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# Estimation of intangible quality costs using neutrosophic AHP-TOPSIS

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**Abstract**. This study addresses the challenge of quantifying intangible quality costs (IQCs), which are inherently subjective and often overlooked in traditional quality cost management. We propose a novel hybrid framework that integrates the Neutrosophic Analytic Hierarchy Process (NAHP) with triangular neutrosophic numbers and Neutrosophic TOPSIS (NTOPSIS) with single-valued neutrosophic sets (SVNS) to evaluate and prioritize IQCs. The framework enables the aggregation of expert inputs, transforming qualitative risks—such as supplier mistrust and communication gaps—into quantifiable cost metrics. Applied to a steel mill's, the methodology allowed to cuantificate the IQCs of the scrap reception activity. The study concludes that the framework's structured yet adaptive nature provides organizations with a practical tool for prioritizing and mitigating intangible quality risks, overcoming the limitations of conventional methods. The results validate the importance of neutrosophy in the decision-making process under uncertainty in quality cost management.

**Keywords:** intangible quality cost, neutrosophic AHP, triangular neutrosophic set, neutrosophic TOPSIS, single valued neutrosophic set.

## 1. Introduction

The intangible quality costs (IQC), also referred to as implicit or hidden costs, are challenging to quantify due to their subjective nature and influence on the organization's non-financial aspects [1]. These costs are not typically recorded formally as expenses. Examples of intangible costs include customer loyalty, customer satisfaction, brand reputation, and the value of corporate image. Although these aspects cannot be easily expressed in monetary terms, their impact is significant and can be decisive for the organization's long-term success. According to [2], intangible quality costs are doubly dangerous: on one hand, they represent considerable amounts of money, and on the other, they remain concealed. In a study on the results of 57 investigations regarding hidden quality costs [3], it was identified that these costs range between 16.91% and 26.90% of the company's revenue, with a mean of 21.91% and a standard deviation of 8.38%.

Various proposals for calculating IQC have been developed, primarily based on qualitative exploratory analysis through case studies to determine the composition of hidden costs. The predominant approaches are those based on identifying the dysfunctions that generate these costs, aiming to structure management control models that contribute to their minimization. This group also employs expert judgment methods, cause-and-effect diagrams, and multicriteria decision models such as the Analytic Hierarchy Process (AHP) [4] , [5] and the Technique for Order Preference by Similarity to Ideal Solution

(TOPSIS) [6].

Other researchers have opted for the use of fuzzy logic and the concept of possibility to address the imprecision and subjectivity underlying the quantification processes of intangible quality costs. In [7], a hybrid fuzzy MCDM approach, integrating fuzzy DEMATEL, an antientropy weighting technique, and FVIKOR, was employed to evaluate quality cost models,wich included IQC analysis. A Fuzzy Inference System (FIS) and a Fuzzy Data Envelopment Analysis (FDEA) were utilized in [8] to calculate intangible costs by addressing uncertainty, reaching a consensus among experts, and prioritizing risks through mathematical programming-based weight estimation.

Existing approaches to intangible quality cost (IQC) assessment exhibit key limitations. Qualitative exploration based on expert judgment helps identify dysfunctions but lacks a method for monetizing these costs and assessing their impact on total quality costs. Taguchi's quality loss function assumes symmetric deviations from an optimal value, which does not hold in many engineering processes, requiring complex mathematical adjustments [9]. Fuzzy logic and possibility theory address uncertainty but fail to account for human indeterminacy and the distinction between relative and absolute truths in quality evaluations. In this context, neutrosophic logic may constitute a valid option for the treatment of intangibles, as demonstrated in various studies.

Etymologically, Neutrosophy (from the French *neutre* and Latin *neuter*, meaning neutral, and from Greek *sophia*, meaning knowledge) refers to the knowledge of neutral thoughts. It forms the basis for neutrosophic logic, neutrosophic sets, neutrosophic probability, and neutrosophic statistics. The neutrosophic research method is a generalization of Hegel's dialectics, which posits that science advances not only by considering opposing ideas but also neutral ones. Its fundamental theory asserts that every idea < A > tends to be neutralized, diminished, or balanced by other ideas, so <no A> = what is not <A>, <antiA> = the opposite of <A>, and <neut A>= what is neither <A> nor <antiA> [10].

Neutrosophic logic is a generalization of Zadeh's fuzzy logic and, in particular, of Atanasso's intuitive fuzzy logic, as well as other multivalued logics [10]. It provides an inference mechanism that allows simulating human reasoning procedures in knowledge-based systems. The theory of neutrosophic logic offers a mathematical framework that enables modeling the uncertainty of human cognitive processes in a way that can be processed by computers.

The use of neutrosophic sets allows not only the inclusion of membership functions for truth and falsity but also membership functions for indeterminacy. This indeterminacy arises due to contradictions, ignorance, inconsistencies, among other causes, regarding the knowledge [11]. Neutrosophy has been utilized as a tool for the quantification of intangibles, generating a promising yet nascent research field. Although no specific precedents were found regarding intangible quality costs, the successful application of neutrosophy in evaluating other types of intangibles provides a strong foundation for exploring its applicability in this particular domain.

A dual-valued neutrosophic system were developed by [12] using TODIM-VIKOR to assess performance in sports events, effectively managing uncertainty through nuanced information characterization. Similarly, [13] applied TODIM and VIKOR with interval neutrosophic sets to enhance brand competitiveness evaluation in manufacturing, addressing the complexity of subjective assessments. These studies highlight the adaptability of neutrosophic approaches in decision-making contexts requiring precision in handling indeterminate data, reinforcing their relevance for performance measurement and strategic management in dynamic industries.

In the context of innovation and service quality assessment, [14] employed the Neutrosophic Analytic Hierarchy Process (AHP-N) to analyze innovation indicators in Latin America, incorporating intangible elements like intellectual capital and collaborative networks. Likewise, [15] utilized neutrosophic sets combined with bipolar numbers and TOPSIS to refine decision-making in airline service evaluation, mitigating vagueness and uncertainty. Additionally, [16] applied compensatory neutrosophic fuzzy logic for strategic evaluation in education, integrating institutional reputation and community perception.

These contributions emphasize the versatility of neutrosophic logic in addressing complex, qualitative decision-making challenges. Therefore, the adaptation of neutrosophic methods to analyze and measure aspects such as customer perception, brand reputation, and innovation can provide new insights for understanding and managing intangible costs associated with product and service quality. The objective of this research was to design a framework for the hierarchization and quantification of intangible quality costs, based on AHP and TOPSIS neutrosophic methods.

**2. Preliminaries**

The "theory of neutrosophic sets" is based on classical set theory and fuzzy set theory, adding a membership function to the set μ, typically defined as a number x between 0 and 1 (the interval [0,1]), as opposed to the classical binary membership defined in the set {0,1}. Thus, the concept of a neutrosophic set is introduced, associated with a specific linguistic value, defined by a word, adjective, or linguistic label. The truth value in the neutrosophic set is as follows [10]:

Let N be a set defined as:$N = \{(T, I, F): T, I, F \subseteq [0,1]\}$, a neutrosophic valuation nn is a mapping of the set of propositional formulas, meaning that for each statement pp, we have $v(p) = (T, I, F)$.

In order to facilitate real-world applications of neutrosophic sets and operators of theoretical sets, the concept of single-valued neutrosophic sets (SVNS) was introduced. A single-valued neutrosophic set (SVNS) is defined as follows [10]:

Let X be a universe of discourse, a single-valued neutrosophic set (SVNS) A over X has the following form:

$$E = \{\langle x, T_e(x), I_e(x), F_e(x)\rangle : x \in X\}d \quad (1)$$

Where:

$T_e(x): X \to [0,1], I_e(x): X \to [0,1]\ y\ F_e(x): X \to [0,1]$

With:

$0 \le T_e(x), I_e(x), F_e(x) \le 3, \forall\ x \in X$

When multiplying an SVNS by a scalar, according to [17], it is verified that:

$$a\bar{E}_k = \langle 1 - (1 - T_k)^a, {I_k}^a, {F_k}^a \rangle \quad (2)$$

To find a single SVNS that simultaneously describes multiple sets, aggregation operators are used, such as the Single-Valued Neutrosophic Weighted Average Operator (SVNOWA) [10], [17].

$$F_w(E_1, E_2, \dots, E_n) = \langle 1 - \prod_{j=1}^{n}\left(1 - T_{E_j}(x)\right)^{w_j}, \prod_{j=1}^{n}\left(I_{E_j}(x)\right)^{w_j}, \prod_{j=1}^{n}\left(F_{E_j}(w)\right)^{w_j} \rangle \quad (3)$$

Where:

W= ($w_1$,…,$w_n$ ), it´s the weight vector of the E_j SVNS, to (j=1,2,…,n) such $w_j \in [0,1]$ and $\sum_{j=1}^{n} w_j = 1$.

To de-neutrosophize this set in order to obtain a precise value, a scoring or precision function is generally used [18]. The precision function $\widehat{K}$ of a set $E_i$, [17], is based on the difference between the truth and falsity membership degrees and is defined by:

$$\widehat{K}(E_i) = T_i - F_i, \widehat{K}(E_i) \in [-1, 1] \quad (4)$$

The most common application of operations with SVNS is their association with linguistic variables for qualitative evaluation, classification, or, more generally, the collection of information with imprecise, indeterminate, or subjective nature. Using the words of [19] "this is because, generally, experts feel more comfortable providing their knowledge using terms close to the way humans communicate, through linguistic variables." A linguistic variable is a variable whose values are words or phrases in a natural or artificial language [20].

On the other hand, single-valued triangular neutrosophic numbers (SVTNN), defined as ā=⟨(l,m,u); $T_{ā}$, $I_{ā}$, $F_{ā}$⟩, can be converted to precise numbers, according to [11], by:

$$S(E_k) = \frac{1}{8}[l_k + m_k + u_k](2 + T_k - I_k - F_k) \quad (5)$$

The use of SVNS, SVTNN, and other neutrosophic sets and numbers has enabled the introduction of neutrosophic variants of multicriteria decision-making methodologies (MCDM), such as AHP and TOPSIS. This new approach aims to enhance the ability of these techniques to handle the uncertainty inherent in complex decision-making situations [21], [22].

The neutrosophic AHP differs from the classical AHP in that, after defining the problem and decision criteria in the form of hierarchical objectives—considering criteria, sub-criteria, and alternatives—the various elements are evaluated using neutrosophic scales. Based on Saaty's numerical scale, [23] proposed a triangular neutrosophic scale, where the degrees of truth, uncertainty, and falsity are associated with respective degrees of credibility, uncertainty, and inconsistency of decision-makers.

On the other hand, TOPSIS is a mathematical programming technique originally applied in continuous contexts, later modified for discrete multicriteria problems. It is used to identify solutions closest to an ideal solution by applying a distance measure. It´s addresses the problem of ranking alternatives using the concept of distance to ideal and anti-ideal results. Neutrosophic TOPSIS employs neutrosophic sets to capture and manage ambiguity and vagueness in data, making it better suited to situations where the certainty of evaluations is limited [22].

This makes it suitable for applications requiring the management of uncertainty, such as the evaluation of intangibles. In the present research proposal, the AHP-TOPSIS-N technique (Fig. 1) is employed, a combination of both methods in their neutrosophic variants for the evaluation and prioritization of risks that may generate intangible quality costs. This proposal incorporates contributions from various authors to balance the methods' potential with the simplification of their practical application.

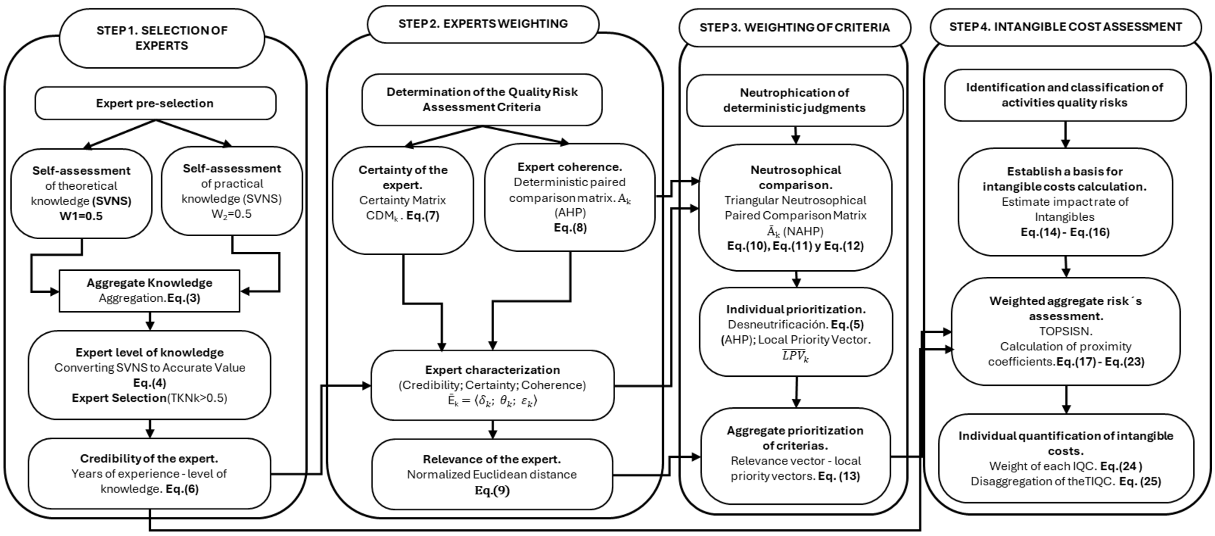


**Fig.1** *Methodological scheme of the AHP-TOPSIS-N technique for the IQCs prioritization and quantification.*

The detailed description of these steps and their mathematical procedure is shown below:

**Step 1. Selection of experts**.

The pre-selection of experts was carried out by the specialists of the research group, based on the years of experience in the profession (more than five years), the prestige achieved by their performance evaluations and the availability to participate in the study. The final selection was made based on the level of knowledge (theoretical and practical) on the subject of quality costs. Both levels of knowledge were measured using the linguistic scale associated with SVNS values shown in Table 2, which includes 11 self-assessment categories.

**Table 2.** *Linguistic terms associated with SVNS for expert assessment*

| Linguistic term | Evaluation | SVNS |
|---|---|---|
| Extremely High | EA | (1; 0; 0) |
| Very Very High | MMA | (0.9, 0.1, 0.1) |
| Very High | MA | (0,8; 0,15; 0,20) |
| High | A | (0.70,0.25,0.30) |
| Medium High | MEA | (0,60; 0,35; 0,40) |
| Medium | ME | (0,50; 0,50; 0,50) |
| Medium Low | MEB | (0,40; 0,65; 0,60) |
| Low | B | (0.30,0.75,0.70) |
| Very Low | MB | (0,20; 0,85; 0,80) |
| Very Very Low | MMB | (0.10,0.90,0.90) |
| Extremely Low | EB | (0; 1; 1) |

Once the self-assessments of the shortlisted experts were obtained, these SVNSS were aggregated using the Eq. (3), and the result was converted into a precise value by equation (4). Experts with knowledge level values greater than 0.5, which constitutes the 75th percentile of the precision function range, were included in the study. This group was then calculated for their degree of credibility ($\delta_k$), by averaging their level of knowledge with the years of relative experiences, through an adaptation of the equation used by [23].

Given selected experts, the credibility of the k-th expert depends on their years of experience ($YE_k$) and their level of knowledge ($TKN_k$).

$$\delta_k = \frac{\left(\frac{YE_k}{max_{k=1\ldots p}\{YE_k\}} + TKN_k\right)}{2} \quad (6)$$

**Step 2. Weighting of experts**

Each expert was associated with a weighting coefficient which was calculated as a relevance index that included three criterion elements: credibility (calculated in the previous step), uncertainty and incoherence. The uncertainty of the k-th expert ($\theta_k$), it was obtained from the certainty matrix that the expert provided, together with the deterministic paired comparison matrix for the risk assessment criteria $A_k=\{a_{kij}\}$. To each judgment $a_{ij}$, therefore, a value of certainty corresponded ($SC_{ij} \in [0-1]$) on the criterion issued, as explained in [23]. Then the index of certainty was calculated:

$$\theta_k = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}(1 - SC_{ij})}{n^2} \quad (7)$$

On the other hand, the incoherence of the k-th expert ($\varepsilon_k$), was calculated as the consistency ratio of the paired comparison matrix $A_k$, therefore:

$$\varepsilon_k = \frac{IC_k}{IR} \quad (8)$$

Where $IC_k$ is the consistency index of $A_k$, and IR is the random index or minimum consistency allowed for the number of items compared. Each expert was then characterized by the neutrosophical triad $\bar{E}_k=\langle\delta_k, \theta_k, \varepsilon_k\rangle$, where $\bar{E}_k$ is the neutrosophical triad associated with the k-th expert. Next, the precise relevance of the k-th expert ($\varphi_k$), was obtained as the normalized Euclidean distance between $\bar{E}_k$ and the ideal point of neutrosophic reliability ⟨1,0,0⟩, as described in [23].

$$\varphi_k = \frac{1-\sqrt{\{(1-\delta_k)^2+\theta_k{}^2+\varepsilon_k{}^2\}/3}}{\sum_{k=1}^{p}\left(1-\sqrt{\{(1-\delta_k)^2+\theta_k{}^2+\varepsilon_k{}^2\}/3}\right)} \quad (9)$$

**Step 3. Weighting criteria**

For the paired comparison neutrosophical matrix $\bar{A}_k$, with n criterias and $\bar{a}_{ij}=\langle(l_{ij},m_{ij},u_{ij}); T_{ij}, I_{ij}, F_{ij}\rangle\ \forall\ i,j \in\{1,\ldots,n\}$, it was assumed as the main diagonal $\bar{a}_{ii}=\langle(1,1,1); 1,0,0\rangle\ \forall\ i \in \{1,\ldots,n\}$, while the reciprocal elements were expressed as $\bar{a}_{ji}=1/\bar{a}_{ij}=\langle(1/u_{ij},1/m_{ij},1/l_{ij}); T_{ij}, I_{ij}, F_{ij}\rangle\ \forall\ i,j \in\{1,\ldots,n\}$[23]. The values $(l_{ij},m_{ij},u_{ij})$ of

each judgment were defined from Saaty's fundamental scale, and therefore are framed in the interval 1/9 - 9. The central values $m_{ij}$ correspond to the judgments made by each expert. They are the values that the conventional AHP technique would consider deriving the weights of each element. In this case, the central $m_{ij}$ values must also satisfy consistency checking.
The lower and upper limits ($l_{ij}$, $u_{ij}$) depend on the degree of $SC_{ij}$ certainty that the expert stated in relation to his $a_{ij}$ judgment, and are calculated as follows:

$$l_{ij} = \mathrm{m_{ij}} - \Delta\mathrm{V_{ij}} \tag{10}$$

$$u_{ij} = \mathrm{m_{ij}} + \Delta\mathrm{V_{ij}} \tag{11}$$

Where $\Delta V_{ij}$ are the number of steps on the Saaty scale between the center value and the extreme values. $\Delta V_{ij}$ was calculated based on the $SC_{ij}$ certainty declared by the k-th expert.

$$\Delta V_{ij} = \begin{cases} 0 \ para & \mathrm{SCij} = 1 \\ 1 \ para \ 0.8 \leq & \mathrm{SC_{ij}} < 1 \\ 2 \ para \ 0.6 \leq & \mathrm{SC_{ij}} < 0.80 \\ 3 \ para \ 0.4 \leq & \mathrm{SC_{ij}} < 0.60 \\ 4 \ para \ 0.2 \leq & \mathrm{SC_{ij}} < 0.40 \\ 5 \ para \quad 0 < & \mathrm{SC_{ij}} < 0.20 \\ 6 \ para & \mathrm{SCij} = 0 \end{cases} \tag{12}$$

Thus, the triangular neutrosophic matrix of paired comparison was obtained, which components were deneutrosified by using the equation (5).

By replicating the conventional AHP method to the matrix obtained, the local priority vector for each expert was calculated ($\overline{LPV_k}$). These results were aggregated by multiplying the relevance vector by each of these local priority vectors.

$$\overline{LPV} = \begin{bmatrix} \bar{\varphi} * \overline{LPV_1} \\ \bar{\varphi} * \overline{LPV_2} \\ \vdots \\ \bar{\varphi} * \overline{LPV_p} \end{bmatrix} = \begin{bmatrix} PC_1 \\ PC_2 \\ \vdots \\ PC_n \end{bmatrix} \tag{13}$$

The components of the aggregate vector constituted the weighting coefficients for each criterion used in the assessment of quality risks.

**Step 4. Evaluation of intangible costs of quality**

The risks due to activities were identified from a brainstorming session among the steel mill's specialists
To assign a value to the estimate of intangible costs, each expert provided an estimate interval of the percentage of sales that are affected by intangible quality risks. The interval estimate of the global risk impact rate (IRR) was calculated:

$$\mathrm{RIRS} = \left[\widehat{RIRS}_{min};\ \widehat{RIRS}_{max}\right] = \left[\sum_{k=1}^{p} \varphi_k \widehat{RIRS}_{kmin};\ \sum_{k=1}^{p} \varphi_k \widehat{RIRS}_{kmax}\right] \tag{14}$$

Therefore, the point estimate of the impact rate of intangible risks on total sales was calculated as the midpoint of the aggregated interval.

$$\widehat{\mathrm{RIRS}} = \left(\frac{\widehat{\mathrm{RIRS}}_{min} + \widehat{\mathrm{RIRS}}_{max}}{2}\right) \tag{15}$$

Luego el valor total del costo intangible de calidad (TIQC) se expresó como la multiplicación de las ventas totales (S) por la tasa de impacto estimada.

$$TIQC = \widehat{\mathrm{RIRS}} * S \tag{16}$$

To distribute this value among the activities, it was necessary to identify risks per activity and classify them as tangible or intangible for prioritization using the TOPSISN method supported by SVNSS. The experts assessed the risks, in accordance with each of the applied criteria, using the linguistic terms presented in **Table 2**. Based on these results, the neutrosophic evaluation matrices for each expert/criterion ($DEC_{ki}$) were constructed. To aggregate the experts' responses, the weighting coefficient $\varphi_k$ and Eq. (2) were applied. This yielded the aggregated neutrosophic evaluation matrices for each criterion ($DEA_i$).

$$DEA_i = \sum_{k=1}^{p} \varphi_k * DEC_{ki} \tag{17}$$

Likewise, the aggregate and criterion-weighted neutral matrix was calculated using this same method and applying the $PC_i$ as aggregation coefficients.

$$DEAP_i = \sum_{i=1}^{n} PC_i * DEA_i \tag{18}$$

Subsequently, the ideal and anti-ideal SVNS solutions were calculated from the obtained matrix. Criteria can be classified as either benefit-type or cost-type. Let $C_b$ denote the set of benefit-type criteria and $C_c$ the cost-type criteria. The ideal alternatives were defined as follows:

$$\gamma^+ = \left(a_{\gamma^+w}(\delta_j), b_{\gamma^-w}(\delta_j), c_{\gamma^-w}(\delta_j)\right) \tag{19}$$

It denotes the positive ideal solution corresponding to $C_b$.

$$\gamma^- = \left(a_{\gamma^-w}(\delta_j), b_{\gamma^+w}(\delta_j), c_{\gamma^+w}(\delta_j)\right) \tag{20}$$

It denotes the positive ideal solution corresponding to $C_c$.

Then, the average distances to the positive and negative SVNS ideal solutions [24] were calculated:

$$s_i^+ = \left(\frac{1}{3}\sum_{j=1}^{n}\left\{\left(a_{ij} - a_j^+\right)^2 + \left(b_{ij} - b_j^+\right)^2 + \left(c_{ij} - c_j^+\right)^2\right\}\right)^{\frac{1}{2}} \tag{21}$$

$$s_i^- = \left(\frac{1}{3}\sum_{j=1}^{n}\left\{\left(a_{ij} - a_j^-\right)^2 + \left(b_{ij} - b_j^-\right)^2 + \left(c_{ij} - c_j^-\right)^2\right\}\right)^{\frac{1}{2}} \tag{22}$$

Each risk proximity coefficient was calculated (CP, con $0 \leq CP_j \leq 1$):

$$CP_j = \frac{s^-}{s^+ + s^-} \tag{23}$$

As in the classical method, the alternatives (the risks) were ordered in a decreasing direction, starting with the one that comes closest to the ideal solution (greater relative proximity). This risk prioritization list included both tangible and intangible quality risks. The weighting of each IQR was then calculated, based on its CP.

$$PIQR_i = \frac{CP_i}{\sum_{i=1}^{m} CP_i} \tag{24}$$

Then, the intangible cost of quality ($IQC_i$) associated with the intangible risk of $IQR_i$ quality was calculated:

$$\boldsymbol{IQC_i = PRIC_i * TIQC} \tag{25}$$

To illustrate the application of the methodology, the results of its partial implementation in the steelmaking area of a company producing and commercializing carbon steel billets, bars, and profiles are presented. Specifically, the results focus on the scrap reception activity.

## 3 Results

The results obtained are shown below in the order proposed on the methodology (Fig. 1). From an initial pre-selection of 10 experts, the seven represented in the Table were selected 3

**Table 3.** *Expertos seleccionados*

| Expert ($E_k$) | Aggregate expert assessment (SVNS) | Level of knowledge ($TKN_k$) | Years of experience |
|---|---|---|---|
| $E_1$ | (0.87,0.11,0.13) | 0.743 | 12 |
| $E_2$ | (0.78,0.2,0.22) | 0.555 | 12 |
| $E_3$ | (0.91,0.07,0.09) | 0.818 | 30 |
| $E_4$ | (0.87,0.11,0.13) | 0.743 | 10 |
| $E_5$ | (0.78,0.2,0.22) | 0.555 | 11 |
| $E_6$ | (0.87,0.11,0.13) | 0.743 | 28 |
| $E_7$ | (0.87,0.11,0.13) | 0.743 | 31 |

Due to space constraints, only the individual results from Expert E1 are presented below, pertaining to the calculation of the credibility index and the local priority vector for criteria weighting. By applying Eq. (6), we obtained: $\delta_1$=0.565.

Through a brainstorming session, the experts selected the following criteria for quality risk evaluation: CR-1: Probability of occurrence; CR-2: Severity; CR-3: Difficulty of detection; CR-4: Impact on customer reputation/trust; CR-5: Financial impact; CR-6: Impact on productivity; CR-7: Impact on worker safety/health; and CR-8: Effect on other risks. Table 4 presents the deterministic pairwise comparison matrix provided by expert $E_1$, along with its corresponding local priority vector, derived from the normalized matrix.

**Table 4.** *Expert's $E_1$ deterministic paired comparison matrix*

| Criteria | CR-1 | CR-2 | CR-3 | CR-4 | CR-5 | CR-6 | CR-7 | CR-8 | Local priority vector |
|---|---|---|---|---|---|---|---|---|---|
| CR-1 | 1 | 1/3 | 5 | 5 | 7 | 5 | 3 | 7 | 0,241 |
| CR-2 | 3 | 1 | 7 | 5 | 9 | 7 | 3 | 5 | 0,334 |
| CR-3 | 1/5 | 1/7 | 1 | 1/3 | 3 | 1/3 | 1/5 | 1/5 | 0,034 |
| CR-4 | 1/5 | 1/5 | 3 | 1 | 5 | 3 | 1/3 | 1/3 | 0,073 |
| CR-5 | 1/7 | 1/9 | 1/3 | 1/5 | 1 | 1/3 | 1/7 | 1/5 | 0,020 |
| CR-6 | 1/5 | 1/7 | 3 | 1/3 | 3 | 1 | 1/5 | 1/3 | 0,047 |
| CR-7 | 1/7 | 1/3 | 5 | 3 | 7 | 5 | 1 | 3 | 0,147 |
| CR-8 | 1/3 | 1/5 | 5 | 3 | 5 | 3 | 1/3 | 1 | 0,104 |

For expert $E_1$, a low inconsistency level was observed ($\varepsilon_1$=0.09). Using the certainty matrix provided by this first expert (see **Table 5**), the third component of the neutrosophic triad was calculated to characterize the uncertainties inherent to the evaluation process.

**Table 5.** *Expert E1's certainty matrix*

| Criterios | CR-1 | CR-2 | CR-3 | CR-4 | CR-5 | CR-6 | CR-7 | CR-8 |
|---|---|---|---|---|---|---|---|---|
| CR-1 | 1 | 0,9 | 0,4 | 0,8 | 0,8 | 0,7 | 0,9 | 0,8 |
| CR-2 | 0,9 | 1 | 0,8 | 0,6 | 0,8 | 0,8 | 0,9 | 0,6 |
| CR-3 | 0,4 | 0,8 | 1 | 0,9 | 0,9 | 0,8 | 0,4 | 0,5 |
| CR-4 | 0,8 | 0,6 | 0,9 | 1 | 0,5 | 0,9 | 0,9 | 0,9 |
| CR-5 | 0,8 | 0,8 | 0,9 | 0,5 | 1 | 0,9 | 0,8 | 0,7 |
| CR-6 | 0,7 | 0,8 | 0,8 | 0,9 | 0,9 | 1 | 0,6 | 0,8 |
| CR-7 | 0,9 | 0,9 | 0,4 | 0,9 | 0,8 | 0,6 | 1 | 0,9 |
| CR-8 | 0,8 | 0,6 | 0,5 | 0,9 | 0,7 | 0,8 | 0,9 | 1 |

The uncertainty index $\theta_1$=0.213 was calculated using Eq. (7), resulting in the neutrosophic characterization $\bar{E}_1$=⟨0.565,0.213,0.09⟩. From these values, the precise relevance weight of expert $E_1$ ($\varphi_1$=0.162) was determined by applying Eq. (9). Table 6 illustrates the triangular neutrosophic pairwise comparison matrix, derived by integrating the neutrosophic triad of $E_1$ with the TNN values corresponding to each of his judgments.

**Table 6.** *Triangular neutrosophic paired comparison matrix*

| Criteria | CR-1 | CR-2 | … | CR-8 |
|---|---|---|---|---|
| CR-1 | ⟨(1,1,1);1,0,0⟩ | ⟨(0,25,0,33,0,49);0.74,0.21,0.09⟩ | … | ⟨(5,7,9);0.74,0.21,0.09⟩ |
| CR-2 | ⟨(2,3,4);0.74,0.21,0.09⟩ | ⟨(1,1,1);1,0,0⟩ | … | ⟨(2,5,8);0.74,0.21,0.09⟩ |
| CR-3 | ⟨(0,11,0,2,1);0.74,0.21,0.09⟩ | ⟨(0,11,0,14,0,19);0.74,0.21,0.09⟩ | … | ⟨(0,13,0,2,0,5);0.74,0.21,0.09⟩ |
| CR-4 | ⟨(0,14,0,2,0,33);0.74,0.21,0.09⟩ | ⟨(0,13,0,2,0,5);0.74,0.21,0.09⟩ | … | ⟨(0,25,0,33,0,49);0.74,0.21,0.09⟩ |

| | | | | |
|---|---|---|---|---|
| CR-5 | ⟨(0,11,0,14,0,19);0.74,0.21,0.09⟩ | ⟨(0,09,0,11,0,14);0.74,0.21,0.09⟩ | … | ⟨(0,14,0,2,0,33);0.74,0.21,0.09⟩ |
| CR-6 | ⟨(0,14,0,2,0,33);0.74,0.21,0.09⟩ | ⟨(0,11,0,14,0,19);0.74,0.21,0.09⟩ | … | ⟨(0,2,0,33,0,97);0.74,0.21,0.09⟩ |
| CR-7 | ⟨(0,12,0,14,0,16);0.74,0.21,0.09⟩ | ⟨(0,25,0,33,0,49);0.74,0.21,0.09⟩ | … | ⟨(2,3,4);0.74,0.21,0.09⟩ |
| CR-8 | ⟨(0,2,0,33,0,97);0.74,0.21,0.09⟩ | ⟨(0,13,0,2,0,5);0.74,0.21,0.09⟩ | … | ⟨(1,1,1);1,0,0⟩ |

By applying Eq. (5), the deneutrosified paired comparison matrix was constructed as it shown in Table 7. These values, while crisp, include the effect of indeterminacy and vagueness associated with the original judgments.

**Table 7.** *Deneutrosified paired comparison matrix*

| Criterios | CR-1 | CR-2 | CR-3 | CR-4 | CR-5 | CR-6 | CR-7 | CR-8 | Vector de prioridad local |
|---|---|---|---|---|---|---|---|---|---|
| CR-1 | 1.125 | 0.306 | 2.855 | 2.855 | 3.997 | 2.855 | 1.713 | 3.997 | 0.275 |
| CR-2 | 1.713 | 1.125 | 3.997 | 2.855 | 5.139 | 3.997 | 1.713 | 2.855 | 0.383 |
| CR-3 | 0.374 | 0.127 | 1.125 | 0.306 | 1.713 | 0.428 | 0.176 | 0.236 | 0.060 |
| CR-4 | 0.193 | 0.236 | 1.713 | 1.125 | 2.855 | 1.713 | 0.428 | 0.306 | 0.102 |
| CR-5 | 0.127 | 0.095 | 0.428 | 0.193 | 1.125 | 0.428 | 0.122 | 0.176 | 0.035 |
| CR-6 | 0.236 | 0.122 | 1.713 | 0.428 | 1.713 | 1.125 | 0.236 | 0.306 | 0.068 |
| CR-7 | 0.122 | 0.428 | 2.855 | 1.713 | 3.997 | 2.855 | 1.125 | 1.713 | 0.185 |
| CR-8 | 0.428 | 0.193 | 2.855 | 1.713 | 2.855 | 1.713 | 0.306 | 1.125 | 0.131 |

This same procedure was applied to the rest of the experts. In this way, the hierarchy of the risk assessment criteria presented in Table 8 was obtained.

**Table 8.** *Prioritization of quality risk assessment criteria*

| Expert | Characterization and relevance | | | | Criterial local priority | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\delta_k$ | $\theta_k$ | $\varepsilon_k$ | $\varphi_k$ | CR-1 | CR-2 | CR-3 | CR-4 | CR-5 | CR-6 | CR-7 | CR-8 |
| $E_1$ | 0.565 | 0.181 | 0.069 | 0.162 | 0.275 | 0.383 | 0.060 | 0.102 | 0.035 | 0.068 | 0.185 | 0.131 |
| $E_2$ | 0.469 | 0.181 | 0.131 | 0.149 | 0.252 | 0.386 | 0.042 | 0.077 | 0.094 | 0.093 | 0.126 | 0.185 |
| $E_3$ | 0.893 | 0.175 | 0.069 | 0.195 | 0.263 | 0.377 | 0.064 | 0.034 | 0.047 | 0.133 | 0.183 | 0.1 |
| $E_4$ | 0.533 | 0.191 | 0.093 | 0.157 | 0.244 | 0.391 | 0.049 | 0.047 | 0.074 | 0.103 | 0.197 | 0.136 |
| $E_5$ | 0.452 | 0.203 | 0.102 | 0.147 | 0.117 | 0.183 | 0.059 | 0.052 | 0.109 | 0.073 | 0.404 | 0.266 |
| $E_6$ | 0.823 | 0.172 | 0.093 | 0.189 | 0.383 | 0.244 | 0.065 | 0.04 | 0.184 | 0.164 | 0.127 | 0.125 |
| $E_7$ | 0.872 | 0.184 | 0.078 | 0.193 | 0.255 | 0.376 | 0.146 | 0.037 | 0.044 | 0.099 | 0.196 | 0.065 |
| | | | Priority vector | | 0.311 | 0.401 | 0.085 | 0.064 | 0.1 | 0.128 | 0.237 | 0.165 |
| | | | Priority order | | 2 | 1 | 7 | 8 | 6 | 5 | 3 | 4 |

Once again, brainstorming was applied between specialists from the technical group and the selected experts, this time to identify and classify the quality risks related to the scrap reception activity, which are shown in Table 9.

**Table 9.** *Quality risks associated with the activity Reception of scrap*

| Code | Identified risk | Clasification |
|---|---|---|
| TR_1 | The scrap contains high content of hidden defects | Tangible |
| TR_2 | Breakage of cranes, their parts and pieces or failures of the weighing system. | Tangible |
| TR_3 | Inhalation or ingestion of harmful substances. | Tangible |
| TR_4 | Entrapment due to machine or vehicle overturns | Tangible |
| IR_1 | Poor communication and negotiation with key suppliers | Intangible |
| IR_2 | Loss of confidence in working with suppliers | Intangible |
| IR_3 | Lack of experience in visual inspection of scrap for classification | Intangible |
| IR_4 | Low motivation due to inadequate working conditions in receiving area | Intangible |

When applying the NTOPSIS, the aggregate decision matrix of the experts was first obtained, which is presented in Table 10.

**Table 10.** *Aggregated expert decision matrix*

| | CR-1 | CR-2 | CR-3 | CR-4 | ... | CR-8 |
|---|---|---|---|---|---|---|
| QR1 | (0.89,0.154,0.18) | (0.836,0.227,0.241) | (0.54,0.438,0.511) | (0.718,0.338,0.358) | … | (0.844,0.154,0.236) |
| QR2 | (0.532,0.449,0.536) | (0.838,0.189,0.239) | (0.539,0.482,0.508) | (0.643,0.352,0.412) | … | (0.652,0.328,0.414) |
| QR3 | (0.115,0.891,0.919) | (0.72,0.298,0.366) | (0.548,0.48,0.517) | (0.552,0.477,0.497) | … | (0.821,0.236,0.27) |
| QR4 | (0.113,0.86,0.899) | (0.818,0.204,0.257) | (0.571,0.458,0.479) | (0.344,0.66,0.689) | … | (0.747,0.267,0.325) |
| QR5 | (0.447,0.582,0.603) | (0.121,0.845,0.908) | (0.835,0.197,0.267) | (0.312,0.667,0.733) | … | (0.745,0.306,0.328) |
| QR6 | (0.303,0.7,0.728) | (0.113,0.872,0.92) | (0.84,0.175,0.258) | (0.508,0.501,0.55) | … | (0.823,0.239,0.243) |
| QR7 | (0.445,0.561,0.611) | (0.228,0.782,0.801) | (0.695,0.357,0.382) | (0.328,0.661,0.714) | … | (0.886,0.172,0.213) |
| QR8 | (0.322,0.654,0.729) | (0.44,0.574,0.603) | (0.818,0.209,0.264) | (0.521,0.477,0.543) | … | (0.753,0.257,0.326) |

Then the matrix weighted according to priority of the Criteria (Table 11), resulted:

**Table 11.** *Aggregate decision matrix, weighted based on the Criteria*

| | CR-1 | CR-2 | CR-3 | CR-4 | … | CR-8 |
|---|---|---|---|---|---|---|
| $QR_1$ | (0.496,0.559,0.587) | (0.515,0.552,0.566) | (0.064,0.932,0.944) | (0.078,0.933,0.936) | … | (0.264,0.734,0.788) |
| $QR_2$ | (0.21,0.78,0.824) | (0.518,0.513,0.564) | (0.064,0.94,0.944) | (0.064,0.935,0.945) | … | (0.16,0.832,0.864) |
| $QR_3$ | (0.037,0.965,0.974) | (0.399,0.616,0.669) | (0.066,0.939,0.945) | (0.05,0.954,0.956) | … | (0.248,0.788,0.805) |
| $QR_4$ | (0.037,0.954,0.967) | (0.495,0.529,0.58) | (0.07,0.936,0.939) | (0.027,0.974,0.976) | … | (0.203,0.804,0.83) |
| $QR_5$ | (0.168,0.845,0.855) | (0.05,0.935,0.962) | (0.143,0.871,0.893) | (0.024,0.974,0.98) | … | (0.202,0.822,0.832) |
| $QR_6$ | (0.106,0.895,0.906) | (0.047,0.947,0.967) | (0.145,0.862,0.891) | (0.045,0.957,0.962) | … | (0.249,0.789,0.791) |
| $QR_7$ | (0.167,0.836,0.858) | (0.098,0.906,0.915) | (0.096,0.916,0.921) | (0.025,0.974,0.979) | … | (0.302,0.748,0.774) |
| $QR_8$ | (0.114,0.876,0.906) | (0.207,0.801,0.817) | (0.135,0.875,0.893) | (0.046,0.954,0.962) | … | (0.206,0.799,0.831) |

From these results, the ideals and anti-ideals shown in Table 12 were calculated, obtained by Eq. (19) and Eq. (20).

**Table 12.** *Ideal and anti-ideal values by criterion*

| Criteria | Ideal value | Anti-ideal value |
|---|---|---|
| Probability of occurrence | (0.037,0.965,0.974) | (0.965,0.974,0.496) |
| Severity | (0.047,0.947,0.967) | (0.947,0.967,0.518) |
| Difficulty of detection | (0.064,0.94,0.945) | (0.94,0.945,0.145) |
| Impact on customer reputation/trust | (0.024,0.974,0.98) | (0.974,0.98,0.078) |
| Financial impact | (0.036,0.963,0.967) | (0.963,0.967,0.165) |
| Impact on productivity | (0.052,0.948,0.956) | (0.948,0.956,0.232) |
| Affect on workers' safety/health | (0.029,0.97,0.977) | (0.97,0.977,0.448) |
| Effect on other risks | (0.16,0.832,0.864) | (0.832,0.864,0.302) |

At the last moment of the application of NTOPSIS, shown in Table 13, the distances from the extremes, the proximity coefficients, were obtained by applying Eq. (21), Eq. (22) and Eq. (23), respectively; as well as the prioritization of quality risks.

**Table 13.** *Risk prioritization*

| Quality risks | $S_i$+ | $S_i$- | $CP_i$ | Priority |
|---|---|---|---|---|
| The scrap contains high content of hidden defects | 0.638 | 0.499 | 0.561 | 1 |
| Breakage of the cranes, their parts and pieces or failure of the weighing system | 0.493 | 0.411 | 0.545 | 2 |
| Inhalation or ingestion of harmful substances | 0.501 | 0.481 | 0.510 | 4 |
| Entrapment by overturning machines or vehicles | 0.546 | 0.459 | 0.543 | 3 |
| Poor communication and negotiation with key suppliers | 0.176 | 0.665 | 0.209 | 7 |
| Loss of confidence in working with suppliers | 0.166 | 0.692 | 0.194 | 8 |
| Lack of experience in visual inspection of scrap for classification | 0.256 | 0.600 | 0.299 | 5 |
| Low motivation due to inadequate working conditions in receiving area | 0.214 | 0.556 | 0.277 | 6 |

Based on the CPi associated with intangible risks, the following $PRIC_i$ coefficients were determined for the disaggregation of the TCIC, applying Eq. (24). So: $PRIC_1$=0.214; $PRIC_2$=0.198; $PRIC_3$=0.305 and $PRIC_4$=0.283. Next, the experts estimated the intervals of the impact rates on sales, of the total intangible costs. Table 14 shows these intervals, as well as the estimated point rate of impact.

**Table 14.** *Estimación intervalar y puntual del RIRS*

| **Expert ($E_k$)** | **RIRS min** | **RIRS max** |
|---|---|---|
| $E_1$ | 0.16 | 0.21 |
| $E_2$ | 0.1 | 0.15 |
| $E_3$ | 0.08 | 0.19 |
| $E_4$ | 0.09 | 0.15 |
| $E_5$ | 0.13 | 0.2 |

| **Expert ($E_k$)** | **RIRS min** | **RIRS max** |
|---|---|---|
| $E_6$ | 0.16 | 0.19 |
| $E_7$ | 0.12 | 0.2 |
| Average | 0.12 | 0.184 |
| RIRS | 0.152 | |

For $3813256.00 in sales, the total intangible quality costs, applying Eq. (16), resulted in TIQC=$579614.91. Then, by distributing the value among the intangible costs of quality through Eq. (25), the results of Table 15 were obtained.

**Table 15.** *Quantified intangible quality costs*

| Intangible quality costs | PRIC | IQC |
|---|---|---|
| Poor communication and negotiation with key suppliers | 0.214 | $124037.59 |
| Loss of trust in collaboration with suppliers | 0.198 | 114763.75 |
| Lack of experience in visual inspection of scrap for classification | 0.305 | 176782.55 |
| Low motivation due to inadequate working conditions in the receiving area. | 0.283 | 164031.02 |
| TOTAL | 1.00 | $579614.91 |

The results presented in Table 15 revealed that the intangible quality costs associated with scrap reception at the steel mill constituted a significant economic burden, totaling $579,614.91. Among the identified factors, the lack of expertise in visual inspection for scrap classification exhibited the highest economic impact, with an estimated cost of $176,782.55, highlighting the urgent need for enhanced personnel training in this area. Low motivation stemming from suboptimal working conditions also represented a substantial cost ($164,031.02), underscoring the influence of internal factors on operational efficiency. Additionally, poor communication and negotiation with key suppliers, along with diminished trust in collaborative partnerships, contributed $124,037.59 and $114,763.75, respectively.

## 5. Conclusions

The study demonstrates the feasibility of integrating Neutrosophic Analytic Hierarchy Process (NAHP) with triangular neutrosophic numbers and Neutrosophic TOPSIS (NTOPSIS) with single-valued neutrosophic sets to quantify intangible quality costs (IQCs). This hybrid approach effectively addresses the inherent complexity and subjectivity of IQCs, such as employee demotivation, supplier trust erosion, and operational inefficiencies, by incorporating truth, indeterminacy, and falsity degrees into evaluations. The methodology's capacity to aggregate expert judgments while managing uncertainty and conflicting information enhances precision in scenarios where traditional methods (e.g., Taguchi's loss function, fuzzy logic) struggle with human-centric indeterminacy. Application in a steel mill revealed significant IQCs attributed to inadequate scrap inspection training, validating its practical utility. Despite the relatively high computational complexity, the framework's structured yet flexible nature enables organizations to prioritize and monetize intangible risks, offering a robust tool for informed decision-making in quality management. This underscores its pertinence in bridging gaps between qualitative assessments and economic quantification.

**References**


[1] Hussinki H, King T, Dumay J, Steinhöfel E. Accounting for intangibles: a critical review. Jour of Acc Lit. 2024;47(5):27-51. doi:10.1108/jal-05-2022-0060

[2] Azebaze F, Takoudjou A. Maîtrise des coûts cachés et efficacité dans les entreprises du secteur industriel. Rev Int Sci Gest. 2021;4(1):788-806.

[3] Mahmood S, Kureshi NI. A literature review of the quantification of hidden cost of poor quality in the historical perspective. *J Qual Technol Manag*. 2015;11(1):1-24.

[4] Pérez-Fernández L, Sebastián MA, González-Gaya C. Methodology to optimize quality costs in manufacturing based on Multi-Criteria analysis and lean strategies. Applied Sciences. 2022;12(7):3295.

[5] Abdelfattah HA. Analysis and Measurement of the hidden elements in the quality cost by using (AHP) approach and its effect on achieving the company's competitive advantage (Case study from Egypt). الفكر المحاسبى. 2021;25(2):621-657. doi:10.21608/atasu.2021.181090

[6] Abbasi H, Zeynolabedin A, Nabi Bidhendi G. Assessment of combined sewer overflows impacts under flooding in coastal cities. *J Water Clim Change*. 2021;12(6):2460-2478.

[7] Wu Q, Xuan J, Zhou F, Mei Y, Su J. New quality cost framework (QCF) based on the hybrid fuzzy MCDM approach. Comput Intell Neurosci. 2022;2022(1):6416989.

[8] Jahangoshai Rezaee M, Yousefi S, Eshkevari M, et al. Risk analysis of health, safety and environment in chemical industry integrating linguistic FMEA, fuzzy inference system and fuzzy DEA. Stoch Environ Res Risk Assess. 2020;34:201-218.

[9] Khan AS, Homri L, Dantan JY, Siadat A. Modularity-based quality assessment of a disruptive reconfigurable manufacturing system-A hybrid meta-heuristic approach. Int J Adv Manuf Technol. 2021;115(5):1421-1444.

[10] Leyva-Vázquez M, Smarandache F. *Neutrosofía: Nuevos avances en el tratamiento de la incertidumbre*. Bruxelles: Pons Publishing House; 2018.

[11] Comas Rodríguez R, Campaña Muñoz L, Beltrán Ayala JM. Evaluation of the company on the internal control applying AHP neutrosophic. Investig Oper. 2024;41(5).

[12] Salama , A. A., Mobarez, O. M., Elfar, M. H., & Alhabib, R. (2024). Neutrosophic Model for Measuring and Evaluating the Role of Digital Transformation in Improving Sustainable Performance Using the Balanced Scorecard in Egyptian Universities. Neutrosophic Systems With Applications, 21, 1-24. https://doi.org/10.61356/j.nswa.2024.21370

[13] Sun P, Wang Y, Song J. Enhanced TODIM method based on VIKOR for interval neutrosophic MAGDM and applications to brand competitiveness evaluation of manufacturing enterprises. *J Intell Fuzzy Syst*. 2023;45(6):11021-11034.

[14] Quemac REC, Santos MEG, Ramos LAC, Zúñiga CPC. Neutrosophic Analytic Hierarchy Process for the analysis of innovation in Latin America. *Neutrosophic Sets Syst*. 2021;44:411-419.

[15] Zaied, A. N. H., Gamal, A., y Ismail, M. (2019). An Integrated Neutrosophic and TOPSIS for Evaluating Airline Service Quality. Neutrosophic Sets and Systems, 29(1), 3.

[16] Ricardo JE, Fernández AJR, Vázquez MYL. Compensatory fuzzy logic with single valued neutrosophic numbers in the analysis of university strategic management. *Int J Neutrosophic Sci*. 2022:151-159.

[17] Senapati T. An Aczel-Alsina aggregation-based outranking method for multiple attribute decision-making using single-valued neutrosophic numbers. *Complex Intell Syst*. 2023;10(1):1185–1199.

[18] Singh, A., & Bhat, S. A. (2021). A novel score and accuracy function for neutrosophic sets and their real-world applications to multi-criteria decision-making process. *Neutrosophic Sets and Systems, 41*, 100-110.

[19] Cabezas, R., Ruiz, J. G. y Leyva, M. (2017) A Knowledge-based Recommendation Framework using SVN. Neutrosophic Sets and Systems, 16, 24-27.

[20] Romero A, Meléndez R, Andino A. Números neutrosóficos de valor único y proceso analítico jerárquico para la discriminación de proyectos. Rev Investig Oper. 2020;41(5):751-760.

[21] Sahmutoglu I, Taskin A, Ayyildiz E. Assembly area risk assessment methodology for post-flood evacuation by integrated neutrosophic AHP-CODAS. Nat Hazards. 2023;116:1071–1103.

[22] Nafei A, Azizi SP, Edalatpanah SA, Huang C. Smart TOPSIS: A neural network-driven TOPSIS with neutrosophic triplets for green supplier selection in sustainable manufacturing. Expert Syst Appl. 2024;255:124744.

[23] Navarro I, Yepes V, Martí J. Sustainability assessment of concrete bridge deck designs in coastal environments using neutrosophic criteria weights. Struct Infrastruct Eng. 2020;16(7):949-967.

[24] Buitrón Recalde, M., et al., Evaluation of the Effectiveness of Preventive Dental Education in Primary Schools. *Neutrosophic Sets and Systems*, 2023. 62: p. 319-326.

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