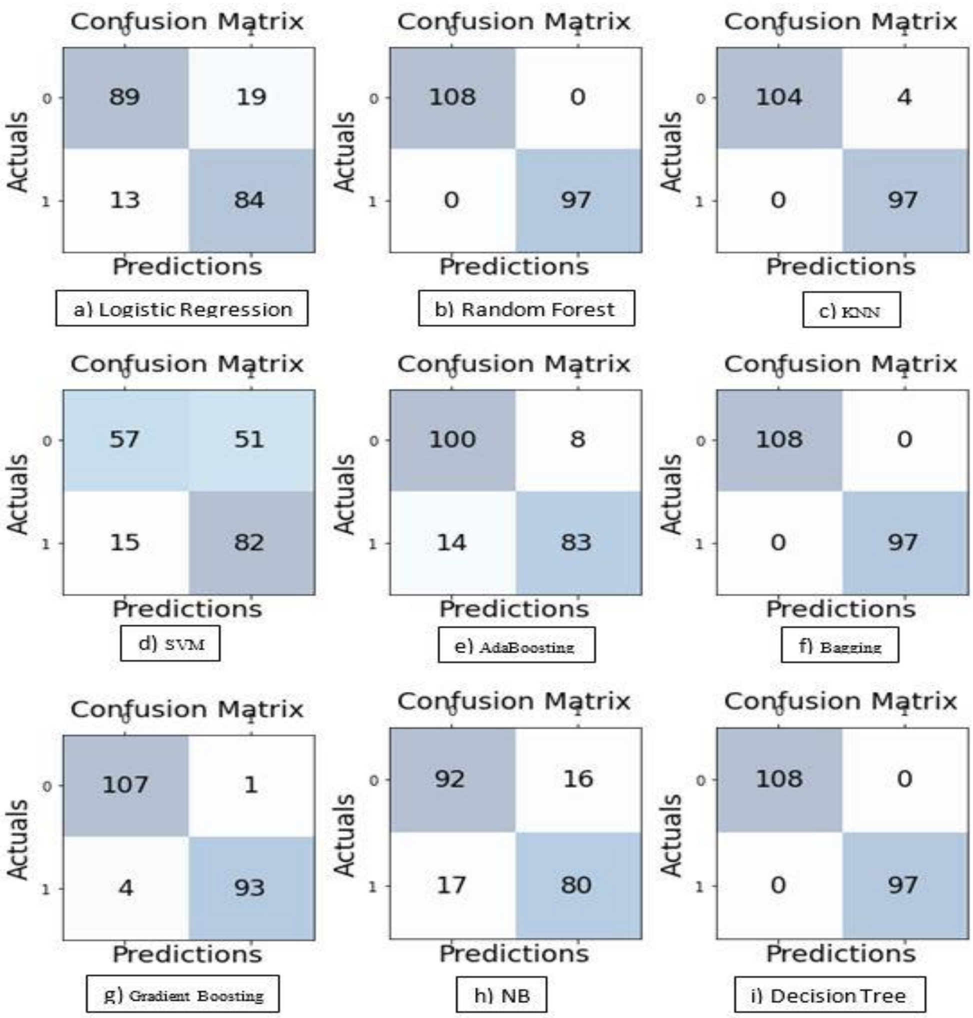

Figure 6. The confusion matrices.

5. Managerial Implications

The administrative implications of heart disease prediction for healthcare organizations and providers are many. Among the repercussions of this are:

Effective resource allocation is possible with the use of heart disease prediction models. Healthcare expenses may be reduced and resource utilization improved by targeting people at the highest risk via preventative measures like screens and treatments.

Healthcare administrators are able to create more effective preventative care programs because of heart disease prediction. High-risk patients might be targeted for preventative measures such as lifestyle changes, medication management, and routine monitoring by healthcare administrators. By taking preventative measures, healthcare outcomes for patients and costs for healthcare systems may both improve.

Workflow and Care Coordination: Prediction models for cardiovascular disease may help with both. Managers can pinpoint those patients most at risk and swiftly arrange them for the necessary preventative measures. Better patient care and results are the results of this effort to standardize care pathways and guarantee timely interventions.

Patient Engagement and Education: Prediction models for cardiovascular disease may help with both goals. Managers may utilize prognostic data to teach patients about their unique risk factors, the value of sticking to their treatment regimens, and the advantages of adopting healthier habits. Patients' desire and ability to make educated choices about their own heart disease prevention and treatment may both be improved by patient engagement.

The efficiency of preventative measures and the quality of treatment as a whole may be tracked using performance metrics such as heart disease prediction models. Managers may monitor the progress of high-risk people to see whether the interventions they've put in place are having the intended effect. With this information, we can make more educated choices about how to best treat cardiac disease.

Insurance firms and other payers may use heart disease prediction algorithms in risk-based contracts and insurance policies. Insurers may adjust customers' premiums, levels of coverage, and methods of payment to account for each person's unique estimated risk of cardiovascular disease by integrating predictive information. This method encourages individualized and economically viable medical protection.

Data generated by heart disease prediction models may be utilized for scientific inquiry and technological advancement. Data produced by prediction models may be analyzed by managers and researchers together to discover new risk factors, verify current models, and improve predictive algorithms. Working together, we can better understand how to anticipate and treat cardiac disease.

Predicting cardiovascular disease has broad administrative implications, including but not limited to budgeting, planning for preventative treatment, streamlining operations, increasing patient participation, enhancing product quality, reducing risk, and facilitating new studies. In the context of heart disease prevention and management, predictive models may help healthcare administrators make better choices, enhance the quality of treatment provided, and improve patient outcomes.

6. Conclusions

Predicting heart disease is important for several reasons, including bettering patient outcomes, maximizing resources, and permitting individualized treatment. By drawing from several data sets to build disease-specific prognostic models, machine learning algorithms have already shown their worth in this area. Better heart disease management and prevention are possible because of these models' ability to stratify risk, diagnose it early, and direct treatment accordingly.

Several administrative considerations arise from using machine learning to the problem of predicting cardiac disease. By focusing on those most at risk and implementing preventative measures first, healthcare systems may make better use of their limited resources. Predictive models are used in personalized care plans to increase patient involvement and treatment compliance. Care coordination and optimization of workflow allow for prompt screenings and treatments for those at high risk. Additionally, cardiovascular disease prediction models allow for better performance tracking, quality enhancement, and groundbreaking new research.

The use of machine learning algorithms for the prediction of heart disease has enormous potential to improve cardiovascular treatment. Risk stratification, individualized care planning, and early identification of cardiac disease are all made possible by these models, which make use of massive datasets and sophisticated computational approaches. We used the neutrosophic AHP as a feature selection to select the best feature, then we applied the association rules to get importance from the rules between datasets. Finally, we used the nine machine learning algorithms to predict heart disease. From our data, we know that the highest accuracy is achieved by random forests and decision trees (100%), then by bagging, k-nearest neighbors, and gradient boosting (98%, 97%, and 89%, respectively), then by AdaBoosting (89%), then by logistic regression and Naive Bayes (84%), and finally by support vector machines (68%).

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Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that there is no conflict of interest in the research.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

References

1. S. Palaniappan and R. Awang, "Intelligent heart disease prediction system using data mining techniques," in 2008 IEEE/ACS international conference on computer systems and applications, IEEE, 2008, pp. 108–115.
2. A. N. Repaka, S. D. Ravikanti, and R. G. Franklin, "Design and implementing heart disease prediction using naives Bayesian," in 2019 3rd International conference on trends in electronics and informatics (ICOEI), IEEE, 2019, pp. 292–297.
3. K. Saxena and R. Sharma, "Efficient heart disease prediction system," Procedia Comput. Sci., vol. 85, pp. 962–969, 2016.
4. M. M. Ali, B. K. Paul, K. Ahmed, F. M. Bui, J. M. W. Quinn, and M. A. Moni, "Heart disease prediction using supervised machine learning algorithms: Performance analysis and comparison," Comput. Biol. Med., vol. 136, p. 104672, 2021.
5. M. Kavitha, G. Gnaneswar, R. Dinesh, Y. R. Sai, and R. S. Suraj, "Heart disease prediction using hybrid machine learning model," in 2021 6th international conference on inventive computation technologies (ICICT), IEEE, 2021, pp. 1329–1333.
6. L. Riyaz, M. A. Butt, M. Zaman, and O. Ayob, "Heart disease prediction using machine learning techniques: a quantitative review," in International Conference on Innovative Computing and Communications: Proceedings of ICICC 2021, Volume 3, Springer, 2022, pp. 81–94.
7. A. H. Chen, S.-Y. Huang, P.-S. Hong, C.-H. Cheng, and E.-J. Lin, "HDPS: Heart disease prediction system," in 2011 computing in Cardiology, IEEE, 2011, pp. 557–560.

8. V. Sharma, S. Yadav, and M. Gupta, “Heart disease prediction using machine learning techniques,” in 2020 2nd international conference on advances in computing, communication control and networking (ICACCCN), IEEE, 2020, pp. 177–181.
9. J. Soni, U. Ansari, D. Sharma, and S. Soni, “Predictive data mining for medical diagnosis: An overview of heart disease prediction,” Int. J. Comput. Appl., vol. 17, no. 8, pp. 43–48, 2011.
10. N. Bhatla and K. Jyoti, “An analysis of heart disease prediction using different data mining techniques,” Int. J. Eng., vol. 1, no. 8, pp. 1–4, 2012.
11. L. Parthiban and R. Subramanian, “Intelligent heart disease prediction system using CANFIS and genetic algorithm,” Int. J. Biol. Biomed. Med. Sci., vol. 3, no. 3, 2008.
12. A. M. AbdelMouty and A. Abdel-Monem, “Neutrosophic MCDM Methodology for Assessment Risks of Cyber Security in Power Management,” Neutrosophic Systems with Applications, vol. 3, pp. 53–61, 2023.
13. V. V Ramalingam, A. Dandapath, and M. K. Raja, “Heart disease prediction using machine learning techniques: a survey,” Int. J. Eng. Technol., vol. 7, no. 2.8, pp. 684–687, 2018.
14. D. Shah, S. Patel, and S. K. Bharti, “Heart disease prediction using machine learning techniques,” SN Comput. Sci., vol. 1, pp. 1–6, 2020.
15. A. Singh and R. Kumar, “Heart disease prediction using machine learning algorithms,” in 2020 international conference on electrical and electronics engineering (ICE3), IEEE, 2020, pp. 452–457.
16. H. Jindal, S. Agrawal, R. Khera, R. Jain, and P. Nagrath, “Heart disease prediction using machine learning algorithms,” in IOP conference series: materials science and engineering, IOP Publishing, 2021, p. 12072.
17. M. Aljanabi, M. H. Qutqut, and M. Hijjawi, “Machine learning classification techniques for heart disease prediction: a review,” Int. J. Eng. Technol., vol. 7, no. 4, pp. 5373–5379, 2018.
18. A. Rajdhan, A. Agarwal, M. Sai, D. Ravi, and P. Ghuli, “Heart disease prediction using machine learning,” Int. J. Eng. Technol., vol. 9, no. O4, 2020.
19. R. Katarya and S. K. Meena, “Machine learning techniques for heart disease prediction: a comparative study and analysis,” Health Technol. (Berl)., vol. 11, pp. 87–97, 2021.
20. S. Mohan, C. Thirumalai, and G. Srivastava, “Effective heart disease prediction using hybrid machine learning techniques,” IEEE access, vol. 7, pp. 81542–81554, 2019.
21. M. A. Khan, “An IoT framework for heart disease prediction based on MDCNN classifier,” IEEE Access, vol. 8, pp. 34717–34727, 2020.
22. M. Jdid, F. Smarandache, and S. Broumi, “Inspection Assignment Form for Product Quality Control Using Neutrosophic Logic,” Neutrosophic Systems with Applications, vol. 1, pp. 4–13, 2023.
23. Y. Hu, Y. Zhang, and D. Gong, “Multiobjective particle swarm optimization for feature selection with fuzzy cost,” IEEE Trans. Cybern., vol. 51, no. 2, pp. 874–888, 2020.
24. S. Arefnezhad, S. Samiee, A. Eichberger, and A. Nahvi, “Driver drowsiness detection based on steering wheel data applying adaptive neuro-fuzzy feature selection,” Sensors, vol. 19, no. 4, p. 943, 2019.
25. F. Aghaeipoor and M. M. Javidi, “A hybrid fuzzy feature selection algorithm for high-dimensional regression problems: An mRMR-based framework,” Expert Syst. Appl., vol. 162, p. 113859, 2020.
26. A. Abdelhafeez, H. K. Mohamed, and N. A. Khalil, “Rank and Analysis Several Solutions of Healthcare Waste to Achieve Cost Effectiveness and Sustainability Using Neutrosophic MCDM Model,” Neutrosophic Systems with Applications, vol. 2, pp. 25–37, 2023.
27. M. Naderi, J. Chakareski, and M. Ghanbari, “Hierarchical Q-learning-enabled neutrosophic AHP scheme in candidate relay set size adaption in vehicular networks,” Comput. Networks, p. 109968, 2023.
28. S. Kotsiantis and D. Kanellopoulos, “Association rules mining: A recent overview,” GESTS Int. Trans. Comput. Sci. Eng., vol. 32, no. 1, pp. 71–82, 2006.
29. R. Agrawal, H. Mannila, R. Srikant, H. Toivonen, and A. I. Verkamo, “Fast discovery of association rules.,” Adv. Knowl. Discov. data Min., vol. 12, no. 1, pp. 307–328, 1996.
30. S. M. Ghafari and C. Tjortjis, “A survey on association rules mining using heuristics,” Wiley Interdiscip. Rev. Data Min. Knowl. Discov., vol. 9, no. 4, p. e1307, 2019.
31. F. Wen, G. Zhang, L. Sun, X. Wang, and X. Xu, “A hybrid temporal association rules mining method for traffic congestion prediction,” Comput. Ind. Eng., vol. 130, pp. 779–787, 2019.
32. B. Mahesh, “Machine learning algorithms-a review,” Int. J. Sci. Res. (IJSR).[Internet], vol. 9, pp. 381–386, 2020.

33. S. Ray, "A quick review of machine learning algorithms," in 2019 International conference on machine learning, big data, cloud and parallel computing (COMITCon), IEEE, 2019, pp. 35–39.
34. A. Singh, N. Thakur, and A. Sharma, "A review of supervised machine learning algorithms," in 2016 3rd International Conference on Computing for Sustainable Global Development (INDIACom), Ieee, 2016, pp. 1310–1315.
35. D. Sharma and N. Kumar, "A review on machine learning algorithms, tasks and applications," Int. J. Adv. Res. Comput. Eng. Technol., vol. 6, no. 10, pp. 1323–2278, 2017.
36. D. Dhall, R. Kaur, and M. Juneja, "Machine learning: a review of the algorithms and its applications," Proc. ICRIC 2019 Recent Innov. Comput., pp. 47–63, 2020.
37. R. Choudhary and H. K. Gianey, "Comprehensive review on supervised machine learning algorithms," in 2017 International Conference on Machine Learning and Data Science (MLDS), IEEE, 2017, pp. 37–43.
38. A. Khan, B. Baharudin, L. H. Lee, and K. Khan, "A review of machine learning algorithms for text-documents classification," J. Adv. Inf. Technol., vol. 1, no. 1, pp. 4–20, 2010.
39. S. B. Kotsiantis, I. Zaharakis, and P. Pintelas, "Supervised machine learning: A review of classification techniques," Emerg. Artif. Intell. Appl. Comput. Eng., vol. 160, no. 1, pp. 3–24, 2007.
40. C. Crisci, B. Ghattas, and G. Perera, "A review of supervised machine learning algorithms and their applications to ecological data," Ecol. Modell., vol. 240, pp. 113–122, 2012.
41. J. Alzubi, A. Nayyar, and A. Kumar, "Machine learning from theory to algorithms: an overview," in Journal of physics: conference series, IOP Publishing, 2018, p. 12012.
42. M. I. Jordan and T. M. Mitchell, "Machine learning: Trends, perspectives, and prospects," Science (80-.)., vol. 349, no. 6245, pp. 255–260, 2015.
43. T. K. Balaji, C. S. R. Annavarapu, and A. Bablani, "Machine learning algorithms for social media analysis: A survey," Comput. Sci. Rev., vol. 40, p. 100395, 2021.
44. J. Latif, C. Xiao, A. Imran, and S. Tu, "Medical imaging using machine learning and deep learning algorithms: a review," in 2019 2nd International conference on computing, mathematics and engineering technologies (iCoMET), IEEE, 2019, pp. 1–5.
45. P. P. Shinde and S. Shah, "A review of machine learning and deep learning applications," in 2018 Fourth international conference on computing communication control and automation (ICCUBEA), IEEE, 2018, pp. 1–6.

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Optimal Agricultural Land Use: An Efficient Neutrosophic Linear Programming Method

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Abstract: The increase in the size of the problems facing humans, their overlap, the division of labor, the multiplicity of departments, as well as the diversity of products and commodities, led to the complexity of business and the emergence of many administrative and production problems. It was necessary to search for appropriate methods to confront these problems. The science of operations research, with its diverse methods, provided the optimal solutions. It addresses many problems and helps in making scientific and thoughtful decisions to carry out the work in the best way within the available capabilities. Operations research is one of the modern applied sciences that uses the scientific method as a basis and method in research and study, and its basic essence is to build a model that helps management in making decisions related to difficult administrative problems. For example, the military field, financial aspects, industry, in construction for building bridges and huge projects to evaluate the time taken for each project and reduce this time, financial markets and stocks and forecasting economic conditions, in hospital management and controlling the process of nutrition and medicines within the available capabilities, in agriculture Agricultural marketing and many other problems that have been addressed using classical operations research methods. We know that the agricultural sector is one of the important sectors in every country, and the agricultural production process is regulated by those responsible for securing the needs of citizens. Also, those responsible for the agricultural sector are responsible for rationalizing the agricultural process so that the surplus is saved. Due to the difficult circumstances that the country may be going through, in this research, we will reformulate the general model for the optimal distribution of agricultural lands using the concepts of neutrosophic science.

Keywords: Operations Research; Neutrosophic Science; Neutrosophic Linear Programming; Optimal Agricultural Land Use Model.

1. Introduction

Securing the needs of citizens is necessary and one of the major responsibilities that falls on officials in the state. This matter requires a scientific study of the reality of the state's situation and optimal exploitation of the available capabilities, that is, organizing work in all sectors of the state in a way that guarantees citizens a stable life in all circumstances. This matter prompted scientists and researchers are prepare scientific studies that help decision-makers make ideal decisions to manage the work of these sectors. The classical linear programming method was one of the most widely used methods [1-3], and it was relied upon even though the solutions it provided were appropriate solutions for conditions similar to those in which, data is collected about the case under study. Any change in this data will affect the optimal solution and thus the decisions of decision-makers, which requires us to search for a new scientific method that provides us with optimal solutions suitable for all circumstances and takes into account all changes that may occur. In the work environment, we find that using the concepts of neutrosophic science, the science that takes into account the changes that can occur in the work environment through the indeterminacy of neutrosophic values. So, we have to reformulate many practical issues using the concepts of this science, which can be viewed from what was presented by the American scientist Florentin Smarandache, the founder of this science, and many researchers in various scientific fields [4-19]. Given the importance of the linear programming method, we presented in previous research the neutrosophic linear models [20]. In another research, we presented one of the most important methods used to find the optimal solution for the models. Linear, which is the simplex neutrosophic method [21]. Among the uses of neutrosophic linear programming, we presented a study on its use in the field of education [22]. As a continuation of our previous work, we present in this research a study whose purpose is to reformulate the model of optimal use of agricultural land using the concepts of neutrosophic. This will help decision-makers obtain an optimal solution that secures the needs of citizens for agricultural crops in all circumstances that the country may go through.

The structure of this paper is organized as follows. In Section 2, we briefly examine the concept used for solving the problem. In Section 3, we apply the introduced approach to a case study and discuss the obtained results. In Section 4, we discuss the conclusions of the paper in Section 3.

2. Materials and methods

The most important stage in linear programming is the stage of creating a linear programming model, and we mean expressing realistic relationships with assumed mathematical relationships based on the study and analysis of reality. In order to formulate a linear programming model, the following basic elements must be present:

- Determine the goal in a quantitative manner
  It is expressed by the objective function, which is the function for which the maximum or minimum value is required. It must be possible to express the goal quantitatively, such as if the goal is to achieve the greatest possible profit or secure the smallest possible cost.

- Determine the constraints
  The constraints on the available resources must be specific, that is, the resources must be measurable, and expressed in a mathematical formula in the form of inequalities or equals.

- Determine the goal in a quantitative manner
  This element indicates that the problem should have more than one solution so that linear programming can be applied because if the problem had one solution, there would be no need to use linear programming because its benefit is focused on helping to choose the best solution from among the multiple solutions [1].

3. Results and discussion

3.1 Problem definition

We will apply the above in Section 2, to the model of optimal use of agricultural land, using the concepts of neutrosophic science. We will take data that is affected by the surrounding conditions, and neutrosophic values.

- Text of the issue:

Let us assume that we have n agricultural areas (plain or cultivated), the area of each of which is equal to $A_1, A_2, \cdots\cdots, A_n$, we want to plant it with m types of agricultural crops to secure the community's requirements for it. Knowing that we need of crop i the amount b_i , if the average productivity of one area in plain j of crop i is equal to Na_{ij}tons/ha. Where $j = 1,2, \dots\dots, n$ and $i = 1,2, \dots\dots, m$, and the profit returned from one unit of crop i equal to Np_i, Where Np_i is a neutrosophic value, an undefined non-specific value that designates a perfect and can be any neighbor of the value a_{ij}, also Np_iwhich can be any neighbor of p_i.

- Required:

Determine the amount of area needed to be cultivated with each crop and in all regions to achieve the greatest possible profit and meet the needs of society.

- Formulation of the mathematical model:

We symbolize by x_{ij} the amount of area in area j that must be cultivated with crop, and we place the data for the problem in Table 1.

Table 1. Issue data.

Regions / *Crops*	1	2	……	n	*Order amount* b_i	*profit amount* Np_i
1	Na_{11} x_{11}	Na_{12} x_{12}	……	Na_{1n} x_{1n}	b_1	Np_1
2	Na_{21} x_{21}	Na_{22} x_{22}	……	Na_{2n} x_{2n}	b_2	Np_2
……	……	……	……	……	……	……
m	Na_{m1} x_{m1}	Na_{m2} x_{m2}	……	Na_{mn} x_{mn}	b_m	Np_m
Available space a_i	a_1	a_2	……	a_n		

Then we find that the conditions imposed on the variables x_{ij} are:

1. Space restrictions

   The total area allocated to various crops in area j must be equal to a_j, that is, it must be:

$$\mathrm{x}_{11} + \mathrm{x}_{12} + \cdots\cdots + \mathrm{x}_{m1} = \mathrm{a}_1$$
$$\mathrm{x}_{12} + \mathrm{x}_{22} + \cdots\cdots + \mathrm{x}_{m2} = \mathrm{a}_2$$
$$\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots$$
$$\mathrm{x}_{1n} + \mathrm{x}_{2n} + \cdots\cdots + \mathrm{x}_{mn} = \mathrm{a}_n$$

2. Conditions for meeting community requirements

   The total production of crop i in all regions must not be less than the amount b_i, that is, it must be:

$$\mathrm{Na}_{11}\mathrm{x}_{11} + \mathrm{Na}_{12}\mathrm{x}_{12} + \cdots\cdots + \mathrm{Na}_{1n}\mathrm{x}_{1n} \geq \mathrm{b}_1$$
$$\mathrm{Na}_{21}\mathrm{x}_{21} + \mathrm{Na}_{22}\mathrm{x}_{22} + \cdots\cdots + \mathrm{Na}_{2n}\mathrm{x}_{2n} \geq \mathrm{b}_2$$
$$\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots$$
$$\mathrm{Na}_{m1}\mathrm{x}_{m1} + \mathrm{Na}_{m2}\mathrm{x}_{m2} + \cdots\cdots + \mathrm{Na}_{mn}\mathrm{x}_{mn} \geq \mathrm{b}_m$$

3. Find the objective function

   - We note that the profit resulting from the production of crop i only and from all regions is equal to the product of the profit times the quantity and i.e.:

$$Np_i(Na_{i1}x_{i1} + Na_{i2}x_{i2} + \cdots\cdots + Na_{in}x_{in})$$

Thus, we find that the objective function, which expresses the total profit resulting from all crops, is equal to:

$$Z = Np_1\left(\sum_{j=1}^{n} Na_{1j}\ x_{1j}\right) + Np_2\left(\sum_{j=1}^{n} Na_{2j}\ x_{2j}\right) + \cdots\cdots + Np_m\left(\sum_{j=1}^{n} Na_{mj}\ x_{mj}\right) \to Max$$

- From the above, we get the following mathematical model:

Find the maximum value of

$$Z = Np_1\left(\sum_{j=1}^{n} Na_{1j}\ x_{1j}\right) + Np_2\left(\sum_{j=1}^{n} Na_{2j}\ x_{2j}\right) + \cdots\cdots + Np_m\left(\sum_{j=1}^{n} Na_{mj}\ x_{mj}\right) \to Max$$

Within restrictions:

$$x_{11} + x_{12} + \cdots\cdots + x_{m1} = a_1$$
$$x_{12} + x_{22} + \cdots\cdots + x_{m2} = a_2$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$
$$x_{1n} + x_{2n} + \cdots\cdots + x_{mn} = a_n$$

$$a_{11}x_{11} + a_{12}x_{12} + \cdots\cdots + a_{1n}x_{1n} \geq b_1$$
$$a_{21}x_{21} + a_{22}x_{22} + \cdots\cdots + a_{2n}x_{2n} \geq b_2$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$
$$a_{m1}x_{m1} + a_{m2}x_{m2} + \cdots\cdots + a_{mn}x_{mn} \geq b_m$$

$$x_{ij} \geq 0 \quad ; i = 1,2,\cdots\cdots, m\ , j = 1,2,\cdots\cdots, n$$

3.2 *Example*

Let us assume that we want to exploit four agricultural areas A_1, A_2, A_3, A_4, and the area of each of them, respectively, is 60,150,20,10, by planting them with the following crops: wheat, barley, cotton, tobacco, and beet, from which we need the following: 800, 200,600,1000,2500 Let us assume that the regions' productivity of these crops and their prices are given in Table 2.

Table 2. Example data.

Regions / Crops	A_1	A_2	A_3	A_4	The order	Price per ton
wheat	{4,6}	*4*	3	*6*	*2500*	{1400,1600}
barley	7	*5*	*4*	{3,5}	*1000*	{900,1100}
cotton	*4*	{9,11 }	*8*	*5*	*600*	{4500,6000}
tobacco	6	{2,4}	*0*	*0*	*200*	{4000,5000}
beet	*3*	{10,14}	*10*	6	*800*	{400,700}
Space	*60*	*150*	*20*	*10*		

- Required:

Formulate the mathematical model for this issue so that the production value is as large as possible. To formulate the mathematical model, we extract the following linear conditions:

- Space restrictions

$$x_{11} + x_{21} + x_{31} + x_{41} + x_{51} = 60$$
$$x_{12} + x_{22} + x_{32} + x_{42} + x_{52} = 150$$
$$x_{13} + x_{23} + x_{33} + x_{43} + x_{53} = 20$$
$$x_{14} + x_{24} + x_{34} + x_{44} + x_{54} = 10$$

- Order restrictions

$$\{4,6\}x_{11} + 4x_{12} + 3x_{13} + 6x_{14} \geq 2500$$
$$7x_{21} + 5x_{22} + 4x_{23} + \{3,5\}x_{24} \geq 1000$$
$$4x_{31} + \{9,11\}x_{32} + 8x_{33} + 5x_{34} \geq 600$$
$$6x_{41} + \{2,4\}x_{42} + 0x_{43} + 0x_{44} \geq 200$$
$$3x_{51} + \{10,14\}x_{52} + 10x_{53} + 6x_{54} \geq 800$$

- Non-Negative restrictions

$$x_{ij} \geq 0 \;\; ; i = 1,2,3,4,5 \quad \text{and} \quad j = 1,2,3,4$$

- Objective function that express the value of production is:

$$\begin{aligned} Z = \; & \{1400,1600\}(\{4,6\}x_{11} + 4x_{12} + 3x_{13} + 6x_{14}) \\ & + \{900,1100\}(7x_{21} + 5x_{22} + 4x_{23} + \{3,5\}x_{24}) \\ & + \{4500,6000\}(4x_{31} + \{9,11\}x_{32} + 8x_{33} + 5x_{34}) \\ & + \{4000,5000\}(6x_{41} + \{2,4\}x_{42} + 0x_{43} + 0x_{44}) + \{400,700\}(3x_{51} \\ & + \{10,14\}x_{52} + 10x_{53} + 6x_{54}) \rightarrow \text{Max} \end{aligned}$$

- Mathematical model:
  - Find the maximum value of

$$\begin{aligned} Z = \; & \{1400,1600\}(\{4,6\}x_{11} + 4x_{12} + 3x_{13} + 6x_{14}) \\ & + \{900,1100\}(7x_{21} + 5x_{22} + 4x_{23} + \{3,5\}x_{24}) \\ & + \{4500,6000\}(4x_{31} + \{9,11\}x_{32} + 8x_{33} + 5x_{34}) \\ & + \{4000,5000\}(6x_{41} + \{2,4\}x_{42} + 0x_{43} + 0x_{44}) + \{400,700\}(3x_{51} \\ & + \{10,14\}x_{52} + 10x_{53} + 6x_{54}) \rightarrow \text{Max} \end{aligned}$$

  - Within restrictions:

$$x_{11} + x_{21} + x_{31} + x_{41} + x_{51} = 60$$
$$x_{12} + x_{22} + x_{32} + x_{42} + x_{52} = 150$$
$$x_{13} + x_{23} + x_{33} + x_{43} + x_{53} = 20$$
$$x_{14} + x_{24} + x_{34} + x_{44} + x_{54} = 10$$
$$\{4,6\}x_{11} + 4x_{12} + 3x_{13} + 6x_{14} \geq 2500$$
$$7x_{21} + 5x_{22} + 4x_{23} + \{3,5\}x_{24} \geq 1000$$
$$4x_{31} + \{9,11\}x_{32} + 8x_{33} + 5x_{34} \geq 600$$
$$6x_{41} + \{2,4\}x_{42} + 0x_{43} + 0x_{44} \geq 200$$
$$3x_{51} + \{10,14\}x_{52} + 10x_{53} + 6x_{54} \geq 800$$
$$x_{ij} \geq 0 \;\; ; i = 1,2,3,4,5 \quad \text{and} \quad j = 1,2,3,4$$

  - It is a linear model; we use the simplex method to obtain an optimal solution.

4. Conclusions

In this study, the authors presented a new formulation of the model for optimal use of agricultural land using the concepts of neutrosophic science, where we took data that are affected by the surrounding conditions. Neutrosophic values take into account fluctuations in ambient conditions, from natural factors that can affect crop yields to price fluctuations that can affect profit. We obtained a linear neutrosophic mathematical model that can be solved using the simplex neutrosophic method that was presented in previous research. Then, the optimal solution is the values of the variables that express the areas that can be allocated in each of the regions for each crop.

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Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that there is no conflict of interest in the research.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

References

1. Alali. Ibrahim Muhammad, Operations Research. Tishreen University Publications, 2004. (Arabic version).
2. Linear and Nonlinear Programming-DavidG. Luenbrgrr. YinyuYe- Springer Science + Business Media-2015.
3. Maissam Jdid Operations Research, Faculty of Informatics Engineering, Al-Sham Private University Publications, 2021
4. Florentin Smarandache, Maissam Jdid, On Overview of Neutrosophic and Plithogenic Theories and Applications, Applied Mathematics and Data Analysis, Vo .2,No .1, 2023
5. Maissam jdid ,Important Neutrosophic Economic Indicators of the Static Model of Inventory Management without Deficit, Journal of Neutrosophic and Fuzzy Systems (JNFS),Vo .5,No .1, 2023
6. Mohammed Alshikho, Maissam Jdid, Said Broumi, Artificial Intelligence and Neutrosophic Machine learning in the Diagnosis and Detection of COVID 19, Journal Prospects for Applied Mathematics and Data Analysis ,Vol 01, No,02 USA,2023
7. Mohammed Alshikho, Maissam Jdid, Said Broumi ,A Study of a Support Vector Machine Algorithm with an Orthogonal Legendre Kernel According to Neutrosophic logic and Inverse Lagrangian Interpolation, , Journal of Neutrosophic and Fuzzy Systems(JNFS),Vo .5,No .1, 2023
8. Maissam Jdid, Khalifa Alshaqsi, Optimal Value of the Service Rate in the Unlimited Model $M\backslash M\backslash 1$, Journal of Neutrosophic and Fuzzy Systems(JNFS),Vo .6,No .1, 2023
9. Maissam Jdid, Florentin Smarandache, The Use of Neutrosophic Methods of Operation Research in the Management of Corporate Work, , Journal of Neutrosophic Systems with Applications, Vol. 3, 2023
10. Maissam Jdid, Florentin Smarandache , Said Broumi, Inspection Assignment Form for Product Quality Control, Journal of Neutrosophic Systems with Applications, Vol. 1, 2023
11. Maissam Jdid, Neutrosophic Mathematical Model of Product Mixture Problem Using Binary Integer Mutant, Journal of Neutrosophic and Fuzzy Systems(JNFS),Vo .6,No .2, 2023
12. Maissam Jdid, Neutrosophic Nonlinear Models, Journal Prospects for Applied Mathematics and Data Analysis, Vo .2,No .1, 2023
13. Maissam Jdid , Florentin Smarandache, Lagrange Multipliers and Neutrosophic Nonlinear Programming Problems Constrained by Equality Constraints, Journal of Neutrosophic Systems with Applications, Vol. 6, 2023

14. Maissam Jdid, Said Broumi, Neutrosophic Rejection and Acceptance Method for the Generation of Random Variables, Neutrosophic Sets and Systems, NSS, Vol.56, 2023.
15. Maissam Jdid, Florentin Smarandache, Optimal Neutrosophic Assignment and the Hungarian Method, Neutrosophic Sets and Systems, NSS, Vol.57, 2023.
16. Sudeep Dey, Gautam Chandra Ray, Separation Axioms in Neutrosophic Topological Spaces, Neutrosophic Systems with Applications, vol.2, (2023): pp. 38–54. https://doi.org/10.61356/j.nswa.2023.9.
17. Ahmed Sleem, Nehal Mostafa, Ibrahim Elhenawy, Neutrosophic CRITIC MCDM Methodology for Ranking Factors and Needs of Customers in Product's Target Demographic in Virtual Reality Metaverse, Neutrosophic Systems with Applications, vol.2, (2023): pp. 55–65. https://doi.org/10.61356/j.nswa.2023.10.
18. Ibrahim M. Hezam, An Intelligent Decision Support Model for Optimal Selection of Machine Tool under Uncertainty: Recent Trends, Neutrosophic Systems with Applications, vol.3, (2023): pp. 35–44. https://doi.org/10.61356/j.nswa.2023.12.
19. Maissam jdid- Hla Hasan, The state of Risk and Optimum Decision According to Neutrosophic Rules, International Journal of Neutrosophic Science (IJNS), Vol. 20, No. 1, 2023
20. Maissam Jdid, Huda E Khalid, Mysterious Neutrosophic Linear Models, International Journal of Neutrosophic Science, Vol.18, No. 2, 2022
21. Maissam Jdid, AA Salama, Huda E Khalid, Neutrosophic Handling of the Simplex Direct Algorithm to Define the Optimal Solution in Linear Programming, International Journal of Neutrosophic Science, Vol.18, No. 1, 2022
22. Maissam Jdid, The Use of Neutrosophic linear Programming Method in the Field of Education, Handbook of Research on the Applications of Neutrosophic Sets Theory and Their Extensions in Education, Chapter 15, IGI-Global, 2023.

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