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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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A Hybrid MCDM Approach for Industrial Robots Selection for the Automotive Industry

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Abstract: The use of robots in various stages of the production process is now commonplace across practically all sectors of the economy. Additionally, even for present-day small and medium-sized businesses, this has developed into a very powerful need in recent years and continues to grow in importance. The selection of an industrial robot is a very complicated decision-making issue due to the fact that there are numerous aspects and criteria that are in conflict with one another, as almost all of the earlier research emphasized. In addition, the many sophisticated requirements that have been added to these robots by the makers of robotics have led the level of complexity to expand even further. As a result, decision-makers are faced with increasingly complex decision-making difficulties that are influenced by a great deal of uncertainty. As a result of this, a combined neutrosophic multi-criteria decision-making (MCDM) approach may assist in resolving a significant number of the ambiguities that are suggested in the present article. Initially, the Entropy method was used to evaluate the criteria set for the study under the neutrosophic environment. Then, the Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA) method was used to evaluate and rank five robots used in the automotive industry. The results indicate that the criteria of performance and working accuracy are the most influential criteria in choosing the most appropriate robot. Also, the results indicate that the KAWASAKI robot is the best choice in the manufacturing process for the automotive industry.

Keywords: Industrial Robots; Automotive Industry; MCDM; Entropy Method; MOORA Method.

1. Introduction

The incorporation of robotics into manufacturing operations was once a concept of recent times, but it has now emerged as a primary objective for nearly all sectors within the manufacturing industry. Based on a report published by Fortune Insight, the global industrial robotic market was valued at USD 21.83 billion in 2019 [1]. Projections from Fortune Business Insight anticipate that this market will reach USD 66.48 billion, while GM Sight estimates a value of USD 80 billion by the year 2027. Currently, the utilization of robotics has achieved extensive adoption across various sectors including food and beverage processing, mining, construction, and the pharmaceutical industry. However, statistical data indicates that the automotive industry continues to be the leading consumer industry, accounting for 28% of the overall installations [2]. This is followed by the electrical/electronics sector with 24% of installations, while the metal and machinery sector accounts for 12%, the plastics and chemical products sector for 5%, and the food and beverages sector for 3%.

Based on the 2016 reports released by the Organisation for Economic Co-operation and Development (OECD), the global sales of industrial robots surpassed 290,000 units. Projections indicate a significant growth trajectory, with an anticipated surge to approximately 1.4 million units within the forthcoming three-year period [3]. Advancements in this particular domain are characterized by their allure, as evidenced by the remarkable achievement of surpassing projected figures in 2019, with a total of 2,722,000 industrial robotics units being sold and installed. According to the International Federation of Robotics, the sales of industrial robotics have reached a total of 2,722,077 units from 2010 to the present. Moreover, it has been estimated by international corporations engaged in market analysis of industrial robotics that these upward trends are projected to persist within a range of 3.5% to 5.5% over the course of the subsequent five years [4]. Based on the aforementioned rates, it is anticipated that the global installation of industrial robotics will attain a substantial figure ranging from 3,584,000 to 4,177,000 units by the year 2027. The current state of the robotic industry is characterized by a significant and swift expansion. Manufacturers actively monitor technological advancements and incorporate novel capabilities, capacities, and functionalities into their products.

Moreover, it is evident that the demands of various industries are undergoing rapid and dynamic transformations in the current era. Hence, the proliferation of robots, accompanied by an expanding range of applications and an increasing variety of types and models, can be regarded as a significant contributing factor [5]. Hence, the task of choosing suitable industrial robotics is a complex and time-consuming endeavour for decision-makers. The presence of numerous conflicting factors within the assessment process contributes to the heightened level of complexity.

The selection of industrial robotics is therefore a highly complex decision-making problem that is quite affected by uncertainties, and it is required to use a powerful and applicable tool that can enable to deal with uncertainties in order to optimally solve these kinds of problems [6]. According to almost all of the earlier works that already exist in the literature, the following statement is true: the selection of industrial robotics is a problem that involves decision-making, and it is highly affected by uncertainties. Due to the fact that these research overlooked uncertainties, the contributions of these earlier studies utilizing objective multi-criteria decision-making (MCDM) approaches are, regrettably, restricted, and their usefulness for finding a solution to a decision-making issue faced in real life is likewise minimal.

Practically all of the earlier publications that have been published in the field of robotics research have neglected to take into account the unique requirements and demands of various sectors with regard to robotics systems [7]. Because the needs of each sector are changeable and unique, a robotic system that is very helpful and effective in one industry may not be suitable for use in other industries. For example, robots that are used in the food processing business are incompatible with those that are used in the vehicle manufacturing industry. The majority of the publications that came before this one chose to overlook this circumstance, which caused bottlenecks in the evaluation process meant to tackle these decision-making issues. In addition, the weights of criteria, choices, and alternatives might shift depending on the industry, since different businesses have distinct requirements and demands for robot selection. As a result, it's possible that a comprehensive analysis of industrial robots systems across all sectors won't be very useful. The purpose of this article is to give academics and practitioners who are responsible for making choices on robot selection with an applicable and realistic model that focuses on industrial robot selection by addressing the needs and requirements of the automobile manufacturing sector specifically. This study deals only with the needs and requirements of the automotive manufacturing industry.

Previous research has examined the selection of robots and has put forth a range of fuzzy techniques in order to mitigate the effects of uncertainties. Nevertheless, a majority of individuals overlooked precise quantitative data pertaining to the various options based on the established criteria. Instead, they relied on the belief that the linguistic evaluations conducted by decision-makers alone would be adequate in resolving the challenges associated with selecting a robot. The aforementioned approaches exhibit a state of misguided perception, and it is evident that decision-makers lacking adequate information cannot attain optimality. It is anticipated that enhancing the level of information possessed by decision-makers will lead to an improvement in the accuracy of their decision-making.

Subsequently, decision-makers were instructed to compile a comprehensive inventory of criteria and decision alternatives. Once these inventories were gathered, researchers proceeded to eliminate redundant criteria and options, resulting in the identification of the ultimate selection criteria and decision alternatives. This process engendered unanimous agreement among the panel of experts. Subsequently, linguistic evaluations were conducted by decision-makers for both the criteria and decision alternatives. The hybrid approach based on the neutrosophic (Entropy method) and the neutrosophic Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA) method was employed to evaluate the chosen criteria for the ultimate decision substitute chosen in the automobile field.

2. Criteria

In this section, a brief description of the criteria used in the study for the selection of industrial robots for the automotive industry is presented. The main criteria used are performance, flexibility, purchase cost, maintenance cost, working accuracy, warranty period, load capacity, and energy consumption. Figure 1 presents the criteria used in the study. Also, Table 1 presents the information of the experts involved in the study and in the selection of criteria used.

Table 1. Information about experts.

Expert	Experience	Institute	Graduation degree	Duty
$Expert_1$	17	Automotive	Int. Trade and Logistics Man.	Supply chain
$Expert_2$	13	Ecoplas	English Business Adm. And Man.	Logistics Engineer
$Expert_3$	12	Pisma industry	Chemical Eng.	Executive
$Expert_4$	24	Eurotec	Industrial Eng.	Production Engineer

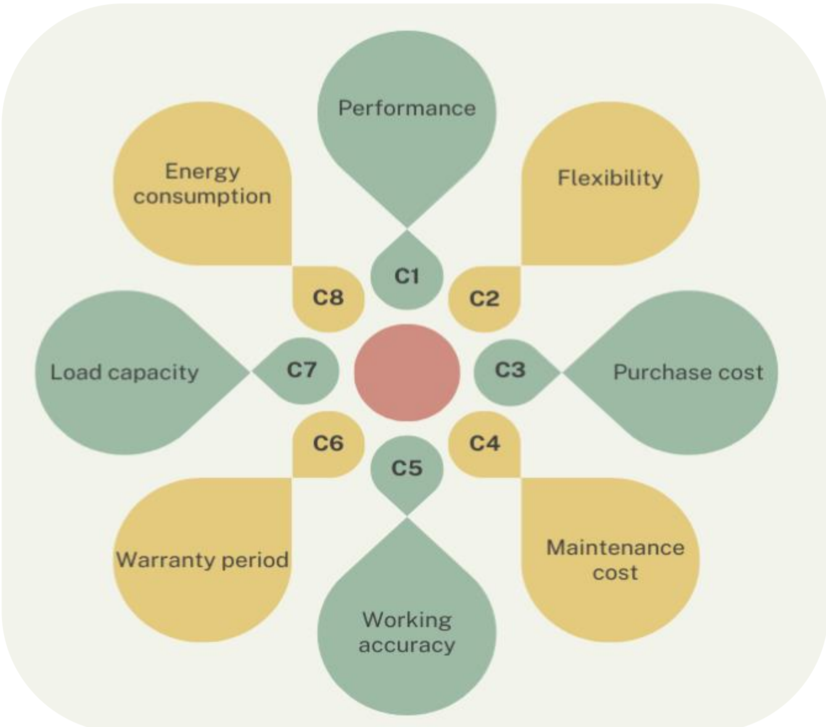

Figure 1. Criteria used in the research work.

2.1 Performance (C_1)

The comprehensive operational parameters of the robot, encompassing its precision, manipulability, dexterity, and other relevant factors, constitute significant criteria for deliberation in the process of selecting robotics systems.

2.2 Flexibility (C_2)

The versatility of a robot is essential to understanding how it will function on a manufacturing line. An industrial robot has the ability to bend and stretch in ways that are impossible for humans to replicate. Therefore, it is possible to characterise it as being flexible in the sense that it can execute a variety of applications.

2.3 Purchase cost (C_3)

The process encompasses the expenses associated with acquiring, implementing, and providing instruction on a particular product or service. Furthermore, the criteria employed in literature, encompassing various definitions such as purchase cost, purchasing cost, and investment cost, were consolidated.

2.4 Maintenance cost (C_4)

Consists of the necessary financial outlay required to carry out operations such as maintenance and repair.

2.5 Working accuracy (C_5)

The accuracy of the robot's position inside a certain workspace may be defined as the greatest inaccuracy that can be assembled from various locations that are evenly dispersed throughout the set workspace or reference frame.

2.6 Warranty period (C_6)

The warranty period refers to a designated timeframe during which the manufacturer guarantees free repair and adjustment services for industrial robots in the event of a malfunction that arises from regular use and adherence to the provided instruction manuals.

2.7 Load capacity (C_7)

The weight that a robot is able to lift is referred to as its load capacity or payload. The weight of the product being selected as well as the weight of the end-of-arm tooling are both included into the payload. Because of its large loading capacity, it may thus give a high operating volume in a production facility. This volume is dependent on the facility.

2.8 Energy consumption (C_8)

The measurement of energy consumed by robots during a specific working hour is a significant determinant in assessing the financial implications associated with the utilisation of robots.

After that, several linguistic terms and their corresponding triangular neutrosophic numbers (TNNs) were identified, to be used in evaluating the criteria and target alternatives in the study, as shown in Table 2.

Table 2. Linguistic terms and their equivalent TNNs for evaluating criteria and alternatives.

Linguistic terms	Abbreviations	TNNs
Fully Low Value	FLV	$\langle(0.1, 0.2, 0.3); 0.4, 0.1, 0.3\rangle$
Very Low Value	VLV	$\langle(0.2, 0.3, 0.4); 0.5, 0.1, 0.3\rangle$
Low Value	LOV	$\langle(0.3, 0.4, 0.5); 0.6, 0.2, 0.1\rangle$
Modest Low Value	MLV	$\langle(0.4, 0.5, 0.6); 0.7, 0.3, 0.2\rangle$
Roughly Value	ROV	$\langle(0.5, 0.6, 0.7); 0.8, 0.3, 0.3\rangle$
Modest High Value	MHV	$\langle(0.6, 0.7, 0.8); 0.9, 0.4, 0.4\rangle$
High Value	HVV	$\langle(0.7, 0.8, 0.9); 1.0, 0.3, 0.5\rangle$
Very High Value	VHV	$\langle(0.8, 0.9, 1.0); 1.0, 0.2, 0.3\rangle$
Fully High Value	FHV	$\langle(0.9, 1.0, 1.0); 1.0, 0.2, 0.2\rangle$

3. Materials and Methods

In this section, the proposed Entropy-MOORA methodology is presented to solve the problem of selecting the most efficient robot in the automotive industry. Figure 2 introduce the Illustration of the proposed approach.

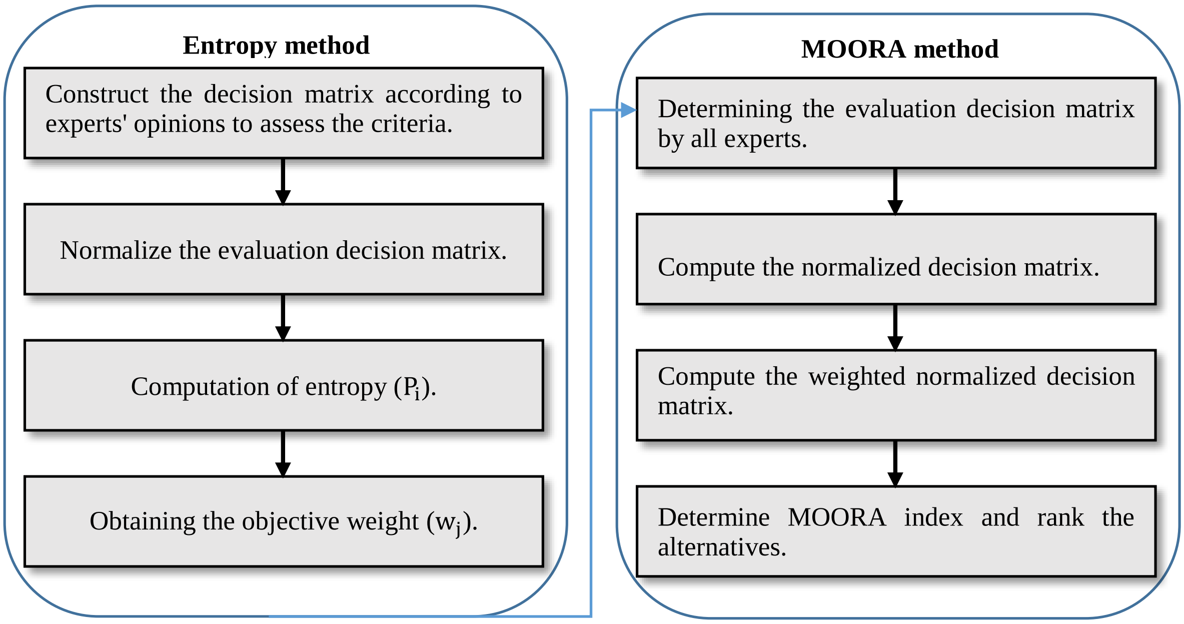

Figure 2. Illustration of the proposed approach.

Step 1: The set $A_i = \{A_1, A_2, \dots, A_m\}$ having i = 1, 2... m alternatives, is measured by n decision criterion of $C_j = \{C_1, C_2, \dots, C_n\}$, with j = 1, 2, ..., n. Let $w = (w_1, w_2, \dots, w_n)$ be the vector set utilized for determining the criteria weights, $w_j > 0$ and $\sum_{j=1}^{n} w_j = 1$.

Step 2: Create the assessment matrix rendering to experts' preferences to measure the main criteria by each expert by using linguistic terms in Table 2.

Step 3: Convert the TNNs to crisp values by applying the score function according to Eq. (1).

$$S(\tilde{x}_{ij}) = \frac{1}{8}(l + m + u) \times (2 + \alpha_{\tilde{x}} - \theta_{\tilde{x}} - \beta_{\tilde{x}}) \quad (1)$$

Step 4: Compute the normalized matrix according to Eq. (2).

$$r_{ij} = \frac{x_j}{\sum_{i=1}^{n} x_{ij}} \quad (2)$$

Step 5: Determinations of valuation aspects weights. The entropy value P_j can be measured for each aspect according to Eq. (3).

$$P_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} r_{ij} \ln(r_{ij}) \quad (3)$$

Step 6: Calculating the diversity degree. The degree of information diversity implicated by every aspect should be calculated according to Eq. (4).

$$d_j = 1- P_j \quad (4)$$

Step 7: Calculate the weight for each criterion according to Eq. (5).

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad (5)$$

Step 8: Build the evaluation decision matrix by all experts between the determined criteria and the available alternatives, as presented in Table 2. Then, convert the TNNs to crisp values by applying the score function according to Eq. (1).

Step 9: Compute the normalized decision matrix between the determined criteria and the available alternatives according to Eq. (6).

$$y_{ij}^* = \frac{y_{ij}}{\sqrt{\sum_{i=1}^{m} y_{ij}^2}} \text{, i = 1, 2,...,m; j = 1, 2, ...,n.} \quad (6)$$

Step 10: Compute the weighted normalized decision matrix according to Eq. (7).

$$u_{ij} = w_j \times y_{ij} \quad (7)$$

Step 11: Compute the normalized assessment value of each alternative according to Eq. (8). Then, rank the alternatives based on the descending value of T_i.

$$T_i = \sum_{j=1}^{l} u_{ij} - \sum_{j=l+1}^{g} u_{ij} \quad (8)$$

4. Application

4.1 Case Study

As a case study, the automobile manufacturing business was chosen, and with the assistance of the recommended hybrid neutrosophic method, industrial robotic selection procedures in this industry were investigated. The automobile manufacturing sector has been using robots as part of its manufacturing systems and in a variety of production processes for more than sixty years at this point. In the production of autos, a great deal of labour-intensive work is amenable to being automated and performed by robots. Welding, assembling, painting, sealing, coating, material removal, inspection, maintenance, machine tending, internal logistics, and other shop floor job needs are some of the tasks that are performed by the robots. One of the most important industries that makes use of industrial robots nowadays is the automotive sector, which produces automobiles. Because of recent advancements in robotic technology, the use of industrial robots in assembly lines has been boosted, and automakers now have the ability to investigate the use of industrial robots in various manufacturing and production lines. Because each car has a large number of wires, components, and other parts, it is difficult to properly route auto parts to their intended locations.

These industrial robots are necessary for both an efficient production system and an automated global supply chain in order to achieve optimal results. As a result, the process of selecting and assessing the capabilities of industrial robots is essential for automotive manufacturers. An intelligent decision support system was presented in this study for the purpose of choosing and assessing the appropriate industrial robot for use in the automobile sector. The robots used in manufacturing cars that will be evaluated in the study are KAWASAKI (A_1), OMRON (A_2), KUKA (A_3), NACHI (A_4), and FANUC (A_5).

4.2 Implementation of the proposed approach

In this part, the steps of the proposed Entropy-MOORA approach are applied under neutrosophic environment to solve the problem of selecting the most efficient robot in the automotive industry.

Step 1: The assessment matrix rendering to experts' preferences to measure the main criteria by each expert by using linguistic terms provided in Table 2, was created, as presented in Table 3. Then, the TNNs was converted to crisp values by applying the score function according to Eq. (1).

Step 2: The normalized matrix was computed according to Eq. (2), as presented in Table 4.

Step 3: The weight for each criterion was obtained according to Eq. (5), as presented in Table 5 and shown in Figure 3.

Table 3. Assessment of the determined criteria using linguistic terms by all experts.

Experts	Criteria							
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
$Expert_1$	VLV	MHV	HVV	ROV	FLV	HVV	ROV	MHV
$Expert_2$	LOV	MHV	VLV	MHV	ROV	HVV	ROV	VHV
$Expert_3$	LOV	MLV	VHV	FHV	MHV	ROV	VLV	VHV
$Expert_4$	FHV	MLV	VHV	FHV	FHV	FHV	VLV	VHV

Table 4. The normalized evaluation matrix of the determined criteria.

Experts	Criteria							
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
$Expert_1$	0.128	0.286	0.256	0.171	0.070	0.239	0.338	0.179
$Expert_2$	0.186	0.286	0.093	0.188	0.234	0.239	0.338	0.274
$Expert_3$	0.186	0.214	0.326	0.321	0.257	0.181	0.162	0.274
$Expert_4$	0.500	0.214	0.326	0.321	0.439	0.341	0.162	0.274

Table 5. The entropy measure and objective weight of the identified criteria.

Experts	Criteria							
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
$Expert_1$	-0.263	-0.358	-0.349	-0.302	-0.186	-0.342	-0.367	-0.308
$Expert_2$	-0.313	-0.358	-0.221	-0.314	-0.340	-0.342	-0.367	-0.355
$Expert_3$	-0.313	-0.330	-0.365	-0.365	-0.349	-0.309	-0.295	-0.355

Expert_4	-0.347	-0.330	-0.365	-0.365	-0.361	-0.367	-0.295	-0.355
P_j	0.891	0.992	0.938	0.970	0.892	0.981	0.955	0.990
$1\text{-}P_j$	0.109	0.008	0.062	0.030	0.108	0.019	0.045	0.010
w_j	0.279	0.020	0.159	0.076	0.276	0.047	0.116	0.027

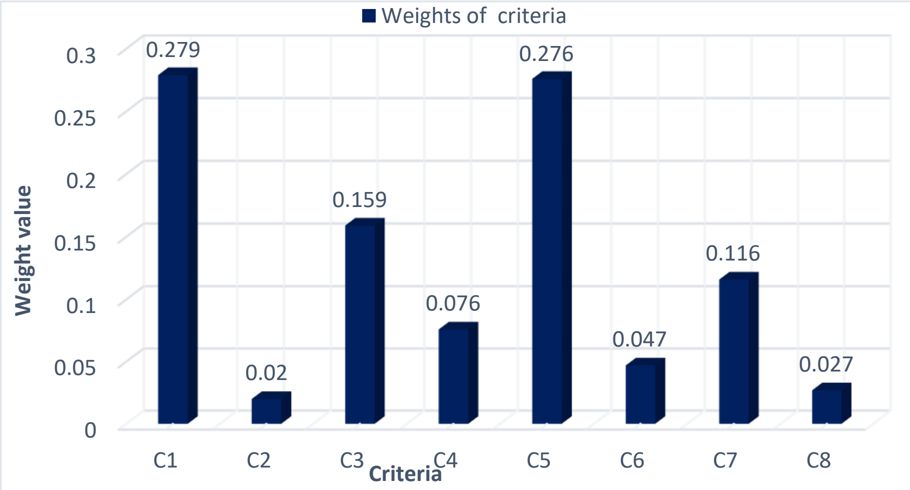

Figure 3. Final weights of the selected criteria using Entropy method.

Step 4: The evaluation decision matrix was constructed by all experts between the determined criteria and the five industrial robots, as presented in Table 6.

Step 5: The normalized decision matrix was computed according to Eq. (6), as presented in Table 7.

Step 6: The weighted normalized decision matrix was calculated according to Eq. (7), as presented in Table 8.

Step 7: The five robots were ranked based on the descending value of T_i, which was computed according to Eq. (8), as presented in Table 9 and Figure 8.

Table 6. Evaluation matrix of five robots regarding all criteria by using linguistic terms.

Experts	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
A_1	VHV	FLV	VHV	FHV	HVV	FHV	MHV	VHV
A_2	MHV	ROV	HVV	ROV	MHV	FLV	FHV	MLV
A_3	FLV	MHV	MLV	MHV	HVV	HVV	HVV	MHV
A_4	LOV	MHV	ROV	ROV	MHV	VHV	MHV	FLV
A_5	FHV	VHV	ROV	HVV	HVV	FHV	HVV	MLV

Table 7. Normalized matrix of five robots regarding all criteria by using linguistic terms.

Experts	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
A_1	0.590	0.119	0.628	0.588	0.477	0.549	0.358	0.719
A_2	0.385	0.393	0.491	0.309	0.398	0.087	0.613	0.351
A_3	0.105	0.438	0.307	0.344	0.477	0.384	0.429	0.469
A_4	0.241	0.438	0.368	0.309	0.398	0.492	0.358	0.128
A_5	0.659	0.670	0.368	0.588	0.477	0.549	0.429	0.351

Table 8. Weighted normalized matrix of five robots regarding all criteria by using linguistic terms.

Experts	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
A_1	0.165	0.002	0.100	0.045	0.132	0.026	0.042	0.019
A_2	0.108	0.008	0.078	0.023	0.110	0.004	0.071	0.009
A_3	0.029	0.009	0.049	0.026	0.132	0.018	0.050	0.013
A_4	0.067	0.009	0.059	0.023	0.110	0.023	0.042	0.003
A_5	0.184	0.013	0.059	0.045	0.132	0.026	0.050	0.009

Table 9. Final ranking of five industrial robots.

Robots	T_i	Rank
A_1	0.530	1
A_2	0.412	3
A_3	0.325	5
A_4	0.336	4
A_5	0.517	2

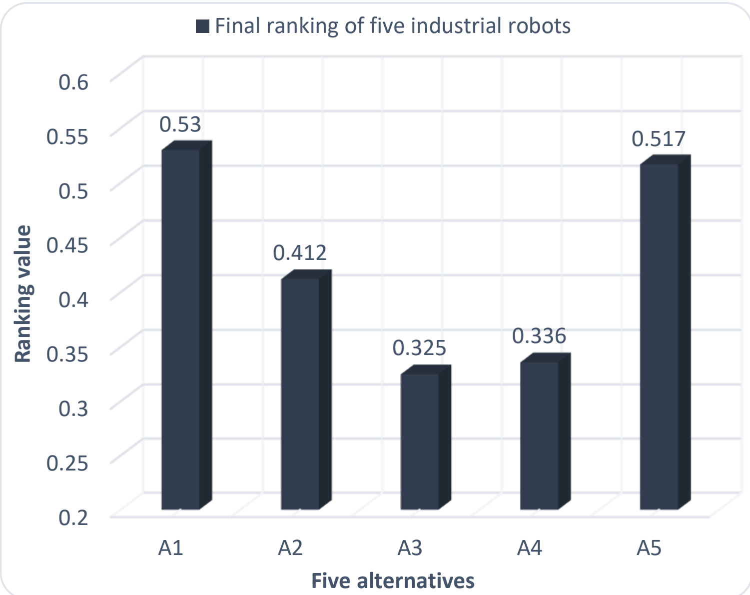

Figure 4. Final ranking of five industrial robots.

4.3 Discussion

In this part, the results obtained from applying the proposed Entropy-MOORA methodology to solve the problem of selecting an optimal robot in the automotive industry are discussed.

Initially, eight criteria were evaluated using the Entropy method under the neutrosophic environment. The results indicate that the performance criterion is the most important with a weight of 0.279, followed by the working accuracy criterion, while the flexibility criterion is the least important with a weight of 0.020.

Then, five robots used in the automotive industry were evaluated using the MOORA method. The results indicate that the KAWASAKI robot is the best robot out of the five used in the study.

5. Conclusion

As a result of recent technical advancements, the meteoric rise of artificial intelligence, and the progression of flexible industrial systems, the adoption of robots in the automobile manufacturing sector has experienced an enormous increase in their use in a variety of different operating mechanisms. Without the need for human intervention, these specially programmed robots in the automobile manufacturing industry are able to do a wide variety of dangerous and laborious activities while maintaining high standards of quality and output. Utilizing robots technology in the production phase of an industrial process leads to an increase in the overall effectiveness of the manufacturing process. The selection of the proper industrial robot may be challenging due to the ongoing development of robotic technology, the introduction of unique features, and the incorporation of the individual needs of the automobile sector into the robot. In the context of the automobile sector, this research developed a robot selection procedure that was adaptable, resilient, and intelligent.

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.

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Neutrosophic MARCOS in Decision Making on Smart Manufacturing System

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Abstract: Business firms prefer software-based smart manufacturing systems to monitor and supervise all production activities in a decentralized manner. The choice of software decides the degree of manufacturing robustness. This paper proposes a neutrosophic-based MARCOS (Measurement of Alternatives and Ranking according to COmpromise Solution) method of MCDM with single-valued triangular neutrosophic numbers to solve the software selection problem. The proposed neutrosophic method is applied to hypothetical data to test the efficacy of the method. The results obtained using the proposed method are compared with crisp, fuzzy, and intuitionistic data representations, and suitable inferences are acquired. The proposed method has several industrial implications and it has several scope of applying to other decision-making scenarios with real data sets.

Keywords: Neutrosophic MCDM; MARCOS; Software; Smart Manufacturing.

1. Introduction

The manufacturing system concerned with any business is twined with the complexities of planning, managing, executing, reviewing and redoing. The traditional system of governing the manufacturing process is manual based and presently it is getting replaced with digital channels of administration in this contemporary era. The business firms are embracing different technologies to govern their production activities. Software based system of managing the process of manufacturing is the highlight of smart manufacturing systems. The choice making of the software is based on several deciding factors. This decision making problem based on several criteria shall be solved using the techniques of decision making.

Decision making is a process encompassing different decision making units of alternatives and criteria. The multi criteria decision making methods are generally applied both to determine the criterion weights and to rank the alternatives. The MCDM methods are broadly classified based on the number of alternatives, data types, hybrid nature and analysis. The two classifications based on the number of alternatives are multi-purpose and multi – qualified. The MCDM methods that fall under the multi-purpose category are vector optimization, goal programming, fuzzy based programming, dynamic programming, multi-stage programming, De nova programming and data envelopment analysis. The methods belonging to the multi-qualified category are AHP, ANP, TOPSIS, ELECTRE, PROMTHEE, DEMATEL. The three classifications of MCDM methods based on data types are Elementary, Unique synthesis criterion and outranking. This classification is also referred to as simple, original and distinguished methods. Hybrid MCDM methods evolve by combining several MCDM methods and using different combinations of deterministic and fuzzy representations. Analysis based type of classification groups the MCDM methods into three categories of basic methods, single analytical and hybrid methods. The number of MCDM methods are ample and hence the decision makers must make a right choice of the methods suiting to the decision making circumstances.

The objective of every decision making method is to derive an optimal ranking solution. The decision making data may not be deterministic in nature at all instances. The imprecise data are handled using fuzzy sets developed by Zadeh [1]. Atanassov [2] extended the fuzzy sets to intuitionistic sets encompassing both membership and non-membership values. Smarandache [3] developed neutrosophic theory, a comprehensive extension of both fuzzy and intuitionistic sets. Neutrosophic sets consist of three values of truth, indeterminate and falsity. The theory of neutrosophy is widely integrated with MCDM methods and is applied in different decision making fields such as engineering, supply chain, finance, supplier selection, agriculture and many others. Researchers have referred to Neutrosophic based MCDM as the best choice to handle complicated situations. As neutrosophic sets are more inclusive in nature, the constraints of data handling shall be easily tackled with time and energy efficiency. However this research work throws light on the applications of neutrosophic based MCDM in the areas of smart manufacturing. As the traditional systems are in a transitional state towards a new kind of technology oriented system, the business managers are forced to a crucial stage of making decisions on digital augmentation of production blocks. The business firms are also equally loaded with the pressures of switching to a new system of management. This baffling scenario certainly requires the intervention of decision making theory to set things upright. In align to the aforementioned, this paper intends to address the following queries:

i. Do manufacturing sectors need MCDM method to make their production system smart?
ii. How MCDM methods shall assist the decision makers in choice making?
iii. How will the neutrosophic based MARCOS MCDM be effective in decision making in comparison to other data set representations?

In response to the research queries stated, the contributions in this paper are as follows:

- This research work focuses on a more intricate kind of decision making problem of software selection for a smart manufacturing system.
- Resolves the decision making problem using the method of MARCOS with a single valued triangular neutrosophic number.
- Compares the competency of the proposed moderation of Neutrosophic based MCDM with other earlier models.

The remainder of the paper is organized as follows: section 2 presents the state of art of research works related to MARCOS MCDM under different environments. Section 3 sketches out the preliminaries of single valued triangular fuzzy numbers. Section 4 consists of the steps involved in neutrosophic based MARCOS. Section 4 applies the proposed method to make optimal selection of software in a smart manufacturing system. Section 5 compares the neutrosophic based results with crisp, fuzzy and intuitionistic results. Section 6 briefs the industrial applications, scope and future directions of the research work and the last section concludes the work.

2. Literature Review

This section presents the contributions of the researchers in the arena of decision making with special reference to 90the MCDM method of MARCOS under different environments of crisp, fuzzy, intuitionistic and neutrosophic. Stevic et al [4] developed the method of MARCOS in the year 2020. This new MCDM is applied first in health care industries especially in supplier selection. Researchers

Paradowski et al [5], Ghaleb et al [6] , Wang et al [7] have also compared the efficacy of this method with other MCDM methods and found that the results obtained using the method of MARCOS are more promising. The method of MARCOS is discussed with representations of fuzzy sets, intuitionistic sets and neutrosophic sets. In addition other kinds of extended fuzzy sets are also used in making representations. The applications of MARCOS method discussed under different environments and in various decision making circumstances are presented in the following Table 1.

Table 1. Survey on MARCOS MCDM applications.

Author & Year	Nature of MARCOS Crisp (C)/Fuzzy (F)/Intuitionistic (IF) /Neutrosophic (N)	Integrated MCDM method	Decision Making problem
Stević Ž et al.,(2020) [4]	C	-	Sustainable supplier selection in healthcare industries.
Ulutaş, A et al., (2020) [8]	C	CCSD-ITARA--	Stackers selection in a logistics system.
Stević, Ž., & Brković, N. (2020).[9]	C	FUCOM-	Evaluation of human resources in a transport company
Chakraborty S et al .,(2020) [10]	C	D-MARCOS	Supplier selection in an iron and steel industry
Badi, I., & Pamucar, D. (2020).[11]	C	Grey Analysis	Supplier selection for steelmaking company
Stević, Ž et al., (2020) [12]	C	FUCOM-	Evaluation of road sections in assessment of traffic risk
Karabasevic, D., et al., (2020)[13]	C	CCSD-ITARA--	Stackers Selection in a Logistics System.
Đalić, I et al., (2020)[14]	C	FUCOM	Selection of a distribution channel
Puška A etal., (2020) [15]	C	-	Evaluation software of project management
Ozdagoglu A et al., (2020) [16]	C	COCOSO	Ranking of Turkish universities
Celik, E., & Gul, M. (2021).[17]	C	BWM	Dam construction and safety
Zaher, M., & ElGhitany, N. E. K. (2021).[18]	C	-	Platform selection in IoT healthcare industry
Trung, D. D. (2021).[19]	C	EDAS, , TOPSIS, MOORA and PIV	Milling process
Miškić, S et al.,(2021) [20]	C	SWARA	Inventory classification
Bouraima, M. B et al.(2021) [21]	C	Entropy	Performance of Sub-Saharan African (SSA) railways
Dwivedi, R et al., (2021)[22]	C	CRITIC	Performance of steel industry
Deveci, M et al., (2021)[23]	C	Best-Worst Method	Site selection for Offshore wind farm

Saha, A et al., (2021)[24]	C	FUCOM	Dombi power aggregation
Fan, J et al., (2021)[25]	C	FMEA approach using Best-Worst and MARCOS	Prioritization of failures
AYÇİN, E., & Talip, A. R. S. U. (2021).[26]	C	MEREC	Social Development
Sarja, N. et al., (2021) [27]	C	BWM	Tour Package Recommendation in Bali
Özdağoğlu A et al., (2021)[28]	C	GREY PIPRECIA	Performance evaluation of ground operations agents
Zhang, Z et al., (2022) [29]	C	Bayesian best-worst method	Market-oriented business regulatory risk of power grid enterprises
Memarpour Ghiaci, A et al. (2022)[30]	C	-	Improving emergency departments during COVID-19 pandemic
Nguyen, H. Q (2022)[31]	C	TOPSIS and MAIRCA	PMEDM process
Badi, I., et al., (2022) [32]	C	FUCOM	Measuring sustainability performance indicators
Mitra, A. (2022).[33]	C	-	Cotton fibre selection
Trung, D. D. (2022).[34]	C	-	Development of data normalization
Varghese, B., & Karande, P. (2022).[35]	C	AHP-	Selecting gears and cutting fluids
Kang, D., et al., (2022)[36]	C	-	Determine a used PPE kit disposal.
Hashemkhani Zolfa ni, S., et al., (2022)[37]	C	Bayesian BWM	Determine the optimal lithium battery plant located in South America
Huy, T. Q et al., (2022)[38]	C	-	Selecting the Best Schema of Scissors Mechanism
Dehshiri, S. S. H., & Firoozabadi, B. (2022).[39]	C	-	solar site location for electricity and hydrogen production(southern climate of Iran)
Matić,et al., (2022)[40]	C	IMF D-SWARA—rough -	selection construction machinery for sustainable construction of road infrastructure.
Huy, T. Q et al.,(2022)[41]	C	-	Wire-EDM Process
Karaaslan, A et al., (2022)[42]	C	AHP	Evaluation of renewable energy sources in Turkey
Narkhede, G., & Rajhans, N (2022)[43]	C	-	Efficient and Sustainable Supplier Selection Strategy for SME
Ivanović, B et al., (2022)[44]	C	MEREC-	Selection of truck mixer concrete pump
Iordache, M et al., (2022)[45]	C	Dombi MARCOS	Prioritizing the alternatives of the natural gas grid conversion to hydrogen
Abdullah, A., et al., (2022)[46]	C	FUCOM	Healthcare performance management

Shanmugasundar, G et al., (2022)[47]	C	NSWOA	Optimization of Variable Stiffness Joint in Robot Manipulator
Biswal, S et al., (2023)[48]	C	Taguchi	Electrical discharge machined Al-WC–B4C hybrid composite
SARIGÜL, S. S et al., (2023)[49]	C	MEREC and CoCoSo	Evaluating Airport Service Quality
Liu, Z. (2023).[50]	C	-	Selecting renewable desalination
El-Araby, A. (2023).[51]	C	-	Different Engineering Applications
Toslak, M et al., (2023)[52]	C	PSI-SV	Selection of peanut butter machine
Hosseini Dehshiri, S. S et al., (2023)[53]	C	-	To identify dust storm sources
Bitarafan, M et al.,(2023) [54]	C	Grey BWM-	To identify man-made threats to cities
Son, N. H et al., (2023)[55]	C	DOE	Applications of MCDM
Yadav, A. K., & Kumar, D. (2023).[56]	C	BWM	Sustainable vaccine supply chain
Huskanović, E., et al., (2023)[57]	C	CRITIC	Selection forklift in internal transport technology
SARIGÜL, S. S et al., (2023)[58]	C	CRITIC	Financial Performance Analysis of Airlines Operating in Europe
Badi, I., et al., (2023)[59]	C	BWM-AHP-	Wind farm site selection
Saha, A., et al., (2023)[60]	C	-	Generalized Dombi operator for decision-making
Birkocak, D et al., (2023)[61]	C	-	Sustainability to Determine the Optimum Recycled Fibre-Containing Fabric
Boral S et al.,(2020)[62]	F	fuzzy AHP	Failure mode and effect analysis
Stanković M et al .,(2020)[63]	F	-	Road traffic risk analysis
Mitrović Simić J et al,(2020) [64]	F	CRITIC-Fuzzy FUCOM-DEA	Safety evaluation of road sections
Kovač, Met al., (2021)[65]	F	Spherical fuzzy	Drone-based city logistics concepts
Puška, A et al.,(2021)[66]	F	-	Selection of sustainable suppliers
Bakır, M et al.,(2021)[67]	F	Fuzzy PIPRECIA	Aircraft selection
Kovac, M et al., (2021)[68]	F	Spherical Fuzzy	Drone-Based City Logistics Concepts
Bakır, M., & Atalık, Ö. (2021).[69]	F	Fuzzy AHP	Evaluation of e-service quality in the airline industry
Büyüközkan, G et al., (2021)[70]	F	SWOT based fuzzy AHP	Digital transformation strategy analysis in airline industry
Ali, J. (2021).[71]	F	CRITIC	Score function

Taş, M. A., & Çakır, E. (2021)[72]	F	-	Ranking on Road Risk
Wang, C. N et al., (2022)[73]	F	OPA -	Sustainable supplier selection with technology 4.0 evaluation
Abualkishik, A. Z., et al., (2022)[74]	F	-	Evaluating Smart Agricultural Production
Du, P et al., (2022)[75]	F	Fuzzy best-worst	Regional distribution network outage loss assessment
Khosravi, M et al., (2022)[76]	F	fuzzy FUCOM-	Selecting the most suitable organizational structure for hospitals
Jamalud, D. (2022).[77]	F	DIBR	Selecting a location for a heavy mechanized bridge.
Ayşegül, T. U. Ş., & ADALI, E. A. (2022).[78]	F	SWARA	Green supplier selection
Kılıç, R., et al., (2022)[79]	F	FUCOM	Housing location problem
Rong, Y et al., (2022)[80]	F	-	Evaluation and selecting cold chain logistics distribution center
Ucal Sari, I., & Sargin, S. N. (2022).[81]	F	-	Prioritization of R&D Projects
Simic, V., et al., (2022)[82]	F	Fuzzy ITARA	Locating a disinfection facility for hazardous healthcare waste in the COVID-19
Wu, P et al., (2022)[83]	F	AHP	Green mining strategy selection
Tešić, D et al., (2023)[84]	F	fuzzy LMAW-grey analysis	Selection of a dump truck
Zhao H et al., (2023)[85]	F	Fuzzy-Delphi, AEW, BWM	Evaluation of 31 provincial level regions in China.
Jafarzadeh Ghoushchi, S et al., (2023)[86]	F	SWARA	Road safety assessment and risks prioritization
Wang, W et al., (2023)[87]	F	-	Occupational risk evaluation
Mishra, A. R et al., (2023)[88]	F	-	solving the sustainable circular supplier selection
Tarafdar, A.,(2023)[89]	F	MCGDM	Performance-emission optimization in a single cylinder CI-engine with diesel hydrogen dual fuel:
Görçün, Ö. F., & Doğan, G. (2023).[90]	F	BWM	Mobile crane selection in project logistics
Li, G et al., (2023)[91]	F	-	The supplier performance evaluation of sports event service under COVID-19
Krishankumar, R., et al. (2023)[92]	F	CRITIC	Assessment of Zero-Carbon Measures for Sustainable Transportation in Smart Cities
Chaurasiya, R., & Jain, D. (2021).[93]	IF	Entropy	Advances in Computing and Data Sciences

Ecer, F., & Pamucar, D. (2021).[94]	IF	-	COVID-19 pandemic performance of insurance companies
Salimian, S et al., (2022)[95]	IF	VIKOR -	sustainable supplier selection in organ transplantation networks for healthcare devices
Ecer, F et al., (2022)[96]	IF	EDAS-	Evaluation of cryptocurrencies for investment decisions in the era of Industry 4.0:
Zarhaoui, O., et al.,(2023) [97]	IF	-	Green Supplier Selection Problem
Pamucar, D et al.,(2021)[98]	N	FUCOM	Fuel vehicles for sustainable road transportation of US
Çakır, E et al., (2021)[99]	N	-	Sustainable hybrid electric vehicle
Tang, N et al., (2021)[100]	N	-	English teaching systems
Haq, R. S. U et al. (2022) [101]	N	MEREC	Sustainable material selection
Majumder, P et al., (2023)[102]	N	Best Worst Method	Efficiency analysis of surface water treatment plants
Majumder, P. (2023).[103]	N	FUCOM	Determine the alternatives weight and its applications in efficiency analysis of water treatment plant.

From the above presentation of the survey of MARCOS applications, it is found that the method of MARCOS is discussed under neutrosophic environment and single valued neutrosophic numbers are used in data representations. Also to the best of our knowledge the applications of neutrosophic MARCOS are limited and comparative analysis of neutrosophic MARCOS are not undertaken. This has motivated the authors to explore the method of MARCOS with single valued triangular neutrosophic numbers. In addition to it, the method of MARCOS is not applied to the decision making context of smart manufacturing. Hence this research work applies the method of MARCOS with single valued triangular neutrosophic numbers to the decision making problem of software selection for a smart manufacturing system. Also the results obtained using the proposed method are compared under different cases.

3. Preliminaries

This section presents the basics of neutrosophic set, neutrosophic numbers and operations.

Definition 3.1. Let X be a universal set of discourse. A neutrosophic set A in X is defined by a truth-membership function$T_A(x)$, an indeterminacy-membership function $I_A(x)$ and a falsity-membership function $F_A(x)$, where $T_A(x), I_A(x)\ , F_A(x): X \to [0,1]$ and $T_A(x) + I_A(x) + F_A(x) \leq 3$.

Definition 3.2. Let X be a universal set of discourse. A single valued neutrosophic set A over X is an object having the form A=$\{\langle x, T_A(x), I_A(x), F_A(x)\rangle : x \in X\}$, where $T_A(x), I_A(x)\ , F_A(x): X \to [0,1]$ and $T_A(x) + I_A(x) + F_A(x) \leq 3$.

Definition 3.3. Let $\alpha_{\tilde{a},}\theta_{\tilde{a},}\beta_{\tilde{a},} \in [0,1]$ and $a_1, a_2, a_3 \in R$ such that $a_1 \le a_2 \le a_3$. A single valued triangular neutrosophic number, $\tilde{a} = \langle (a_1, a_{2,} a_3); \alpha_{\tilde{a},}\theta_{\tilde{a},}\beta_{\tilde{a},}\rangle$ is a special neutrosophic set on the real line set R, with truth-membership, indeterminacy-membership and falsity-membership functions are defined as follows:

$$= \begin{cases} \alpha_{\tilde{a}}\left(\dfrac{x - a_1}{a_2 - a_1}\right) & \text{if } a_1 \le x \le a_2 \\ \alpha_{\tilde{a}} & \text{if } x = a_2 \\ \alpha_{\tilde{a}}\left(\dfrac{a_3 - x}{a_3 - a_2}\right) & \text{if } a_2 < x \le a_3 \\ 0 & \text{otherwise} \end{cases}$$

$$I_{\tilde{a}}(x) = \begin{cases} \dfrac{(a_2 - x + \theta_{\tilde{a}}(x - a_1))}{(a_2 - a_1)} & \text{if } a_1 \le x \le a_2 \\ \theta_{\tilde{a}} & \text{if } x = a_2 \\ \dfrac{(x - a_2 + \theta_{\tilde{a}}(a_3 - x))}{(a_3 - a_2)} & \text{if } a_2 < x \le a_3 \\ 1 & \text{otherwise} \end{cases}$$

$$F_{\tilde{a}}(x) = \begin{cases} \dfrac{(a_2 - x + \beta_{\tilde{a}}(x - a_1))}{(a_2 - a_1)} & \text{if } a_1 \le x \le a_2 \\ \beta_{\tilde{a}} & \text{if } x = a_2 \\ \dfrac{(x - a_2 + \beta_{\tilde{a}}(a_3 - x))}{(a_3 - a_2)} & \text{if } a_2 < x \le a_3 \\ 1 & \text{otherwise} \end{cases}$$

where $\alpha_{\tilde{a}}$, $\theta_{\tilde{a}}$ and $\beta_{\tilde{a}}$ denote the maximum truth-membership degree, minimum indeterminacy-membership degree and minimum falsity-membership degree respectively. A single valued triangular neutrosophic number $\tilde{a} = \langle (a_1, a_2, a_3); \alpha_{\tilde{a},}\theta_{\tilde{a},}\beta_{\tilde{a},}\rangle$.

Definition 3.4. Let $\tilde{a} = \langle (a_1, a_2, a_3); \alpha_{\tilde{a},}\theta_{\tilde{a},}\beta_{\tilde{a},}\rangle$ and $\tilde{b} = \langle (b_1, b, b_3); \alpha_{\tilde{b},}\theta_{\tilde{b},}\beta_{\tilde{b},}\rangle$ be two single valued triangular neutrosophic numbers and $\gamma \neq 0$ be any real number. Then,

$$\tilde{a} + \tilde{b} = \langle (a_1 + b_1, a_2 + b_2, a_3 + b_3); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \rangle$$

$$\tilde{a} - \tilde{b} = \langle (a_1 - b_3, a_2 - b_2, a_3 - b_1); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \rangle$$

$$\tilde{a}\tilde{b} = \begin{cases} \langle (a_1b_1, a_2b_2, a_3b_3); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \rangle \text{if}(a_3 > 0, b_3 > 0) \\ \langle (a_1b_3, a_2b_2, a_3b_1); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \rangle \text{if}(a_3 < 0, b_3 > 0) \\ \langle (a_3b_3, a_2b_2, a_1b_1); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \rangle \text{if}(a_3 < 0, b_3 < 0) \end{cases}$$

$$\frac{\tilde{a}}{\tilde{b}} = \begin{cases} \langle \left(\dfrac{a_1}{b_3}, \dfrac{a_2}{b_2}, \dfrac{a_3}{b_1}\right); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \rangle \text{ if}(a_3 > 0, b_3 > 0) \\ \langle \left(\dfrac{a_3}{b_3}, \dfrac{a_2}{b_2}, \dfrac{a_1}{b_1}\right); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \rangle \text{ if}(a_3 < 0, b_3 > 0) \\ \langle \left(\dfrac{a_3}{b_3}, \dfrac{a_2}{b_2}, \dfrac{a_1}{b_3}\right); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}} \rangle \text{ if}(a_3 < 0, b_3 < 0) \end{cases}$$

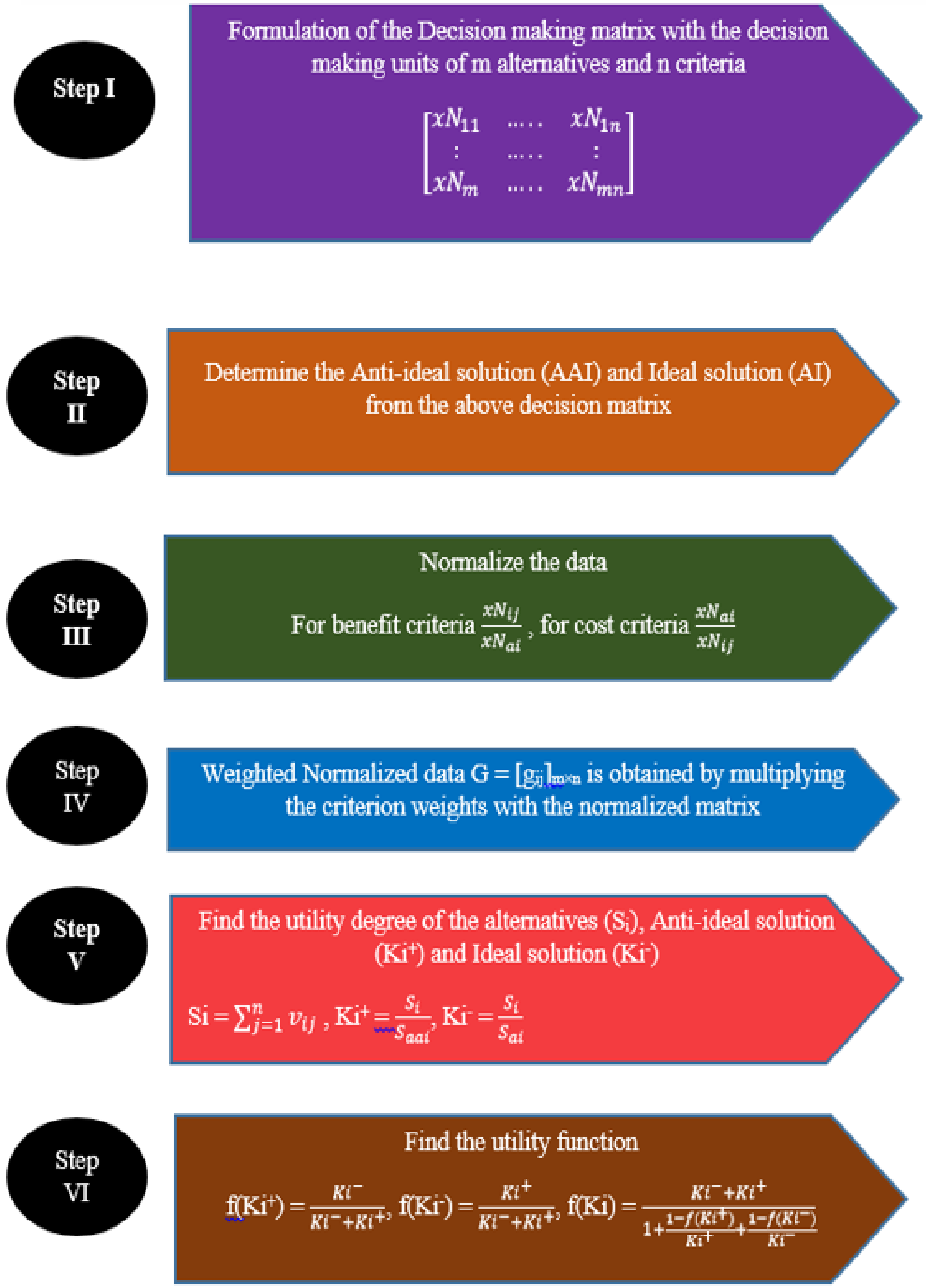
$$\gamma\tilde{a} = \begin{cases} \langle \gamma a_1, \gamma a_2, \gamma a_3); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \rangle \text{ if}(\gamma > 0) \\ \langle \gamma a_3, \gamma a_2, \gamma a_1); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \rangle \text{ if } (\gamma < 0) \end{cases}$$

$$\tilde{a}^{-1} = \langle \left(\frac{1}{a_3}, \frac{1}{a_2}, \frac{1}{a_1}\right); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \rangle \text{ where } (\tilde{a} \neq 0)$$

Definition 3.5. Let $\tilde{a} = \langle (a_1, a_2, a_3); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \rangle$ be a single valued triangular neutrosophic number. The score value of $\tilde{a}$ is defined as $S(a) = \frac{1}{16}[a_1 + a_2 + a_3] \times (2 + \alpha_{\tilde{a}} - \theta_{\tilde{a}} - \beta_{\tilde{a}})$.

4. Methodology

This section sketches out the steps involved in the method of Neutrosophic MARCOS. The below schematic gives a vivid presentation of deriving optimal ranking results.



5. Application of the Proposed Method

This section presents the application of the MARCOS MCDM with single valued triangular neutrosophic number representations.

5.1 Problem Description

Let us consider a decision making situation of a manufacturing firm dealing with the decision making on software selection. There are many consultancies that offer software services to the companies for making their administration smart and robust. The manufacturing firms are in need of augmenting technology interfaced management and hence installation of software is a necessary step towards building a smart manufacturing system. The decision making situation is developed with the decision making units of five alternatives and four criteria.

5.2 Description of Decision Making Units

The decision making units comprise five alternatives and four criteria. The alternatives are labelled as S1 S2, S3, S4 and S5. These alternatives are different software services offered by five different consultancies. The criteria chosen are costs (C1), time (C2), integrity (C3) and versatility (C4). The criteria C1 and C2 are non-beneficial criteria whereas C3 and C4 are the beneficial criteria.

The initial decision making matrix with single valued triangular neutrosophic numbers is represented in Table 2.

Table 2. Initial decision making data.

Alternatives/ Criteria	Cost in ten thousands	Time in hours	Integrity in percentage	Versatility in percentage
Type	**Min**	**Min**	**Max**	**Max**
S1	⟨(5,7,9); 0.8,0.2,0.3⟩	⟨(2,3,4); 0.9,0.1,0.1⟩	⟨(45,65,70); 0.7,0.3,0.4⟩	⟨(40,50,60); 0.6,0.1,0.3⟩
S2	⟨(13,15,17); 0.7,0.3,0.3⟩	⟨(1,3,5); 0.8,0.1,0.3⟩	⟨(70,75,80); 0.5,0.1,0.1⟩	⟨(70,80,90); 0.6,0.1,0.1⟩
S3	⟨(14,17,20); 0.4,0.1,0.7⟩	⟨(6,7,8); 0.5,0.2,0.6⟩	⟨(60,70,80); 0.6,0.1,0.5⟩	⟨(65,75,85); 0.8,0.1,0.4⟩
S4	⟨(7,8,9); 0.9,0.1,0.2⟩	⟨(1,2,3); 0.7,0.3,0.2⟩	⟨(55,65,75); 0.6,0.1,0.2⟩	⟨(50,75,85); 0.7,0.2,0.2⟩
S5	⟨(4,6,8); 0.6,0.3,0.1⟩	⟨(2,4,6); 0.7,0.1,0.1⟩	⟨(50,75,85); 0.5,0.2,0.1⟩	⟨(75,85,95); 0.6,0.3,0.1⟩

The anti-ideal solution and ideal solutions are obtained from the above initial data as in Table 3. The maximum value with respect to benefit criteria and minimum value with respect to cost criteria are considered as ideal solutions. Similarly the minimum value with respect to benefit criteria and maximum value with respect to cost criteria are considered as anti- ideal solutions.

Table 3. Anti-ideal solution and Ideal solutions.

Alternatives/ Criteria	Cost in ten thousands	Time in hours	Integrity in percentage	Versatility in percentage
Type	**Min**	**Min**	**Max**	**Max**
AAI	⟨(14,17,20); 0.4,0.1,0.7⟩	⟨(6,7,8); 0.5,0.2,0.6⟩	⟨(45,65,70); 0.7,0.3,0.4⟩	⟨(40,50,60); 0.6,0.1,0.3⟩
S1	⟨(5,7,9); 0.8,0.2,0.3⟩	⟨(2,3,4); 0.9,0.1,0.1⟩	⟨(45,65,70); 0.7,0.3,0.4⟩	⟨(40,50,60); 0.6,0.1,0.3⟩
S2	⟨(13,15,17); 0.7,0.3,0.3⟩	⟨(1,3,5); 0.8,0.1,0.3⟩	⟨(70,75,80); 0.5,0.1,0.1⟩	⟨(70,80,90); 0.6,0.1,0.1⟩

S3	⟨(14,17,20); 0.4,0.1,0.7⟩	⟨(6,7,8); 0.5,0.2,0.6⟩	⟨(60,70,80); 0.6,0.1,0.5⟩	⟨(65,75,85); 0.8,0.1,0.4⟩
S4	⟨(7,8,9); 0.9,0.1,0.2⟩	⟨(1,2,3); 0.7,0.3,0.2⟩	⟨(55,65,75); 0.6,0.1,0.2⟩	⟨(50,75,85); 0.7,0.2,0.2⟩
S5	⟨(4,6,8); 0.6,0.3,0.1⟩	⟨(2,4,6); 0.7,0.1,0.1⟩	⟨(50,75,85); 0.5,0.2,0.1⟩	⟨(75,85,95); 0.6,0.3,0.1⟩
AI	⟨(4,6,8); 0.6,0.3,0.1⟩	⟨(1,2,3); 0.7,0.3,0.2⟩	⟨(70,75,80); 0.5,0.1,0.1⟩	⟨(75,85,95); 0.6,0.3,0.1⟩

The above decision data set is dealt under different cases

Case (i) Neutrosophic MARCOS with Equal criterion Weights

The weighted normalized matrix is presented in Table 4.

Table 4. Weighted Normalized Matrix.

Alternatives/ Criteria	Cost in ten thousands	Time in hours	Integrity in percentage	Versatility in percentage
AAI	0.088235	0.071429	0.2	0.147059
S1	0.214286	0.1	0.2	0.147059
S2	0.107143	0.166667	0.25	0.235294
S3	0.088235	0.071429	0.233333	0.220588
S4	0.1875	0.25	0.216667	0.205882
S5	0.25	0.125	0.233333	0.25
AI	0.25	0.25	0.25	0.25

The utility degree values of Saai, Si and Sai are obtained using and presented in Table 5.

Table 5. Utility degree values.

Alternatives	Si
AAI	0.506723
S1	0.661345
S2	0.759104
S3	0.613585
S4	0.860049
S5	0.858333
AI	1

Using the steps V and VI ,the final ranking values are obtained and it is presented in Table 6.

Table 6. Ranking values with equal criterion weights

Alternatives	K-	K+	f(K-)	f(K+)	f(Ki)	Ranking
S1	1.305141	0.661345	0.336308	0.663692	0.565051	4
S2	1.498065	0.759104	0.336308	0.663692	0.648577	3
S3	1.21089	0.613585	0.336308	0.663692	0.524246	5
S4	1.697278	0.860049	0.336308	0.663692	0.734824	1
S5	1.693892	0.858333	0.336308	0.663692	0.733358	2

In the following cases the criterion weights are obtained using different methods

Case(ii) Neutrosophic MARCOS with CRITIC

The criterion weights are obtained by using the method of CRITC (CRiteria Importance through Intercreteria Correlation) and it is presented in Table 7.

Table 7. CRITIC criterion weights.

Criteria	Criterion Weights
C1	0.35
C2	0.21
C3	0.24
C4	0.20

The final ranking values obtained integrating neutrosophic MARCOS with CRITIC are presented in Table 8.

Table 8. Ranking values with CRITIC criterion weights.

Alternatives	K-	K+	f(K-)	f(K+)	f(Ki)	Ranking
S1	1.406489	0.661345	0.319825	0.680175	0.57489	4
S2	1.456345	0.759104	0.342641	0.657359	0.644074	3
S3	1.18416	0.613585	0.341308	0.658692	0.521378	5
S4	1.7138	0.860049	0.334149	0.665851	0.73654	2
S5	1.782323	0.858333	0.325045	0.674955	0.742159	1

Case(iii) Neutrosophic MARCOS with SWARA

The criterion weights are obtained by using the method of SWARA (Stepwise Weight Assessment Ratio Analysis) and it is presented in Table 9.

Table 9. SWARA criterion weights.

Criteria	Criterion Weights
C1	0.855
C2	0.1425
C3	0.0023
C4	0.0042

The final ranking values obtained integrating neutrosophic MARCOS with SWARA are presented in Table 10.

Table 10. Ranking values with SWARA criterion weights.

Alternatives	K-	K+	f(K-)	f(K+)	f(Ki)	Ranking
S1	2.290056	0.661345	0.224078	0.775922	0.621149	4
S2	1.348603	0.759104	0.360156	0.639844	0.631153	3
S3	1.004446	0.613585	0.379217	0.620783	0.498181	5
S4	2.275738	0.860049	0.274269	0.725731	0.779276	2
S5	2.689229	0.858333	0.24195	0.75805	0.796801	1

Case (IV) Neutrosophic MARCOS with SECA

The criterion weights are obtained by using the method of SECA (Simultaneous evaluation of criteria and alternatives) and it is presented in Table 11.

Table 11. SECA criterion weights.

Criteria	Criterion Weights
C1	0.209
C2	0.01
C3	0.784
C4	0.001

The final ranking values obtained integrating neutrosophic MARCOS with SECA are presented in Table 12.

Table 12. Ranking values with SECA criterion weights.

Alternatives	K-	K+	f(K-)	f(K+)	f(Ki)	Ranking
S1	1.15122	0.661345	0.364867	0.635133	0.546744	4
S2	1.250946	0.759104	0.377654	0.622346	0.617574	3
S3	1.148816	0.613585	0.348153	0.651847	0.517379	5
S4	1.202482	0.860049	0.416987	0.583013	0.662472	2
S5	1.344009	0.858333	0.389737	0.610263	0.687271	1

6. Discussions

Table 13 presents the ranking results with equal and unequal criterion weights. The unequal criterion weights are obtained using the methods of CRITIC, SWARA and SECA.

Table 13. Comparison of ranking score values.

Alternatives	Ranking Score Values			
	Equal Weights	Unequal Weights		
		CRITIC	SWARA	SECA
S1	0.565051	0.57489	0.621149	0.546744
S2	0.648577	0.644074	0.631153	0.617574
S3	0.524246	0.521378	0.498181	0.517379
S4	0.734824	0.73654	0.779276	0.662472
S5	0.733358	0.742159	0.796801	0.687271

The below Figure 1 clearly explains the ranking of the alternatives with respect to different criterion weights.

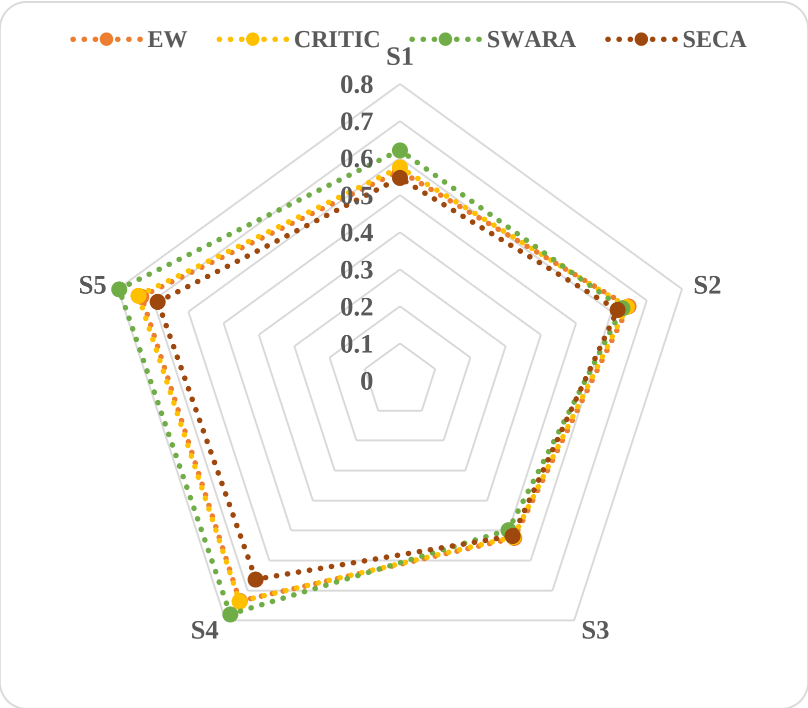


Figure 1. Ranking of the alternatives.

Table 14 presents the comparison of the ranking results of the alternatives

Table 14. Comparison of ranking results.

Alternatives	Ranking Results			
	Equal Weights	Unequal Weights		
		CRITIC	SWARA	SECA
S1	4	4	4	4
S2	3	3	3	3
S3	5	5	5	5
S4	1	2	2	2
S5	2	1	1	1

The ranking frequencies of the alternatives are presented in the following Table 15.

Table 15. Frequencies of the ranking results.

Alternatives	Ranking Positions				
	I	II	III	IV	V
S1	-	-	-	4	-
S2	-	-	4	-	-
S3	-	-	-	-	4
S4	1	3	-	-	-
S5	3	1	-	-	-

Also the Ranking correlation coefficient is presented in Table 16 between the ranking results to determine the consistency of the results.

Table 16. Correlational coefficient of the ranking results.

MARCOS with	Equal Weights	CRITIC	SWARA	SECA
Equal Weights	1	0.9	0.9	0.9
CRTIC		1	1	1
SWARA			1	1
SECA				1

7. Industrial Implications

As a result of recent technical advancements, the meteoric rise of artificial intelligence, and the progression of flexible industrial systems, the adoption of robots in the automobile manufacturing sector has experienced an enormous increase in their use in a variety of different operating mechanisms.

The theory of decision making finds wide-ranging applications in industrial activities. Since business operations involve various decision-making stages, the use of Multi-Criteria Decision-Making (MCDM) techniques becomes crucial. In this context, the proposed neutrosophic MARCOS, which employs single-valued triangular neutrosophic numbers, emerges as a highly suitable approach for making optimal decisions in the creation of smart manufacturing systems.

As industries often face complex production scenarios with multiple tasks, it becomes necessary to decentralize administrative patterns. This transition from manual-centered administration to technology-based organization inevitably involves software interventions. In such perplexing situations, the comprehensive nature of the neutrosophic-based MCDM method, MARCOS, proves to be exceptionally useful.

The use of single-valued triangular neutrosophic numbers for data representation enhances its adaptability. This method's feasibility for industrial applications is supported by the following:

i. The data representation is highly adaptable to various scenarios.
ii. The results obtained are more convincing and reliable.
iii. The method can be applied to any number of alternatives and criteria, making it versatile and practical for diverse decision-making situations in industries.

8. Conclusion & Future Directions

This research work proposes a neutrosophic based MARCOS MCDM with single valued triangular number. A survey on applications of MARCOS MCDM under different decision making environments is presented. An application with respect to software selection is presented in this work with hypothetical data. The comparative analysis with respect to different integrated MARCOS with other methods is also well articulated with suitable substantiation. In this research work the ranking results are discussed under various cases especially with equal and unequal weights. The proposed neutrosophic based MCDM shall be extended with other various kinds of data representations. Also the method of MARCOS shall be integrated with other MCDM methods.

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.

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Analysis the Role of the Internet of Things and Industry 4.0 in Healthcare Supply Chain Using Neutrosophic Sets

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Abstract: In today's global economy, the Healthcare supply chain (HCSC) must be aware of the market that is both complicated and ever-changing. The HCSC in Industry 4.0 aims to give patients the medicine they need as quickly and cheaply as possible. The HCSC can improve operations by automating routine tasks, and reducing human error by using new technologies like the "Internet of Things" (IoT); so that, there is a need to analyze the role of IoT and Industry 4.0 in the Healthcare Supply Chain. This paper aims to analyze the role of IoT and Industry 4.0 in HCSC. Also, this paper proposed a framework using a single-valued neutrosophic set with multi-criteria decision-making (MCDM) to overcome uncertainty and deal with the various criteria and features. This paper used the 18 criteria and nine suppliers as an application in the healthcare supply chain. The results concluded that the proposed framework can handle uncertain data and give more effective results in analyzing the role of IoT and Industry 4.0 in HCSC.

Keywords: Internet of Things; Multi-Criteria Decision-Making; Healthcare Supply Chain.

1. Introduction

The Healthcare supply chain (HCSC) in Industry 4.0 aims to give patients the medicine they need as quickly and cheaply as possible. It streamlines operations by automating routine tasks and reducing human error while simultaneously lowering costs and improving care quality. In order to increase the effectiveness of their supply chains, businesses are now using technology developments to construct efficient routes for contact and methods for cooperation. Traditional supply chains need to rapidly adapt in order to effectively and efficiently embrace the ideas of Industry 4.0 innovations, and this is true even as firms seek techniques to adapt to these emerging innovations [1, 2]. The drug industry is making use of 4.0 technologies. Many academics have thus begun using 4.0 technologies as an evaluation factor in the supplier selection problem. Drug production, availability, value, and cost-effectiveness may all be better controlled with the use of Industry 4.0 technology. The supplier analysis and selection problem in the drug sector especially should be undertaken with care; especially because the health of the patients is directly affected. Scholars from a wide variety of fields have used a wide variety of concepts and methods to add to the supplier analysis and selection problem within a stochastic setting [3, 4]. To keep up with the rapid evolution of client needs, a sustainable supply chain is essential. The feedback shows that manufacturers need to move quickly in moving their attention towards sustainability and using technologies like IoT to achieve their objectives; so, there is a need to analyze the role of IoT and Industry 4.0 in the Healthcare Supply Chain. Sometimes the criteria for analysis and assessment are presented as hard numbers; for example, a student's grade, the cost of an automobile, etc. However, it is sometimes difficult to deliver their assessments in the form of particular values. Scholar Zadeh came up with the novel idea of a fuzzy set (FS) to address this issue, making him a trailblazer in the field of fuzzy membership research. Unfortunately, FS only has the membership degree (MD), which is incapable of handling complicated problems. Atanassov built the theory of the intuitionistic fuzzy set (IFS) on top of FS [5, 6]. The neutrosophic set (NS) was first proposed by Smarandache. Truth membership (TM), faulty membership (FM), and indeterminacy membership (IM) are the three constituent parts of NS. Although NS is more comprehensive, it is still challenging to implement. Several subclasses of NS, such as the interval neutrosophic set, have been developed throughout the years to address difficulties with applications [7-9]. The concept of multi-criteria decision-making (MCDM) is used to deal with the various criteria and features. The concept of MCDM is used to deal with the various criteria and features. This paper aims to analyze the role of IoT and Industry 4.0 in HCSC. Also, this paper proposed a framework using a single-valued neutrosophic set with MCDM to overcome uncertainty and deal with the various criteria and features. This paper used the 18 criteria and nine suppliers as an application in the healthcare supply chain. The results concluded that the proposed framework can handle uncertain data and give more effective results in analyzing the role of IoT and Industry 4.0 in HCSC. This paper is organized as follows: the first section presents the introduction for this work; the second section introduces Industry 4.0; the third section introduces the HCSC; the fourth section provides the IoT and Supply Chain; the fifth section introduces the IoT and Industry 4.0 in Supply Chain; the sixth section introduces the proposed neutrosophic model; the seventh section applying the proposed model; the eighth section provides conclusion; finally give the references.

2. Industry 4.0

The term "Industry 4.0" refers to the incorporation of various types of digital technology into manufacturing processes. This technology relies heavily on the infrastructure provided by the Cyber-Physical System (CPS), and the IoT revolution in innovation. Connecting machines together allows for more customization because of their adaptability and intelligence [10, 11]. Through the use of networked machines and human oversight, Industry 4.0 will revolutionize the whole manufacturing process. Industrial manufacturing processes are predicted to be 30% more rapid and 25% more effective under the impact of Industry 4.0. Germany was the first country to propose Industry 4.0 as an action plan in 2011. There are competing views on what Industry 4.0 really is at first. To begin with, it was assumed that the industrial revolution would have far-reaching effects on the country's finances. Secondly, Industry 4.0 has great potential for improving operational efficiency and paving the way for the introduction of novel company structures. There are many researchers have investigated the effects of Industry 4.0 on manufacturing facilities, proposed a strategy for digitalizing the industrial infrastructure, and investigated several approaches to making the transition from machine-driven to data-driven production [12, 13]. Based on the ideas of Industry 4.0, the CPS envisions an intelligent manufacturing facility in which digital and physical data are linked to enable distributed decision-making. When people, processes, and technologies are all linked together, the result is value chains that are dynamic, adaptive, and continuously connected. The term "Industry 4.0" refers to a new strategic strategy that integrates convergent information and communication networks into the production process [14, 15]. According to previous research, the achievement of the Industry 4.0 approach may be attributed to the highly interconnected architecture that is mostly based on CPS. An important part of CPS's ability to materialize an intelligent production system is the cooperation of information platforms and handheld devices with internet-connected technologies. As a result, the characteristics of Industry 4.0 digital are strengthened [16, 17].

3. Healthcare Supply Chain

There are many businesses now use some kind of supply chain management (SCM). In order to effectively manage its supply chain, an organization has to include its many stakeholders, including producers, retailers, suppliers, and consumers. In the healthcare industry, SCM is crucial. This results from the reality that unsatisfied customers may result from a healthcare system that cannot provide the necessary medical products to its patients when they need them [15, 18]. The healthcare industry has been struggling with rising prices for decades. Scientists and managers alike have been putting more attention to SCM practices that can adapt to the ever-shifting nature, setting, and needs of the industry. Successful healthcare systems may effectively manage and continually regulate their goals thanks to supply chain practices, which are vital administration tools. By increasing product availability and decreasing order cycle time, effective SCM may enhance customer service while decreasing the overall number of resources needed to meet service levels. Increasingly, businesses are realizing the value of SCM because of the coordination and cooperation it facilitates with channel acquaintances such as vendors, agents, providers of services, and consumers. In many ways, hospital supply networks are not like those of other industries. To meet the demands of people who care for clients, the system relies on a constant flow of goods and services. Figure 1 shows the healthcare supply chain devices [1, 19].

Figure 1. Healthcare Supply Chain.

4. IoT and Supply Chain

The Internet of Things (IoT) is a system of interrelated computing devices, sensors, and network nodes that share data and operate in concert to improve human and machine cognition, streamline commercial operations, and open up whole new markets. By 2020, some 37 million more devices will be linked and utilized to track and manage operational procedures. The Internet of Things connects the digital and physical worlds, transforming the SC into a network. IoT facilitates the transfer of data, information, and expertise by means of data sharing, novel analytic approaches, and linked intelligent devices. Learning, mental processes, and intuition allow humans to transfer information learned from one machine to another, which is useful for both internal company knowledge management and external knowledge sharing. An essential use case for IoT is the enhancement of SC monitoring and tracing operations. To cut down on carbon dioxide emissions and the amount of time spent on the job by drivers, for example, leaders may make quick and precise choices on the deployment of independent, green-fuel cars engaged in long-distance redistribution. There are many types of research that addressed the connected IoT and supply chain [20, 21]. Figure 2 shows the connected IoT and supply chain.

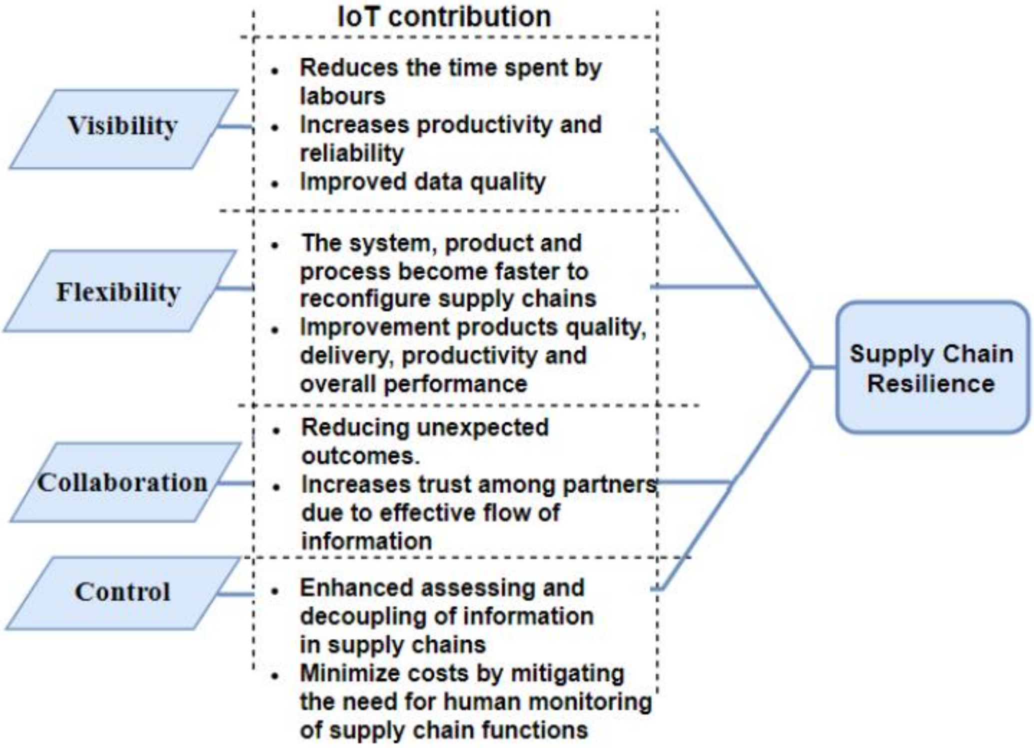

Figure 2. IoT contributions in supply chain resilience.

These days, wireless mobile sensor networks are employed in medical settings that need continuous monitoring of patients via the use of sensor devices. Continuous monitoring of patients, in-ambulatory, in-hospital, in-clinic, and open monitoring of the surroundings (e.g., athlete health surveillance), are all areas where researchers are seeking to implement a Wireless Mobile Sensor system.

5. IoT and Industry 4.0 in Supply Chain

The report concludes that the supply chain sector has to take the lead in order to fully reap the advantages of the IoT and other next-generation technologies. The research also reveals the advantages of IoT and Big data for a Green Supply Chain. In order to gain advantages, an ordinary supply-chain organization must invest in such technology. In addition, sustainable supply chain practices promote green power. The goal of Industry 4.0 at the supply chain, as shown in Figure 3, is to digitally integrate all aspects of the company, therefore cutting down on emissions and empowering stakeholders to make instantaneous, data-driven choices. The IoT makes it possible to link an organization's internal equipment, components, machines, and users. In addition to establishing a link with a single production facility, several such links might be established through the Internet and cloud computing [22, 23].

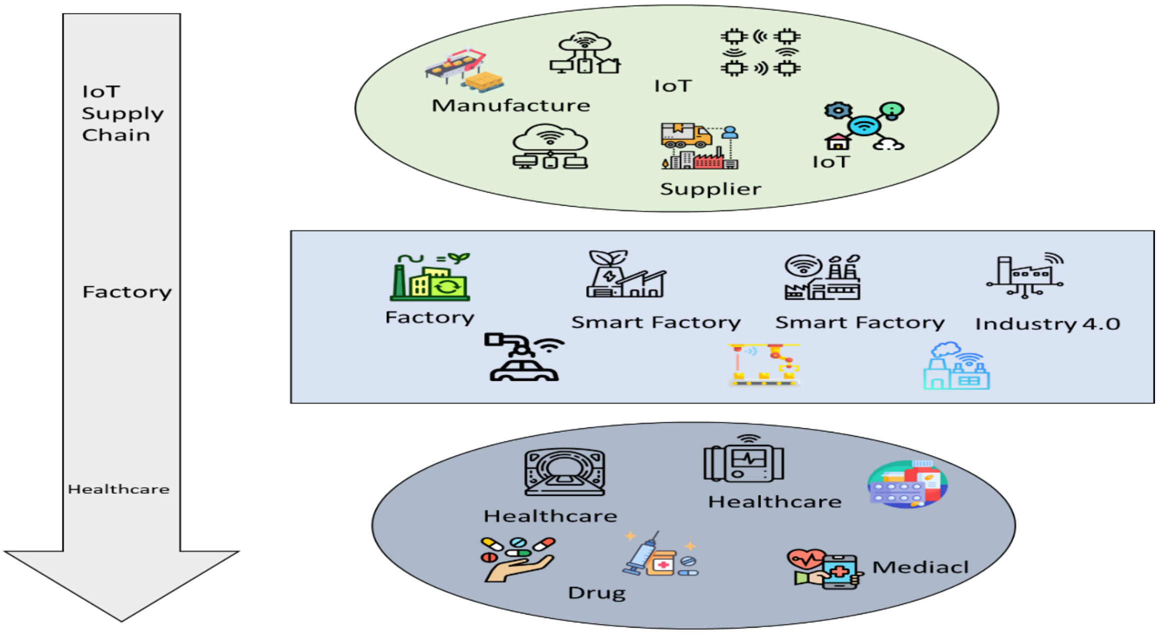

Figure 3. Industry 4.0 and IoT in healthcare supply chain.

According to the review of relevant literature, there is now an unfilled need for solutions that combine the IoT with Industry 4.0 to ensure supply chain sustainability. Figure 4 depicts a suggested new methodology for evaluating sustainability in industry 4.0 supply chain leadership.

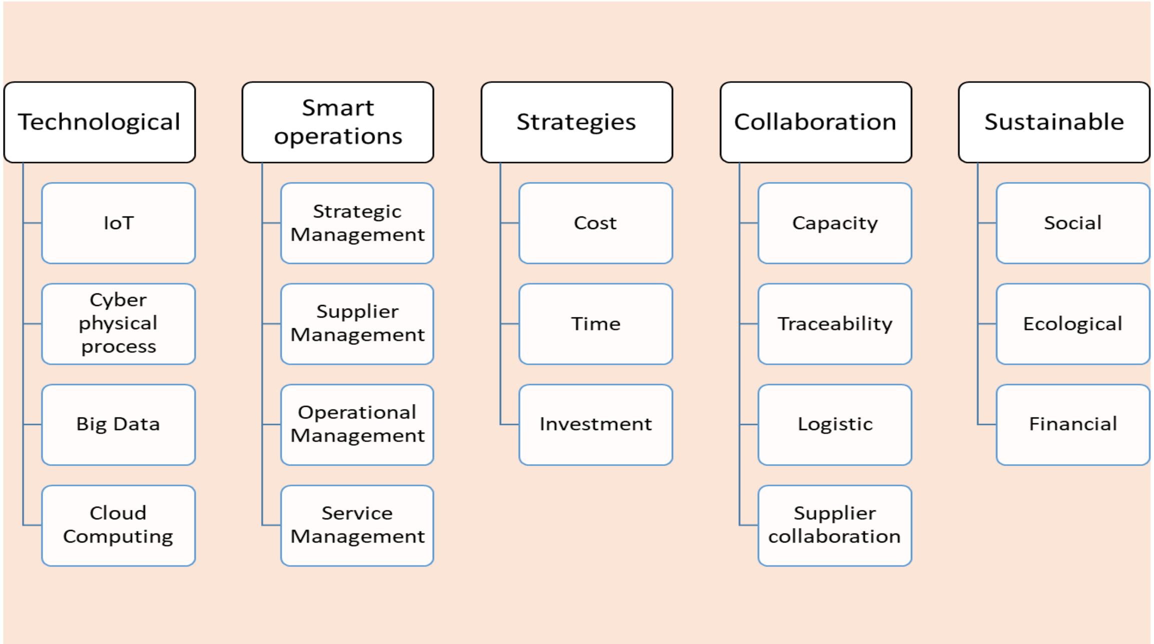

Figure 4. The criteria to show role IoT and Industry 4.0 in HCSC.

6. The proposed Neutrosophic Model

This section introduces the single valued neutrosophic set with the MABAC method. The distance of every alternative's criteria function from the border approximation region is the foundation of the MABAC technique under neutrosophic set [24, 28]. The proposed neutrosophic model consists of the following steps:

1) Formulate the decision matrix [29, 30].

The decision matrix is built D_{ij}

2) Normalize the decision matrix

$$ND_{ij} = \frac{d_{ij} - \min d_i}{\max d_i - \min d_i} \quad (1)$$

$$ND_{ij} = \frac{d_{ij} - \max d_i}{\min d_i - \max d_i} \quad (2)$$

3) Compute the weighted matrix

$$WD_{ij} = w_i \cdot (ND_{ij} + 1) \quad (3)$$

4) Compute the border approximation area.

$$b_i = \left(\prod_{j=1}^{m} WD_{ij}\right)^{\frac{1}{m}} \quad (4)$$

5) Compute the distanceoption from border approximation area

$$R = WD_{ij} - b_i \quad (5)$$

6) Compute the total distance

$$T_i = \sum_{j=1}^{n} R_{ij} \quad (6)$$

7. Applying the Proposed Neutrosophic Model

This section introduces the results of single valued neutrosophic set with the MABAC method in selection best supplier and analysis the role of IoT and industry 4.0 in the HCSC. This paper collected 18 criteria from the previous study as shown in Figure 4, and used nine suppliers. The experts build the decision matrix by the single valued neutrosophic numbers. Then normalized the decision matrix by using Eq. (1-2). Then compute the weights of criteria. Then compute the weighted normalized decision matrix by using Eq. (3). Then compute the border approximation area by using Eq. (4). Then compute the distance of each alternative from the border approximation are by using Eq. (5) as shown in Table 1.

Table1: The distance of each option from border approximation area.

	HCC_1	HCC_2	HCC_3	HCC_4	HCC_5	HCC_6	HCC_7	HCC_8	HCC_9	HCC_{10}	HCC_{11}	HCC_{12}	HCC_{13}	HCC_{14}	HCC_{15}	HCC_{16}	HCC_{17}	HCC_{18}
HCA_1	-0.93	-0.89	-0.88	-0.84	-0.90	-0.91	-0.96	-0.89	-0.89	-0.91	-0.93	-0.89	-0.91	-0.89	-0.90	-0.93	-0.94	-0.91
HCA_2	-0.91	-0.89	-0.90	-0.84	-0.86	-0.91	-0.96	-0.89	-0.92	-0.91	-0.93	-0.92	-0.91	-0.93	-0.90	-0.93	-0.95	-0.91
HCA_3	-0.86	-0.89	-0.88	-0.85	-0.89	-0.91	-0.87	-0.89	-0.89	-0.91	-0.85	-0.89	-0.91	-0.89	-0.90	-0.93	-0.89	-0.88
HCA_4	-0.93	-0.89	-0.90	-0.85	-0.86	-0.92	-0.97	-0.89	-0.92	-0.91	-0.93	-0.92	-0.91	-0.93	-0.90	-0.88	-0.94	-0.91
HCA_5	-0.93	-0.89	-0.91	-0.83	-0.87	-0.91	-0.87	-0.87	-0.91	-0.91	-0.85	-0.91	-0.91	-0.92	-0.91	-0.92	-0.93	-0.88
HCA_6	-0.91	-0.90	-0.90	-0.85	-0.88	-0.91	-0.96	-0.89	-0.91	-0.91	-0.93	-0.91	-0.88	-0.92	-0.90	-0.88	-0.93	-0.91
HCA_7	-0.93	-0.86	-0.90	-0.84	-0.87	-0.88	-0.94	-0.87	-0.91	-0.91	-0.91	-0.91	-0.92	-0.91	-0.90	-0.92	-0.94	-0.90
HCA_8	-0.93	-0.89	-0.88	-0.84	-0.86	-0.92	-0.94	-0.89	-0.91	-0.91	-0.91	-0.91	-0.88	-0.91	-0.90	-0.91	-0.94	-0.90
HCA_9	-0.93	-0.91	-0.88	-0.84	-0.90	-0.88	-0.96	-0.89	-0.91	-0.91	-0.93	-0.91	-0.92	-0.91	-0.90	-0.91	-0.94	-0.91

Then compute the total distance by using Eq. (6) as shown in the following Figure 5.

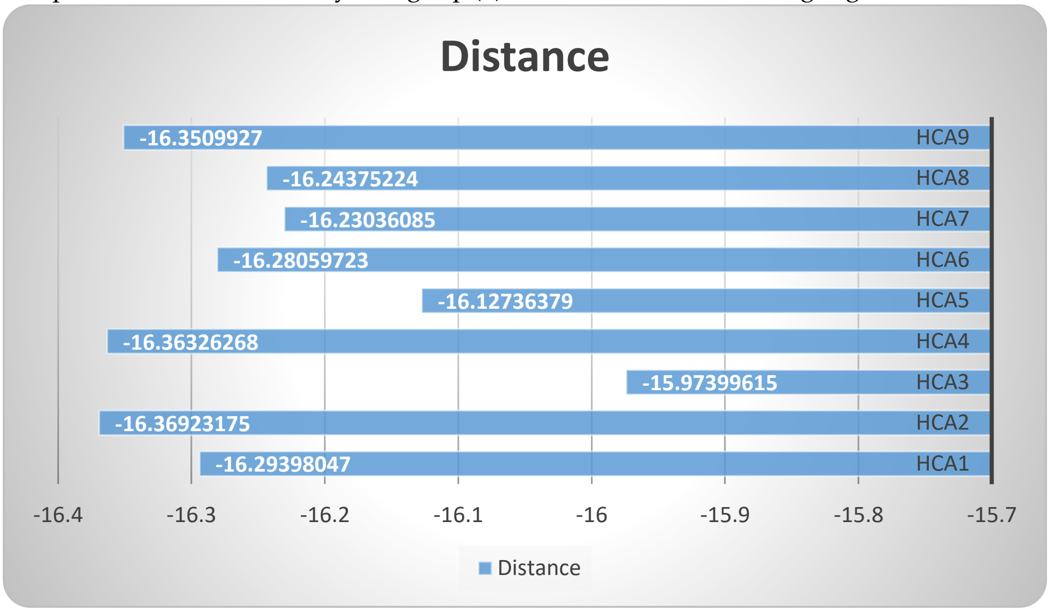

Figure 5. The total distance of each alternative from border approximation area.

This paper used the single valued neutrosophic set to overcome uncertain information. This paper used 18 criteria and 9 alternatives. The alternatives were evaluated and chosen utilizing the innovative multi-criteria MABAC (Multi-Attributive Border Approximation Area Comparison) technique The single valued neutrosophic is integrated with the MABAC method to show the rank of alternatives.

The results concluded that the proposed framework can handle uncertainty data and give more effective results in analyzing the role of IoT and industry 4.0 in HCSC. Also by using the single valued neutrosophic can handle the uncertainty which exists in data for giving more accurate results during ranking alternatives in HCSC.

8. Conclusion

The HCSC industry stands to benefit greatly from the automation, digitalization, and precision offered by Industry 4.0 technology. The paper discusses the assessment of an HCSC supplier's effectiveness in light of Industry 4.0, which is becoming more important as new technologies emerge. Businesses increasingly use IoT and other digital technologies to improve operations and productivity. It ensures extensive potential for competitive advantage and establishes a benchmark for future eco-friendly supply chain procedures. With the help of Industry 4.0, businesses can quickly adjust to changing consumer preferences. Productivity rises, and stakeholders can make better, more timely decisions at the moment. It opens the door to better business practices and more efficient production. This paper used the single-valued neutrosophic set to overcome uncertain information. This paper used 18 criteria and 9 alternatives. The single-valued neutrosophic is integrated with the MABAC method to show the rank of alternatives. The results concluded that the proposed framework can handle uncertain data and give more effective results in analyzing the role of IoT and Industry 4.0 in HCSC.

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.

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Analysis Impact of Intrinsic and Extrinsic Motivation on Job Satisfaction in Logistics Service Sector: An Intelligent Neutrosophic Model

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Abstract: The success of every company relies heavily on the happiness of its workforce, and the logistics service sector is no exception. The capacity of logistics suppliers to satisfy the demands of their clients depends on the efficiency and efficacy of operations, which in turn is affected by the level of employee satisfaction. This paper aims to analyze the factors of employee satisfaction in the logistic service industry to achieve productivity and a satisfied workforce. This paper used the multi-criteria decision-making (MCDM) methodology to handle various factors. The SWARA method is an MCDM method used to compute the importance of factors. The SWARA is integrated with the neutrosophic set to handle uncertain data. This paper used single-valued neutrosophic numbers to evaluate the factors by the experts. The application of the proposed methodology is conducted. We achieved the positive work ecological is essential to the success of any business, and this is especially true in the logistics service sector. When workers feel appreciated and supported, they are more likely to give their all at work, which in turn boosts output, morale, and retention. However, given that job security isn't the only element that influences employee happiness and retention, some would say that it's the least essential aspect. So this paper can aid any organization to increase productivity and employee satisfaction by showing the importance of various employee satisfaction in logistic services.

Keywords: Logistic Service Industry; Logistic Service Provider; Neutrosophic Set; MCDM..

1. Introduction

Logistics plays an important role in the worldwide economy and is an integral part of business and financial structures. Due to its global scope and diversity, the logistics business demands a cautious, diligent, and forward-thinking attitude. Meeting record completion time constraints, adhering to new import/export rules, guaranteeing travel conformity, meeting transparency standards for product manufacturing, and traversing time zone or cultural variances with agents are just a few examples of the obstacles that may arise at any stage or type of job. These difficult problems call for highly competent people who can perform well under duress. Therefore, HRM is essential to comprehending employee happiness, which has a major bearing on the prosperity of service industries like logistics [1, 2].

Supervisors and managers need to be aware of what makes their staff happy to increase morale and productivity. Nevertheless, several research has demonstrated that the intangible aspects of staff inspiration and demotivation make it difficult to use statistical methods to analyze employee happiness. In addition, the complicated nature of employee happiness is difficult to understand since quantitative research does not take into consideration the inherent ambiguity and inaccuracy of human behavior. On the other hand, qualitative research may help you get a deeper understanding of the elements that drive employee behavior, but it is time-consuming and difficult to quantify because of all the variables involved. Therefore, it is important to take a holistic approach to investigate to find and quantify the connections between elements associated with staff inspiration and discouragement [3, 4].

By creating and applying frameworks for decision-making for challenges that include many criteria or decision characteristics in settings where ambiguities and partial information are present multiple-criterion decision-making (MCDM) provides a workable answer to this issue. The widely used characteristics may be approximate and expressed as fuzzy data. After Zadeh introduced fuzzy sets, scholars all over the globe dove into the subject to learn more about its theoretical and practical applications [5, 6].

The idea of fuzzy sets has been expanded in several ways, with some of the most recent proposals being intuitive fuzzy sets. Neutrosophic sets are offered as a generalization of the intuitive concept of fuzzy sets. Its true, false, and ambiguous values are analogous to those of human thinking logic. The suggested study is motivated by the application of neutrosophic numbers related to MCDM approaches for the analysis of employee satisfaction in logistic service. This paper extended the SWARA method under a single-valued neutrosophic set to analyze factors of employee satisfaction in the logistic service industry [7, 8].

2. Logistic Service

From the ancient days of caravans carrying textiles and spices from India and China to Europe to the current day's Industry 4.0-driven worldwide system of linked multifaceted transport networks, logistics has gone a long way. Over the course of the previous century, international commerce and logistics have multiplied. All around the globe, new centers of industry, consumer markets, and supporting infrastructure have emerged. Logistics is the backbone of international commerce and an essential cog in international supply chain arrangements. In 2007, the Globe Bank recognized the impact that inefficient logistics has on international trade and began producing a country-level logistics performance index (LPI) every two years. The LPI is a compilation of comments from logistics experts all across the globe on six logistical factors.

Logistics, sometimes known as the "7Rs of logistics," refers to the people, procedures, and technology involved in ensuring the timely, cost-effective, and optimal delivery of goods to the intended customers. Services are more challenging to track, maintain, and enhance than physical goods. The growing specialization of the field can be attributed to the rise of novel business models [9, 10].

3. Logistic Strategy

A company's logistics strategy is derived from its overarching business plan. Assessments of both the outside world and the company's own resources and skills are used to inform strategic decisions. The proper competencies must be invested in if a logistics plan is to be put into action. It is important to use a portfolio strategy to evaluate, select, prioritize, execute, and manage these logistics investments. One of the most difficult aspects of putting a logistics strategy into action within the framework of logistics outsourcing is figuring out how to convert needed skills into choosing criteria and the appropriate performance levels of the resulting providers. Sustainability factors and the use of mixed MCDM methodologies have further complicated the discussion of criterion choice, weighting, and effectiveness aggregation.

4. Challenges of Logistic Service

The sector that Logistics Service Providers (LSPs) operate in is evolving fast. The success of your business might be hindered by factors including rising consumer expectations, a proliferation of international supply chains, fleet and staffing constraints, and elevated fixed and variable costs. If used properly, technology has the potential to address many of these concerns. It's important to figure out how to deal with specific issues.

The majority of an LSP's problems will be of the type:

i. Tracking the status of shipments in real-time, sharing that information with customers, and collecting all relevant data in one place are all examples of "visibility."
ii. Having sufficient capacity for all aspects of your fleet, including road transit and driver availability.
iii. Budgeting: including both fixed and variable expenses into profit margins and client quotations to increase predictability.
iv. Value for the customer is achieved by setting oneself apart from competitors and gaining loyalty via individualized service provision.

Large amounts of both fixed and variable expenses are assumed by LSPs, all of which must be included in price bids to assure profitability. Knowing exactly where your money is going helps you set more accurate prices for your services and better prepare your budget for future development. Advantages may be gained by LSPs by

i. Keeping up with the ever-changing price of petrol and repairs for your vehicle.
ii. Gaining insight into fees assessed by third parties like warehousing or port facilities.
iii. Cost estimation for logistics personnel, including wages, benefits, and other associated charges.
iv. Estimating the Full Cost of Operations, Including Supporting Personnel and Activities.
v. Deducting the Right Taxes.

Maintaining profit margins and reducing expenses may be accomplished with the use of a centralized perspective of all of these areas. You may plan for expansion with the use of financial data by comparing projected consumer demand with your present production capacity. It's possible to prepare for expansion in advance by acquiring the necessary trucks, personnel, and infrastructure [11, 12].

5. Employee Satisfaction in Logistic Service

Organizations can't function without happy workers, since these workers' dedication, conscientiousness, and honesty directly affect the quality of their work. Because of its impact on workers' daily lives, attitudes, and actions, the workplace is a key factor in fostering contentment in the workforce.

Based on Surugiu & Surugiu, globalization has had a major impact on the nature of work and the competitiveness of businesses. The scenario is not drastically different for businesses in the shipping and transportation service sector. In the logistical and transport sector. The position of employees has worsened dramatically as a result of cheaper service offerings from overseas logistics and transport service providers. Workers, as well as businesses, feel the effects of such precarious situations. Administrative structures are under more pressure than ever to provide high-quality services quickly and cheaply, yet this has led to a widespread disregard for certain employee demographics. Karimi et al. claims that workers' stress, frustration, or dissatisfaction might have an impact on their productivity on the job due to the variety of mental and physical demands placed on them [13, 14].

Problems and strains at work increase disproportionately affect low- and no-skilled employees when they try to acquire the necessary linguistic and temporal competence.

6. Benefits of Logistic Service

There are many benefits of logistic service:

It might be difficult for a single company to build a team of specialists in the appropriate use of cutting-edge technology, but reputable logistics service providers will have just that. They may monitor the distribution of your items to make sure they are efficiently distributed based on customer demands and the most efficient routes. It will take years of dedicated work for a single company to reach the level of proficiency that will be obtained by working together. The finest candidates for each position in the division will be chosen after a rigorous screening procedure. Therefore, they will appreciate having access to experts who are familiar with all aspects of the procedure. These factors are crucial for efficient multi-level execution, which is necessary for optimal output [15, 16].

If you want to stay ahead of the competition, you need to use cutting-edge, up-to-date technology across the board. However, if your company provides services unrelated to logistics, it might be too expensive to deploy cutting-edge technology. However, because of the consistency with which a logistics firm must deal with comparable tasks, they are more likely to incorporate cutting-edge tools into their everyday operations. If you work with a reputable Logistics firm, you'll have access to state-of-the-art technology and services.

Investment in components like cars, storage spaces, employees, etc., may raise operating expenditures, as indicated above, especially if you run a unique firm that is unrelated to logistics. Working with a Logistics provider may help you save money on overhead and stay on top of everything that needs doing. This will aid in lowering operating costs and producing the desired results more efficiently. It's been demonstrated to be more efficient than spending money on a larger infrastructure while yet allowing you to maintain market competitiveness via astute financial management [17, 18].

Among the many advantages of working with a reliable Logistics supplier is the time you'll save. Time is of the essence if you want to ship your goods to several places. The nature of the goods your company sells is also a major factor. If the products have a shorter shelf life, timely delivery is essential. Finding a trustworthy and knowledgeable service provider will be of great assistance in this regard. Products will be delivered more quickly since they will be familiar with local customs and regulations.

The supply chain relies heavily on the logistics system, which in turn relies heavily on the needs of the client base as a whole. In the modern day, most purchases are made via applications on mobile devices, and consumers are quite particular about which delivery they want. Reliable order fulfillment is possible when companies team up with a reputable logistics service provider. There will be no hiccups in the delivery process, and everything from packaging to warehousing to shipment will go as planned. To guarantee that their products are delivered according to the specifications of their clients, professionals will intelligently involve the essential aspects [19, 20].

7. Neutrosophic SWARA Model

Neutrosophy, which literally translates to "knowledge of neutral thought," is a relatively young philosophical subfield that investigates questions such as where neutralities come from, how far they extend, and how they interact with other types of ideas.

Zadeh was the first to propose using fuzzy logic. In contrast to the black-and-white values used in classical logic, facts in fuzzy logic may take on any number between zero and one. The range [0,1] is not required but is often desirable in technical contexts. Fuzzy logic allows for the evaluation of a case with values that are ambiguous or grayed out. This allows for a more nuanced assessment.

Smarandache discussed neutrosophy and the cluster methodology used in neutrosophy. In opposition to fuzzy logic, this method uses just three possible truth values to describe a statement or observation: T for truth, I for ambiguity, and F for falsehood.

A linguistic parameter is one that uses words or phrases rather than numbers to express values, whether in a natural or synthetic language. A word from the term set is used to represent the value of a linguistic parameter. It is widely agreed that the idea of a linguistic factor is helpful for resolving difficult decision-making situations. Very important, somewhat important, not too important, not at all important, etc. are all language variables that may be used to rate the performance of alternatives based on their qualitative features. It is also possible to use one-valued neutrosophic numbers to express these linguistic characteristics [21, 22]. This section provides the neutrosophic set with the SWARA method to analyze factors of employee satisfaction in logistic service industry as shown in Figure 1.

Kersuliene et al. advocated SWARA as a weighting technique due to its ease of implementation. It relies heavily on expert judgment and employs a limited number of pair evaluations [23, 24].

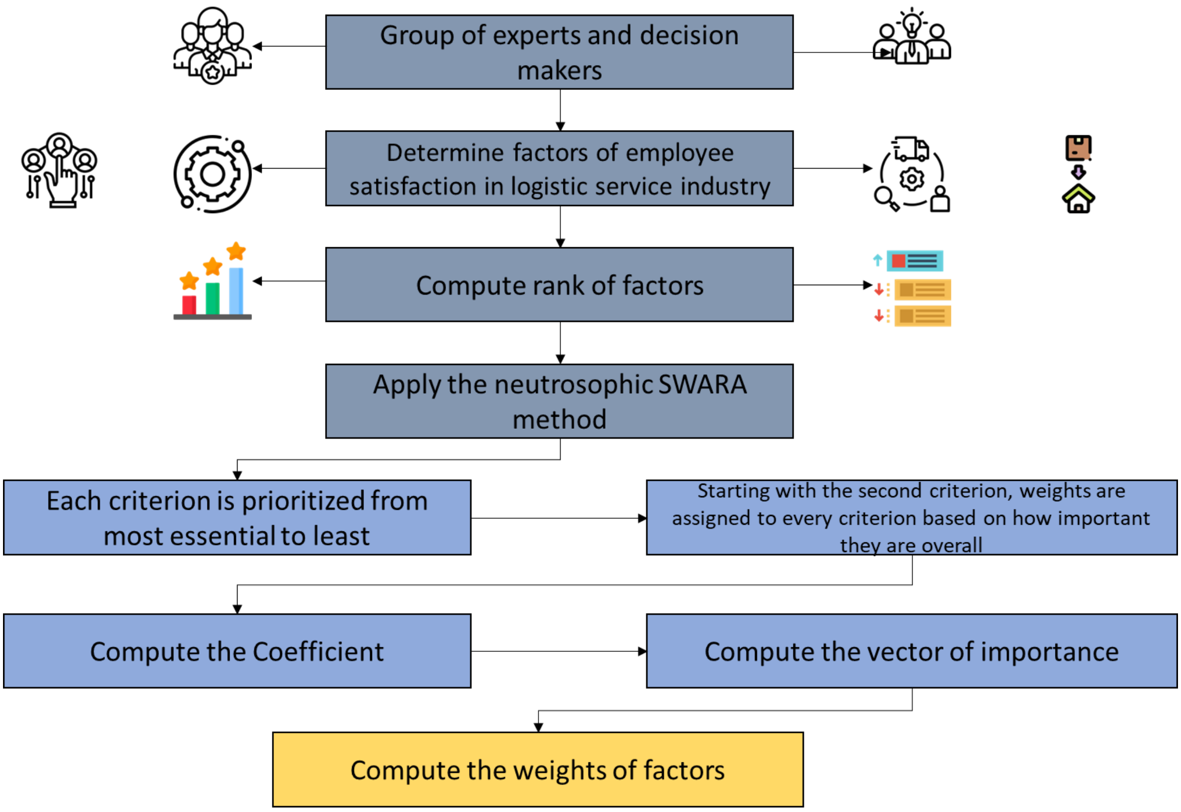

Figure 1. The framework to analysis employee satisfaction in logistic service industry.

Stage 1. Each criterion is prioritized from most essential to least.

Stage 2. Starting with the second criterion, weights are assigned to every criterion based on how important they are overall. Thus, we compare the j criteria to the $j-1$ criterion that came before it. "The relative importance of the average score" is the term used to describe this proportion.

Stage 3. Compute the Coefficient

$$p_j = \begin{cases} 1 & j = 1 \\ a_j + 1 & j > 1 \end{cases} \tag{1}$$

Where a_j value of comparison matrix

Stage 4. Compute the vector of importance

$$t_j = \begin{cases} 1 & j = 1 \\ \frac{t_{j-1}}{p_j} & j > 1 \end{cases} \tag{2}$$

Stage 5. Compute the weights of factors

$$q_j = \frac{\sum_{j=1}^{n} t_j}{n} \tag{3}$$

8. Results

Employee happiness is crucial in every business, and the logistics service sector is no exception. This section provides an analysis of factors of employee satisfaction in the logistic service industry. The research review served as the starting point for defining the factors. The studies' factors of employee satisfaction in the logistic service industry were compiled as a result of the literature review. The factors were then explored in detail during interviews with subject matter experts. This back-and-forth of ideas led to the establishment of the problem's proper factors. Specialists reached a consensus on new considerations, which were subsequently implemented. In the logistics and service sector, worker happiness is influenced by a number of variables as shown in Figure 2.

Figure 2. Employee satisfaction factors in logistic industry.

Experts evaluate the factors by building the single valued neutrosophic numbers matrix to obtain the weights of factors as shown in Table 1. Then compute the coefficient by using Eq. (1). Then compute the importance vector by using Eq. (2). Then compute the weights of factors by using Eq. (3) as shown in Figure 3.

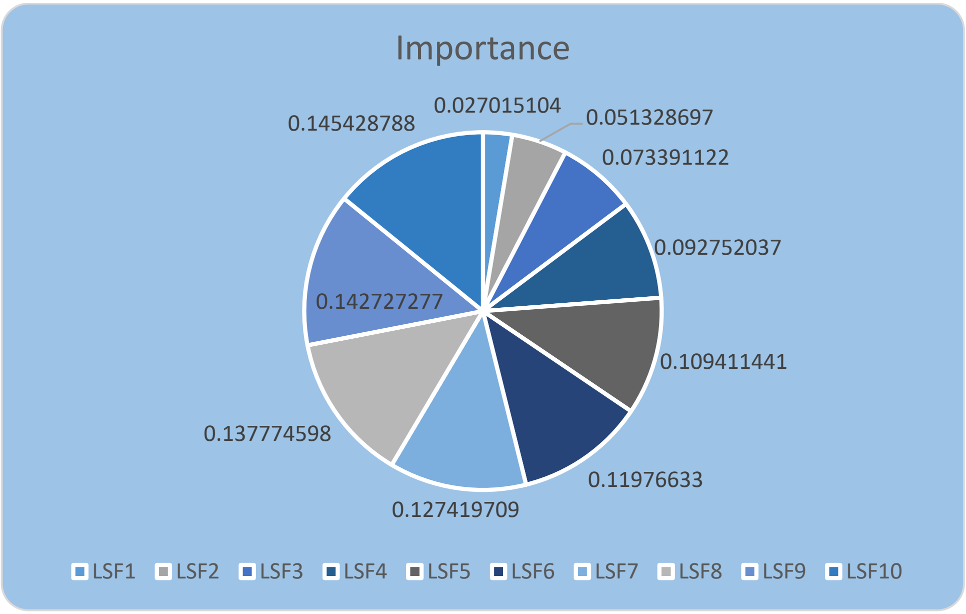

Figure 3. The importance of factors of employee satisfaction in logistic service industry.

Table 1. The neutrosophic numbers of factors employee satisfaction in logistic service industry.

	LSF_1	LSF_2	LSF_3	LSF_4	LSF_5	LSF_6	LSF_7	LSF_8	LSF_9	LSF_{10}
LSF_1	1	(0.70, 0.25, 0.30)	(0.90, 0.10, 0.10)	(0.10, 0.90, 0.90)	(0.60, 0.35, 0.40)	(0.70, 0.25, 0.30)	(0.90, 0.10, 0.10)	(0.30, 0.75, 0.70)	(0.70, 0.25, 0.30)	(0.90, 0.10, 0.10)
LSF_2	1/(0.70, 0.25, 0.30)	1	(0.40, 0.65, 0.60)	(0.60, 0.35, 0.40)	(0.30, 0.75, 0.70)	(0.70, 0.25, 0.30)	(0.30, 0.75, 0.70)	(0.60, 0.35, 0.40)	(0.90, 0.10, 0.10)	1/(0.70, 0.25, 0.30)
LSF_3	1/(0.90, 0.10, 0.10)	1/(0.40, 0.65, 0.60)	1	(0.20, 0.85, 0.80)	(0.90, 0.10, 0.10)	(0.30, 0.75, 0.70)	(0.70, 0.25, 0.30)	(0.70, 0.25, 0.30)	(0.30, 0.75, 0.70)	(0.80, 0.15, 0.20)
LSF_4	1/(0.10, 0.90, 0.90)	1/(0.60, 0.35, 0.40)	1/(0.20, 0.85, 0.80)	1	(0.80, 0.15, 0.20)	(0.20, 0.85, 0.80)	(0.30, 0.75, 0.70)	(0.40, 0.65, 0.60)	(0.90, 0.10, 0.10)	(0.40, 0.65, 0.60)
LSF_5	1/(0.60, 0.35, 0.40)	1/(0.30, 0.75, 0.70)	1/(0.90, 0.10, 0.10)	1/(0.80, 0.15, 0.20)	1	(0.90, 0.10, 0.10)	(0.10, 0.90, 0.90)	(0.30, 0.75, 0.70)	(0.40, 0.65, 0.60)	(0.60, 0.35, 0.40)
LSF_6	1/(0.70, 0.25, 0.30)	1/(0.70, 0.25, 0.30)	1/(0.30, 0.75, 0.70)	1/(0.20, 0.85, 0.80)	1/(0.90, 0.10, 0.10)	1	(0.80, 0.15, 0.20)	(0.10, 0.90, 0.90)	(0.40, 0.65, 0.60)	(0.70, 0.25, 0.30)
LSF_7	1/(0.90, 0.10, 0.10)	1/(0.30, 0.75, 0.70)	1/(0.70, 0.25, 0.30)	1/(0.30, 0.75, 0.70)	1//(0.10, 0.90, 0.90)	1/(0.80, 0.15, 0.20)	1	(0.90, 0.10, 0.10)	(0.30, 0.75, 0.70)	(0.60, 0.35, 0.40)
LSF_8	1/(0.30, 0.75, 0.70)	1/(0.60, 0.35, 0.40)	1/(0.70, 0.25, 0.30)	1/(0.40, 0.65, 0.60)	1/(0.30, 0.75, 0.70)	1/(0.10, 0.90, 0.90)	1/(0.90, 0.10, 0.10)	1	(0.80, 0.15, 0.20)	(0.80, 0.15, 0.20)
LSF_9	1/(0.70, 0.25, 0.30)	1/(0.90, 0.10, 0.10)	1/(0.30, 0.75, 0.70)	1/(0.90, 0.10, 0.10)	1/(0.40, 0.65, 0.60)	1/(0.40, 0.65, 0.60)	1/(0.30, 0.75, 0.70)	1/(0.80, 0.15, 0.20)	1	(0.90, 0.10, 0.10)
LSF_{10}	1/(0.90, 0.10, 0.10)	1/(0.90, 0.10, 0.10)	1/(0.80, 0.15, 0.20)	1/(0.40, 0.65, 0.60)	1/(0.60, 0.35, 0.40)	1/(0.70, 0.25, 0.30)	1/(0.60, 0.35, 0.40)	1/(0.80, 0.15, 0.20)	1/(0.90, 0.10, 0.10)	1

A positive work ecology is essential to the success of any business, and this is especially true in the logistics service sector. When workers feel appreciated and supported, they are more likely to give their all at work, which in turn boosts output, morale, and retention. A safe and clean workplace, pleasant working conditions, and a supportive business culture are all important to employees in the logistics service sector. Staff members who report feeling safe and valued at work are more likely to be enthusiastic about their work and committed to their success. It is particularly crucial for workers in physically demanding or possibly dangerous workplaces to have a sense of community and belonging at work, and a pleasant work environment may help foster that. Feeling appreciated and supported at work is facilitated by a business culture that encourages cooperation, collaboration, and respect.

In the logistics and service business, it is hard to choose one characteristic that workers value the least since they all contribute to a great work environment and employee retention. However, given that job security isn't the only element that influences employee happiness and retention, some would say that it's the least essential aspect. While employment stability is crucial, today's workers also value other factors, such as the chance to learn and advance in their careers, being appreciated for their contributions, being compensated fairly, and having a flexible schedule. Even when employment stability is unclear, such as in temporary roles or economic downturns, these considerations may help keep workers happy and in their jobs. Furthermore, the personal circumstances and professional aspirations of each individual may result in a varied order of importance for many aspects. An employee nearing retirement age, for instance, may value work security more highly than other considerations, whereas an individual still early in their career may value possibilities for growth and development more highly than job security. Overall, all aspects of employee happiness matter in the logistics service sector, and organizations should seek to foster an atmosphere that caters to employees' needs.

9. Conclusion

To recruit and retain top talent, boost output and efficiency, and ultimately delight consumers, logistics service providers must place a premium on employee happiness. Logistics service providers that want to stand out in a crowded market where customer pleasure is king may consider making an investment in their employees' happiness. There are many factors of employee satisfaction in the logistics service industry. So, the MCDM methodology is used in this paper to Yandel the various conflicting criteria. The SWARA method is an MCDM methodology used to compute the weights of factors. The SWARA is integrated with the single-valued neutrosophic set. This paper used single-valued neutrosophic numbers to handle the uncertain data. This paper collected ten factors to be ranked. A positive work ecology is essential to the success of any business, and this is especially true in the logistics service sector. When workers feel appreciated and supported, they are more likely to give their all at work, which in turn boosts output, morale, and retention. Job security is the least factor in employee satisfaction factors.

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.

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Neutrosophic MCDM Methodology for Evaluation Onshore Wind for Electricity Generation and Sustainability Ecological

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Abstract: The conviction in the necessity of renewable energy has been prompted by both the constantly increasing need for power production and the ecological issues of recent years. When it comes to generating power in a sustainable manner, wind is among the most essential renewable energy sources. This research attempts to present a structural technique for assessing the performance of operational onshore wind facilities with respect to the three dimensions of sustainability. The energy production, environmental effect, and practicability of onshore wind facilities are all dependent on accurate assessments. Wind resources, site accessibility, environmental impact, permitting and regulatory requirements, turbine technology, maintenance and operation, interconnection and transmission, and other criteria and factors are discussed in this research paper. Renewable energy, cost-effectiveness, dependability, and job creation are only a few of the advantages of onshore wind facilities that are mentioned. This study used the interval-valued neutrosophic set with the Weighted Sum Model (WSM) method to compute the weights of criteria and rank the alternatives. We got the wind speed and direction as the best criterion. The potential energy production of a wind plant is heavily dependent on the local wind speed and direction.

Keywords: Interval Valued Neutrosophic Sets; WSM; Onshore Wind Plant; Renewable Energy.

1. Introduction

The fast advancement of technology makes it very necessary for mankind and the survival of our planet to satisfy our energy requirements via a variety of different forms of energy. Awareness of renewable energy (RE) sources, which minimize the energy dependency of society on fossil fuels, has developed as cultures have become more mindful of their environment. In recent years, there have been various possible factors that explain why there has been such an interest in RE. To begin, there has been a considerable and ongoing rise in requests for environmentally friendly forms of energy all across the globe. Second, the price of renewable energy sources may now be compared favorably to that of traditional forms of energy production. Last but not least, the real estate industry has a considerable labor capacity, which is growing by leaps and bounds each year [1, 2].

In recent years, there has been a consistent rise in the amount of interest in wind energy. Even while wind energy does have a very little negative impact on the surroundings, this impact may be disregarded as inconsequential when compared to the impacts that are caused by energy sources that are produced from fossil fuels and pose a risk to both the natural world and human life. Wind energy, which is naturally clean, helps to lessen the impact that humans have on the environment. In addition to all of these legitimate reasons, several nations have been adopting wind plant (WP) expenditures in recent years owing to the ease, speed, and cost-effectiveness with which wind plants may be installed. Wind power is a substantial and valued source of clean energy, and its installed capacity is growing at a rate that is comparable to that of other renewable energy sources due to the fast expansion of wind turbines in conjunction with advances in technology [3, 4].

In the context of micro-site selection, WPs often address wind energy sources. Social, financial, and ecological variables may make the location with the greatest wind power density unsuitable for WPs. The rivers and water supply, birds, public health, animals, habitat, buffer distance inhabitants, etc. are all examples of limiting factors. Although it is required that each WP prepare a sustainability report as part of their preliminary work, these reports often overlook regional growth, especially in regard to the larger process of growth for the natural world and financial development's broad impact [5, 6].

Considering the close relationship between economic growth and energy consumption, it's clear that trying to safeguard the environment by restricting the growth of the energy industry is not a workable strategy. For this reason, it is recognized that there must be harmony among economic development, social progress, and environmental safeguards. Sustainable development was proposed as a means to this end [7, 8].

In this study, we use a straightforward multi-criteria decision-making (MCDM) approach, the Weighted Sum Model (WSM), to rank the onshore wind plant based on their performance across a variety of parameters.

The lack of precision in the language used to evaluate intangible criteria while using traditional MCDM techniques. As a result, fuzzy sets have been included in these approaches to broaden their usefulness in such a context. Zadeh created fuzzy sets as a way to indicate an element's conditional membership in a set. Since the introduction of fuzzy sets theory to the literature, it has been expanded to include a wide variety of topics. In order to deal with the ambiguity of the membership function, Zadeh introduced type-2 fuzzy sets to the field of fuzzy set theory. Later, multiple scholars separately proposed interval-valued fuzzy sets (IVFSs). To address the issues of how a hesitant decision maker (DM) should be taken into account, Atanassov introduced intuitionistic fuzzy sets (IFSs) in 1986 [9]–[11].

To address both the fuzziness of the data and the degree of completeness of an administrator, Smarandache created neutrosophic sets (NSs) in 1995. Torra first introduced hesitant fuzzy sets (HFSs), which are an extension of regular fuzzy sets in which a single element may have many membership degrees. To provide decision-makers access to a broader domain than IFSs for conveying their decisions [12]–[14].

In 1995, Smarandache created NS as an extension of IFS as a means of capturing data ambiguities and the indeterminacy of the expert. The levels of truthiness, indeterminacy, and falsity that make up an NS are denoted by the parameters Truth, Indeterminacy, and Falsity. Uncertainty in the information is represented in NS by truth (degrees of belongingness), falsehood (degrees of non-belongingness), and indeterminacy (degrees of hesitating) values. To differentiate between relativism and absoluteness, NS provides characteristics that indicate ambiguity and unpredictability by characterizing paraconsistent, and unreliable data as subsets [15, 16]. This study employed the interval neutrosophic set with the WSP to compute the weights of criteria and rank the alternatives. Figure 1 shows the onshore wind plant assessment model.

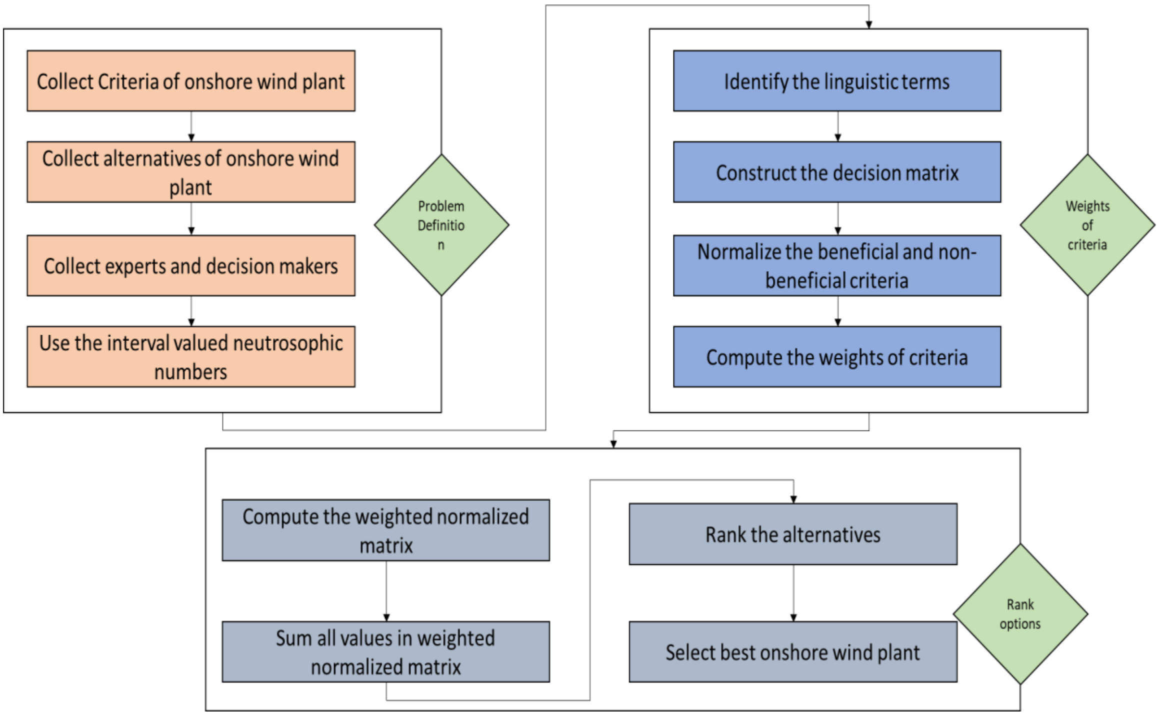

Figure 1. The onshore wind plant assessment model.

2. Barriers to Onshore Wind Energy

Onshore wind energy (WE) is growing as a prominent renewable energy source (RES) option as governments aim to minimize greenhouse gas emissions linked with electricity produced from traditional sources. In only ten years, onshore wind capacity throughout the world has increased by a factor of five, reaching 486.79 GW. Along with additional advantages, like the generation of millions of new employment, WE will be in charge of saving roughly 23 billion tons of CO2 by 2030 assuming global dedication to the renewable energy revolution and WE dissemination continues to expand at the current rate [17, 18].

The continued investment of governments in fossil fuels, the insufficient assessment of the downsides of fossil fuels, and the constant revisions and adjustments of RES support mechanisms are all examples of factors that negatively affect the cost-competitiveness of WE. These and other obstacles make it hard or impossible to expand onshore WE globally, preventing us from reaping its full advantages and jeopardizing the realization of the GWEC's 2050 global wind deployment goal in the process [19, 20].

So far, answering these concerns has necessitated reassembling empirical data from several investigations. Only a handful of studies have conducted a systematic literature review and those that have tended to concentrate on individual roadblocks. The SLR provides a synopsis of the obstacles' occurrence patterns, taking into account the economic environment and the degree of WE dissemination in the nations where they were detected and determines which hurdles have had a greater influence on adoption in every nation. Limitations to onshore WE diffusion (that is, the spread of wind farms) are also analyzed, and their compatibility with the original general framework given by Painuly is evaluated [21, 22].

When electricity markets are highly regulated, utility companies are often handled by states or private businesses that have, concurrently or not, the monopoly of production, distribution, and grid connection. This is the case when energy marketplaces are highly regulated. It is possible for monopolistic utilities to discourage investments in WE by arguing convincingly against the establishment of a regulatory structure for RES and by continuing to rely mostly on conventional energy sources as their primary generating resources. Because they already possess conventional resources have the potential to play a substantial part in these monopolies' generation portfolios. Conventional powers provide electricity at cheap rates (assuming the external expenses are omitted), which makes them an attractive option [23, 24].

In most cases, these monopolies only invest in WE when they are required to do so in order to meet minimum quotas for the production of non-hydro renewable energy sources that are established by governments. In addition to having the power to determine the sources of generation, monopolist utilities often also have the independence to decide which energies may enter their transmission networks. This gives them the ability to impede the incorporation of renewable energy sources into their transmission networks. According to the publications that were examined, highly regulated energy markets can be found in 11 nations, the majority of which are emerging economies with very recent WE diffusion [25, 26].

3. Neutrosophic Weighted Sum Model

A wide variety of approaches may be used to address the MCDM issue. The WSM is a widely used, straightforward, and efficient MCDM technique in the field of decision science. The data for each option must have the same unit for it to be of any use [27]–[29]. This paper used the interval valued neutrosophic set with the WSM method to compute the weights of criteria and rank the alternatives.

3.1 Identify the linguistic terms.

This paper used the interval valued neutrosophic terms as a linguistic term.

3.2 Construct the decision matrix.

The decision matrix is built by the interval valued neutrosophic numbers for each criteria and alternatives.

3.3 Normalize the beneficial and non-beneficial criteria.

This step identify the positive and negative criteria then compute the normalize value

$$n_{ij}^{+} = \frac{x_{ij}}{\max x_{ij}} \quad (1)$$

$$n_{ij}^{-} = \frac{\min x_{ij}}{x_{ij}} \quad (2)$$

3.4 Compute the weights of criteria.

3.5 Compute the weighted normalized matrix.

3.6 Sum all values in weighted normalized matrix.

3.7 Sum each row in weighted normalized matrix.

3.8 Rank the alternatives.

The alternatives are ranked based on previous step.

4. Onshore Wind Plant Assessment

A renewable energy facility that uses land-based wind turbines to produce power is known as an onshore wind plant. The blades of the turbines turn in reaction to the wind, powering a generator to produce energy. One of the most popular renewable energy sources, onshore wind farms have shown to be both dependable and sustainable. This study applied the interval-valued neutrosophic WSM to rank the alternatives. We collected eight criteria and twelve alternatives in this study.

Onshore wind plants are evaluated based on the following criteria:

Energy production from a wind farm depends heavily on the quality and reliability of the wind resource at the farm's location.

Construction and maintenance of the wind farm depend on easy access to the site, which means that transportation and other infrastructure must be in place.

It is important to evaluate and lessen the wind plant's negative effects on surrounding inhabitants, animals, and their environments.

Assessing the wind plant's regulatory and licensing needs ensures that it will operate in accordance with all applicable state and federal laws.

Potential energy production is heavily influenced by the wind speed and direction at the wind plant's location.

The efficiency, dependability, and cost of a wind power plant are all susceptible to the technology and design of the wind turbines that power the facility.

Regular inspections and repairs are an essential part of keeping the wind farm running smoothly and reliably for as long as possible.

To guarantee an effective and dependable supply of power, it is important to evaluate the wind plant's connections and transmission of energy to the grid.

The advantages of an on-land wind farm are:

The power produced by onshore wind generators is a sustainable energy source that helps cut down on the usage of nonrenewable fossil fuels and the release of greenhouse gases.

When compared to other renewable energy sources like solar and offshore wind, onshore wind farms have lower life-cycle costs.

Despite times of low wind speeds, electricity may be generated at onshore wind generators, making them a stable energy source.

Onshore wind project development and operation has the potential to generate new employment and boost regional economies.

We form a committee of experts to evaluate the criteria and alternatives. This study used interval-valued neutrosophic numbers. The experts build the decision matrix between criteria and alternatives as shown in Table 1. Then identify all positive and negative criteria. All criteria in this study are beneficial. Then normalize the decision matrix by using Eq. (2) as shown in Table 2. Then compute the weights of the criteria as shown in Figure 2. Then compute the weighted normalized decision matrix. Then sum each row in a weighted normalized decision matrix to rank the alternatives as shown in Figure 3.

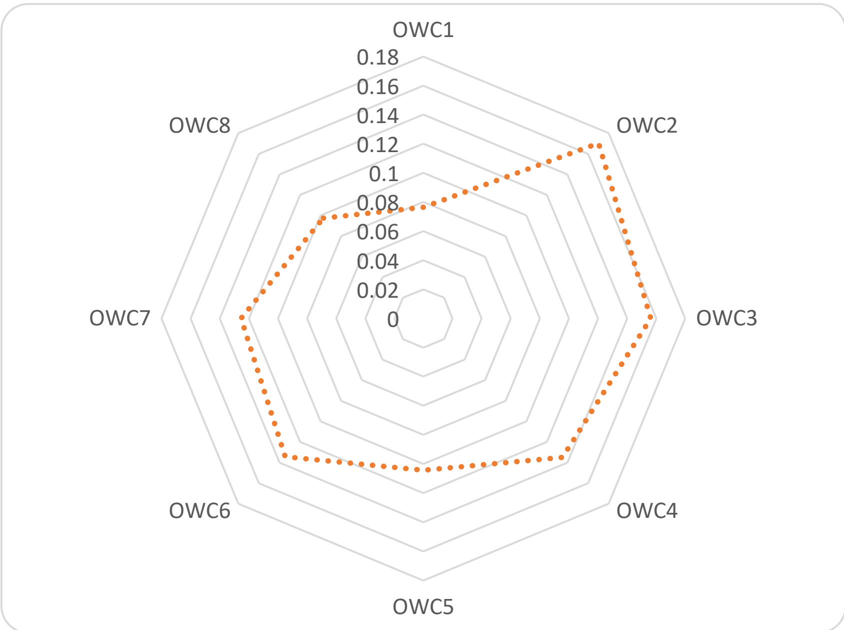

Figure 2. Weights of criteria in onshore wind plants.

Table 1. The interval valued neutrosophic numbers for criteria and alternatives.

	OWC_1	OWC_2	OWC_3	OWC_4	OWC_5	OWC_6	OWC_7	OWC_8
OWA_1	<[0.04, 0.06], [0.12, 0.15], [0.26, 0.28]>	<[0.15, 0.18], [0.12, 0.17], [0.1, 0.13]>	<[0.15, 0.18], [0.12, 0.17], [0.1, 0.13]>	<[0.15, 0.18], [0.12, 0.17], [0.1, 0.13]>	<[0.04, 0.06], [0.12, 0.15], [0.26, 0.28]>	<[0.21, 0.23], [0.12, 0.17], [0.06, 0.09]>	<[0.21, 0.23], [0.12, 0.17], [0.06, 0.09]>	<[0.04, 0.06], [0.12, 0.15], [0.26, 0.28]>
OWA_2	<[0.06, 0.09], [0.13, 0.18], [0.22, 0.24]>	<[0.29, 0.3], [0.12, 0.15], [0.03, 0.05]>	<[0.29, 0.3], [0.12, 0.15], [0.03, 0.05]>	<[0.06, 0.09], [0.13, 0.18], [0.22, 0.24]>	<[0.21, 0.23], [0.12, 0.17], [0.06, 0.09]>	<[0.21, 0.23], [0.12, 0.17], [0.06, 0.09]>	<[0.04, 0.06], [0.12, 0.15], [0.26, 0.28]>	<[0.21, 0.23], [0.12, 0.17], [0.06, 0.09]>
OWA_3	<[0.09, 0.13], [0.12, 0.19], [0.16, 0.19]>	<[0.29, 0.3], [0.12, 0.15], [0.03, 0.05]>	<[0.15, 0.18], [0.12, 0.17], [0.1, 0.13]>	<[0.29, 0.3], [0.12, 0.15], [0.03, 0.05]>	<[0.09, 0.13], [0.12, 0.19], [0.16, 0.19]>	<[0.06, 0.09], [0.13, 0.18], [0.22, 0.24]>	<[0.21, 0.23], [0.12, 0.17], [0.06, 0.09]>	<[0.06, 0.09], [0.13, 0.18], [0.22, 0.24]>
OWA_4	<[0.06, 0.09], [0.13, 0.18], [0.22, 0.24]>	<[0.15, 0.18], [0.12, 0.17], [0.1, 0.13]>	<[0.29, 0.3], [0.12, 0.15], [0.03, 0.05]>	<[0.15, 0.18], [0.12, 0.17], [0.1, 0.13]>	<[0.21, 0.23], [0.12, 0.17], [0.06, 0.09]>	<[0.21, 0.23], [0.12, 0.17], [0.06, 0.09]>	<[0.15, 0.18], [0.12, 0.17], [0.1, 0.13]>	<[0.06, 0.09], [0.13, 0.18], [0.22, 0.24]>
OWA_5	<[0.04, 0.06], [0.12, 0.15], [0.26, 0.28]>	<[0.29, 0.3], [0.12, 0.15], [0.03, 0.05]>	<[0.15, 0.18], [0.12, 0.17], [0.1, 0.13]>	<[0.29, 0.3], [0.12, 0.15], [0.03, 0.05]>	<[0.09, 0.13], [0.12, 0.19], [0.16, 0.19]>	<[0.06, 0.09], [0.13, 0.18], [0.22, 0.24]>	<[0.21, 0.23], [0.12, 0.17], [0.06, 0.09]>	<[0.04, 0.06], [0.12, 0.15], [0.26, 0.28]>
OWA_6	<[0.09, 0.13], [0.12, 0.19], [0.16, 0.19]>	<[0.15, 0.18], [0.12, 0.17], [0.1, 0.13]>	<[0.29, 0.3], [0.12, 0.15], [0.03, 0.05]>	<[0.09, 0.13], [0.12, 0.19], [0.16, 0.19]>	<[0.04, 0.06], [0.12, 0.15], [0.26, 0.28]>	<[0.15, 0.18], [0.12, 0.17], [0.1, 0.13]>	<[0.21, 0.23], [0.12, 0.17], [0.06, 0.09]>	<[0.09, 0.13], [0.12, 0.19], [0.16, 0.19]>
OWA_7	<[0.09, 0.13], [0.12, 0.19], [0.16, 0.19]>	<[0.04, 0.06], [0.12, 0.15], [0.26, 0.28]>	<[0.15, 0.18], [0.12, 0.17], [0.1, 0.13]>	<[0.04, 0.06], [0.12, 0.15], [0.26, 0.28]>	<[0.15, 0.18], [0.12, 0.17], [0.1, 0.13]>	<[0.15, 0.18], [0.12, 0.17], [0.1, 0.13]>	<[0.21, 0.23], [0.12, 0.17], [0.06, 0.09]>	<[0.06, 0.09], [0.13, 0.18], [0.22, 0.24]>
OWA_8	<[0.06, 0.09], [0.13, 0.18], [0.22, 0.24]>	<[0.15, 0.18], [0.12, 0.17], [0.1, 0.13]>	<[0.29, 0.3], [0.12, 0.15], [0.03, 0.05]>	<[0.29, 0.3], [0.12, 0.15], [0.03, 0.05]>	<[0.09, 0.13], [0.12, 0.19], [0.16, 0.19]>	<[0.04, 0.06], [0.12, 0.15], [0.26, 0.28]>	<[0.21, 0.23], [0.12, 0.17], [0.06, 0.09]>	<[0.04, 0.06], [0.12, 0.15], [0.26, 0.28]>
OWA_9	<[0.04, 0.06], [0.12, 0.15], [0.26, 0.28]>	<[0.29, 0.3], [0.12, 0.15], [0.03, 0.05]>	<[0.15, 0.18], [0.12, 0.17], [0.1, 0.13]>	<[0.15, 0.18], [0.12, 0.17], [0.1, 0.13]>	<[0.09, 0.13], [0.12, 0.19], [0.16, 0.19]>	<[0.21, 0.23], [0.12, 0.17], [0.06, 0.09]>	<[0.09, 0.13], [0.12, 0.19], [0.16, 0.19]>	<[0.09, 0.13], [0.12, 0.19], [0.16, 0.19]>
OWA_{10}	<[0.06, 0.09], [0.13, 0.18], [0.22, 0.24]>	<[0.29, 0.3], [0.12, 0.15], [0.03, 0.05]>	<[0.29, 0.3], [0.12, 0.15], [0.03, 0.05]>	<[0.06, 0.09], [0.13, 0.18], [0.22, 0.24]>	<[0.09, 0.13], [0.12, 0.19], [0.16, 0.19]>	<[0.21, 0.23], [0.12, 0.17], [0.06, 0.09]>	<[0.21, 0.23], [0.12, 0.17], [0.06, 0.09]>	<[0.21, 0.23], [0.12, 0.17], [0.06, 0.09]>
OWA_{11}	<[0.09, 0.13], [0.12, 0.19], [0.16, 0.19]>	<[0.29, 0.3], [0.12, 0.15], [0.03, 0.05]>	<[0.09, 0.13], [0.12, 0.19], [0.16, 0.19]>	<[0.29, 0.3], [0.12, 0.15], [0.03, 0.05]>	<[0.06, 0.09], [0.13, 0.18], [0.22, 0.24]>	<[0.21, 0.23], [0.12, 0.17], [0.06, 0.09]>	<[0.21, 0.23], [0.12, 0.17], [0.06, 0.09]>	<[0.06, 0.09], [0.13, 0.18], [0.22, 0.24]>
OWA_{12}	<[0.04, 0.06], [0.12, 0.15], [0.26, 0.28]>	<[0.29, 0.3], [0.12, 0.15], [0.03, 0.05]>	<[0.29, 0.3], [0.12, 0.15], [0.03, 0.05]>	<[0.29, 0.3], [0.12, 0.15], [0.03, 0.05]>	<[0.09, 0.13], [0.12, 0.19], [0.16, 0.19]>	<[0.06, 0.09], [0.13, 0.18], [0.22, 0.24]>	<[0.21, 0.23], [0.12, 0.17], [0.06, 0.09]>	<[0.04, 0.06], [0.12, 0.15], [0.26, 0.28]>

Table 2. The normalized interval valued neutrosophic numbers for criteria and alternatives

	OWC_1	OWC_2	OWC_3	OWC_4	OWC_5	OWC_6	OWC_7	OWC_8
OWA_1	0.51754	0.77214	0.77214	0.77214	0.31635	1	1	0.31635
OWA_2	0.79386	1	1	0.42739	1	1	0.31635	1
OWA_3	1	1	0.77214	1	0.61126	0.48525	1	0.48525
OWA_4	0.79386	0.77214	1	0.77214	1	1	0.87668	0.48525
OWA_5	0.51754	1	0.77214	1	0.61126	0.48525	1	0.31635
OWA_6	1	0.77214	1	0.53837	0.31635	0.87668	1	0.61126
OWA_7	1	0.27863	0.77214	0.27863	0.87668	0.87668	1	0.48525
OWA_8	0.79386	0.77214	1	1	0.61126	0.31635	1	0.31635
OWA_9	0.51754	1	0.77214	0.77214	0.61126	1	0.61126	0.61126
OWA_{10}	0.79386	1	1	0.42739	0.61126	1	1	1
OWA_{11}	1	1	0.53837	1	0.48525	1	1	0.48525
OWA_{12}	0.51754	1	1	1	0.61126	0.48525	1	0.31635

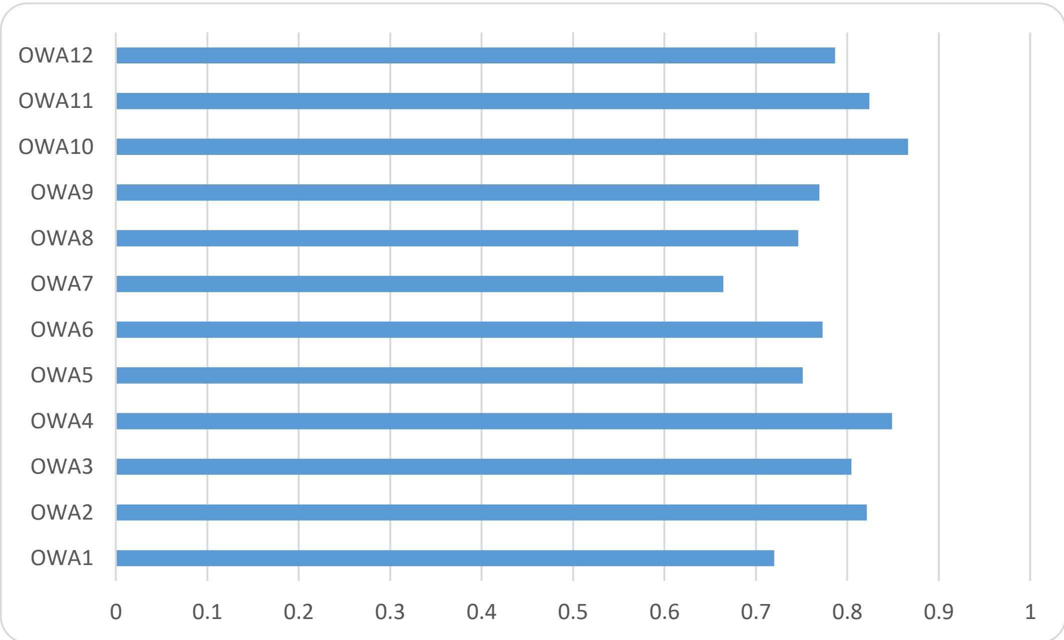

Figure 3. The rank of onshore wind plants.

5. Conclusion

The process of assessing onshore wind facilities is crucial, calling for the thoughtful assessment of many different criteria and aspects. To assess the viability of an onshore wind plant and guarantee its successful implementation, developers must consider a number of factors, including wind resource, site accessibility, environmental impact, permitting and regulatory requirements, turbine technology, maintenance and operation, interconnection and transmission, and so on. Onshore wind facilities are a useful instrument for reaching long-term energy sustainability objectives because of their many advantages. Maintaining relevance with changing requirements and objectives requires that developers routinely revisit and revise their evaluation criteria and considerations. This paper introduced eight criteria and twelve onshore wind plants. This study used interval-valued neutrosophic numbers to evaluate the criteria and alternatives. The interval-valued neutrosophic number was used with the WSM to rank the alternatives. We got the wind speed and direction as the best criterion. The potential energy production of a wind plant is heavily dependent on the local wind speed and direction.

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.

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