Application of Neutrosophic Techniques for the Selection of the in-Hospital Triage System

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Abstract

Multicriteria decision problems are present in all branches of life and present a high degree of complexity in determining a feasible solution. In the public health sector, decisions are even more delicate because they work not only with the direct influence of human needs but also with limited financial resources. Saturation in hospital emergency services occurs when the need identified exceeds the resources available for patient care in the emergency unit. One of the elements of primary regulatory effect on saturation levels in emergency services is undoubtedly an adequate triage system. The present study presents the application of multicriteria evaluation techniques as a method for the best selection of different types of triage according to certain pre-established parameters of interest. For them, we rely on a method that combines the TODIM and PROMETHEE methods to obtain the results. In addition, the neutrosophic single value sets based on the neutrosophic logic are used so that the indeterminate and inconsistent information typical of the real world can be adequately handled. The application of the method used demonstrates the efficiency of this kind of method in solving complex problems in real life and in different fields of society, particularly

Keywords: Triage systems; selection; multicriteria decision method; neutrosophy; TODIM; PROMETHEE

1. Introduction

The term triage comes from the French *trier*, defined as choosing, separating, or classifying. Since this term began to be used in the Napoleonic battles, it has persisted as a classification or prioritization of urgent patient care. It is the process that allows clinical risk management to properly and safely manage patient flows when demand and clinical needs exceed resources.

Hospital triage is a preliminary assessment process; that is, it is performed before the full diagnostic and therapeutic assessment; and is designed to classify patients based on criteria of their clinical severity so that the most urgent are treated first, and the rest are continuously monitored and reevaluated until care can be offered. It is relatively common for the concepts of urgency and severity to be confused, being frequent that when defining triage, we speak of the classification of patients by levels of severity when in reality, what is classified is the level of urgency.

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Depending on where, how, and when this classification occurs, different types of triage can be differentiated, including urgency triage, emergency triage, or catastrophe triage, all variants of the same concept. For example, in the extra-hospital setting, emergency triage is generally used mainly due to disaster or crises in which there are multiple victims, and special conditions differentiate it from the in-hospital setting. In these cases, the priority of care will not be the severity but the survival of the patient [1].

On the other hand, hospital triage is carried out in hospitals' Emergency Services to classify patients. This process, by which a person is assessed upon arrival at the hospital to determine their problem and assign the appropriate resource to solve it, increases the quality of care and the safety of patients. Initially, the proposal to classify patients according to their severity was carried out in three levels of categorization: emergent, urgent, and non-urgent. Later, a system created in the United States that had one more level was given rise. At the same time, Australia successfully implemented the National Triage Scale for Australasian Emergency Departments, based on five levels: resuscitation, emergency, urgent, semi-urgent, and non-urgent. From this classification, multiple structured triage models have been developed with the same number of categories, such as the ATM (Andorran Triage Model), the STS (Spanish Triage System), among others, which aim to be able to be applied safely in both adults and children, regardless of the type of hospital. [2]

After the start of the COVID 19 pandemic, it became more evident than ever how important it is for hospitals and their emergency services to have a triage method appropriate to their needs and fully operational [3]. However, sometimes the necessary elements are not available to apply a specific method, and the mechanisms for selecting the most appropriate triage system according to certain criteria are unknown. [4]

This study presents the application of multicriteria evaluation techniques as a method for the best selection of different types of triage, according to certain pre-established parameters of interest. To develop the proposed objective, the study relies on the use of multiple criteria decision methods (MCDM). MCDM allows taking very complex real-life situations and developing actions to, by simplifying them, achieve decision-making under certain conditions so that the problems initially raised reach a resolutive state [5] .

Many are the MCDMs developed for solving problems in various areas of life and society. However, in traditional methods, the alternatives are usually evaluated with clear values. Moreover, due to the environment's complexity and the human being's subjectivity, MCDM problems are often accompanied by uncertainty, so the decision information provided is often confusing or linguistic. [6]–[9]

This paper presents the method proposed by Xu et al. [10], based on the TODIM and PROMETHEE methods, using single-valued neutrosophic sets (SVNS). As part of philosophy, Neutrosophy analyzes the nature of neutralities and everything related to them [3], [11]. The indeterminacy membership functions are included for the first time regarding the neutrosophic logic and the neutrosophic sets. The indeterminacy is caused by a lack of information and contradictory, inconsistent, paradoxical information. For this study, neutrosophic sets are used to eliminate the impossibility of traditional methods to handle indeterminate and inconsistent information typical of the real world. [12]

For greater clarity of the information used, first, the preliminary aspects of the neutrosophic theory and the methodology of the method used are introduced. Subsequently, they are applied, and finally, the results achieved are presented and the conclusions derived from the study.

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2. Conceptual framework

Definition 1[13] Let X be a space of points (objects) with generic elements in X denoted by x. A single-valued neutrosophic set (SVNS) A in X is characterized by truth-membership function $T_A(x)$, indeterminacy-membership function $I_A(x)$, and falsity membership function $F_A(x)$. Then, an SVNS A can be denoted by $A = \{x, T_A(x), I_A(x), F_A(x) \in X\}$ where $\{ T_A(x), I_A(x), F_A(x) \in [0, 1]\}$ for each point x in X. Therefore, the sum of T_A (x), I_A (x) and F_A (x) satisfies the condition $0 \leq T_A(x) + I_A(x) + F_A(x) \leq 3$. [14]

Decision-making normally involves human language or is commonly referred to as linguistic variables. A linguistic variable simply represents words or terms used in human language. Therefore, this linguistic variable approach allows decision-makers to express their assessments. Ratings of criteria can be expressed by using linguistic variables. Linguistic variables can be transformed into SVNSs [11], [15], [16] as shown in Table 1.

Table 1: Linguistic variable and Single Valued Neutrosophic Numbers (SVNNs). Source: [17]

Definition	SVNS
Extremely preferred (EXP)	(1,0,0)
Very very preferred (VVP)	(0.9, 0.1, 0.1)
Very preferred (VP)	(0.8,0,15,0.20)
Preferred (P)	(0.70,0.25,0.30)
Equally preferred (EP)	(0.50,0.50,0.50)
Not preferred (NP)	(0.35,0.75,0.80)
Very not preferred (VNP)	(0.20,0.85,0.80)
Very very not preferred (VVNP)	(0.10,0.90,0.90)
Extremely not preferred (ENP)	(0,1,1)

Definition 2. Let $E_k = \left(T_k, I_{k,}, F_k\right)$ be a neutrosophic number defined for the rating of k-th decision-maker. Then, the weight of the k-th decision-maker can be written as [17]

$$\psi_k = \frac{1-\sqrt{[(1-T_k(x))^2+(I_k(x))^2+(F(x))^2]/3}}{\sum_{k=1}^{p} \sqrt{[(1-T_k(x))^2+(I_k(x))^2+(F(x))^2]/3}} \tag{1}$$

Further, group decision-making is important in any decision-making process in achieving a favorable solution. All the individual decision-maker assessments need to be aggregated to one aggregated neutrosophic decision matrix in the group decision-making process [18]. This can be done by employing a single-valued neutrosophic weighted averaging (SVNWA) aggregation operator proposed by Ye [19]

Definition 3 [20] Let $D(k) = \left(d_{ij}(k)\right)_{mxn}$ be the single-valued neutrosophic decision matrix of the k-th decision-maker and be the weight vector of the decision-maker such that each where $\psi = (\psi_1 \psi_2, \dots, \psi_p)^T \psi_k \in [0,1], D = (d_{ij})_{mxn}$

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$$d_{ij} = \langle 1 - \prod_{k=1}^{p} \left(1 - T_{ij}^{(p)}\right)^{\psi_k}, \prod_{k=1}^{p} \left(I_{ij}^{(p)}\right)^{\psi_k}, \prod_{k=1}^{p} \left(F_{ij}^{(p)}\right)^{\psi_k} \rangle \quad (2)$$

Definition 4. Let A and B be two single-valued neutrosophic numbers (SVNNs), then the normalized Hamming distance between them is:

$$d(A,B) \frac{|TA - TB| + |IA - IB| + |FA - FB|}{3} \quad (3)$$

Definition 5 [21] Let $A = (T_A, I_A, F_A)$ be a SVNN, the complement of SVNN A is:

$$AC = (F_A, 1 - I_A, T_A) \quad (4)$$

3. Method

Let $A = (A_1, \dots, A_m)$ be the alternatives, and $G = (G_1, G_2 \dots, G_n)$ be the attributes. Let $W = w_1, w_2 \dots, w_n$ be the weights of the attributes, where 0≤wj≤1, $\sum_{j=1}^{n} w_j = 1$. Let a_{ij}, i = 1, 2… m, j = 1, 2, .., n, be the attribute value of the alternative A_i with attribute G_j, the $A = (a_{ij})_{mxn} = \langle (T_{ij}, I_{ij}, F_{ij}) \rangle_{mxn}$ is a SVNNs matrix, where Tij, Iij, and Fij are membership degree, indeterminacy-membership degree, and non-membership degree, respectively. The steps to perform the analysis are described below [10]:

Step 1: Identify the decision alternatives to evaluate.

Step 2: Determine the weights of decision-makers. Due to the method's logic, each decision-maker can have a unique and different evaluation from the rest of the decision-makers since each evaluation is awarded according to the level of knowledge of each expert regarding the decision topic discussed. The relative weight of each decision-maker is considered as a linguistic variable and is transmitted in SVNN to later be identified by equation (1).

Step 3: Convert linguistic assessments into SVNN given by experts. From the individual integer matrixes obtained from the expert evaluations, the individual neutrosophic matrices of the decision-makers are constructed, as indicated in Table 1.

Step 4: Obtain the initial relation matrix of alternatives $A = (A_1, \dots, A_m)$ and attributes $G = (G_1, G_2 \dots, G_n)$, where each aij, i = 1, 2… m, j = 1, 2, .., n, is the value of the attribute of the alternative Ai with the attribute G. The $A = (a_{ij})_{mxn} = \langle (T_{ij}, I_{ij}, F_{ij}) \rangle_{mxn}$ is an SVNNs matrix, where Tij, Iij, and Fij are the degree of membership, degree of indeterminacy- membership, and degree of non-membership, using equation (2).

Step 5: Standardize decision information. That is, normalize $A = (a_{ij})_{mxn}$into $B = (b_{ij})_{mxn}$. If the decision is a cost factor, the decision information should be changed to its complementary set using equation (3), while if it is an efficiency factor, it should not be changed.

Step 6: Construct a preference function Pj (Bi, Br) of the alternative Bi relative to Br under the attribute Gj using (5).

$$P_j(B_i, B_r) = \{0, d \leq p \; \frac{d-p}{q-p}, p < d < q \; 1, d \geq q \quad (5)$$

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Step 7: Calculate the relative weight of the attributes w_{jr}, which is the relative weight of Gj to Gr, where

$$w_{jr} = \frac{w_j}{w_r} = (j, r = 1,2, \dots, n) \quad (6)$$

Step 8: Define the priority index π (Bi, Br) of the Bi scheme relative to Br by

$$\pi(B_i, B_r) = \frac{\sum_{j=1}^{n} \quad w_{jr} P_j(B_i,B_r)}{\sum_{j=1}^{n} \quad w_{jr}} \quad (7)$$

Step 9: Calculate inflow Φ^+ (Bi), the outflowΦ^- (Bi) and the net flow Φ (Bi) as follows

$$^+(B_i) = \frac{\sum_{r=1}^{m} \quad \pi(B_i,B_r) - \{\sum_{r=1}^{m} \quad \pi(B_i,B_r)\}}{\{\sum_{r=1}^{m} \quad \pi(B_i,B_r)\} - \{\sum_{r=1}^{m} \quad \pi(B_i,B_r)\}} \quad (8)$$

$$^-(B_i) = \frac{\sum_{r=1}^{m} \quad \pi(B_r,B_i) - \{\sum_{r=1}^{m} \quad \pi(B_r,B_i)\}}{\{\sum_{r=1}^{m} \quad \pi(B_r,B_i)\} - \{\sum_{r=1}^{m} \quad \pi(B_r,B_i)\}} \quad (9)$$

$$(B_i) =^+ (B_i) -^- (B_i) \quad (10)$$

Step 10: Classify all the alternatives according to the value of (B_i). The higher the value of $(B_i)$the better the alternative.

4. Methodological process

Initially, triage systems had three levels of categorization (emergent, urgent, and non-urgent), and later a new American system introduced four categories (Emergency, High potential for urgency, Potential urgency, and non-urgent). However, none of these presented a sufficient level of scientific evidence in terms of validity, utility, and reproducibility. A triage system with five prioritization levels is created in Australia, called the National Triage Scale.

This system was renewed in 2000 and recommended as the Australian Triage Scale (ATS) and, under the influence of this system, different countries began to develop triage systems adopting ATS characteristics. In this way, several 5-level structured systems were created that, up to now, have demonstrated a sufficient degree of scientific evidence by meeting reproductive, useful, and valid criteria, defining them as a structured triage system.

To define the alternatives to be evaluated, the lifting process was used by studying the literature, where it was sought to identify and learn about the main triage protocols known and disseminated in the world:

- The Australian Triage Scale (ATS)
- The Canadian Emergency Department Triage and Acuity Scale (CTAS)
- The Manchester Triage System (MTS)
- The Emergency Severit Index (ESI)
- The Spanish Triage System (STS) adopted by the Spanish Society of Emergency Medicine (SEMES) based on the Andorrá de Triage Model: ATM

The criteria for evaluating the alternatives represent the guidelines to be used in the decision-making process, using them as characteristics of the triage systems so that the alternatives to the problem can be analyzed from the same perspectives. This study was initially structured with 6 evaluation criteria

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presented to decision-makers for validation. Two were excluded from the initial selection, so after validation by the decision-makers, there were four criteria to evaluate: ease of use, ease of implementation, ease of evaluation and scope. For the analysis carried out, the analysts agree on giving each criterion the same weight of importance (value of each weight, w = 0.25).

5. Results and discussion

Table 2 shows the evaluations given to decision-makers according to their relative importance in terms of the topic discussed by using equation (1).

Table 2: Evaluations granted to decision-makers according to their importance. Source: Own elaboration by using equation 1

Decision-makers	Linguistic assessment	SVNN	Numerical value
Decision-maker 1	Very important	(0.9; 0.1; 0.1)	0.21
Decision-maker 2	Moderately important	(0.5; 0.5; 0.5)	0.17
Decision-maker 3	Very important	(0.9; 0.1; 0.1)	0.21
Decision-maker 4	Very important	(0.9; 0.1; 0.1)	0.21
Decision-maker 5	Important	(0.75; 0.25; 0.20)	0.2

Once the decision-makers individually evaluate the indicated alternatives based on each of the chosen criteria or attributes for the evaluation, they are transformed through equation (2) to obtain the normal alternative decision matrix, which is shown in Table 3.

Table 3: Normal decision matrix of alternatives. Source: Own elaboration

	Ease of Use	Ease of Implementation.	Ease of Evaluation	Scope
ATS	(0.61424; 0.38576; 0.35486)	(0.67429; 0.32571; 0.28374)	(0.7626; 0.2374; 0.2081)	(0.7257; 0.2743; 0.2519)
MTS	(0.55653; 0.44347; 0.42667)	(0.5; 0.5; 0.5)	(0.56731; 0.43269; 0.41301)	(0.5; 0.5; 0.5)
STS	(0.68696; 0.31304; 0.2988)	(0.54297; 0.47088; 0.45555)	(0.47187; 0.54413; 0.5515)	(0.6024; 0.4096; 0.3789)
ESI	(0.69071; 0.30929; 0.29523)	(0.61623; 0.38377; 0.35244)	(0.47187; 0.54413; 0.5515)	(0.5673; 0.4327; 0.413)
CTAS	(0.5; 0.5; 0.5)	(0.55653; 0.44347; 0.42667)	(0.5; 0.5; 0.5)	(0.7445; 0.2555; 0.2555)

All the selected criteria are considered to benefit criteria; that is, they should be maximized, except for criterion 4, so that the normalized matrix obtained coincides with the normal matrix shown in table 3. From it, the matrices of degrees of preference $P_j = B_i, B_r$ concerning G_j. This calculation can be carried out using the proposed linear function (4). For this case it is assumed that q = 1, p = 0 (see figure 1).

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$$P_1 = |B_1\ B_1\ 0.0000\ \ B_2\ 0.0000\ \ B_3\ 0.0187\ \ B_4\ 0.0199\ \ B_5\ 0.0000\ \ \ B_2\ 0.0239\ \ 0.0000\ 0.0426\ 0.0438\ 0.0000\ \ \ B_3\ 0.0000\ \ B_4\ 0.0000$$

$$P_2 = |B_1\ B_1\ 0.0000\ \ B_2\ 0.0000\ \ B_3\ 0.0000\ \ B_4\ 0.0000\ \ B_5\ 0.0000\ \ \ B_2\ 0.0721\ \ 0.0000\ 0.0102\ 0.0492\ 0.0244\ \ \ B_3\ 0.0619\ \ B_4\ 0.0229$$

$$\boldsymbol{P_3 = |B_1\ B_1\ 0.0000\ \ B_2\ 0.0000\ \ B_3\ 0.0000\ \ B_4\ 0.0000\ \ B_5\ 0.0000\ \ \ B_2\ 0.0683\ \ 0.0000\ 0.0000\ 0.0000\ 0.0000\ \ \ B_3\ 0.1198}$$

$$P_4 = |B_1\ B_1\ 0.0000\ \ B_2\ 0.0000\ \ B_3\ 0.0000\ \ B_4\ 0.0000\ \ B_5\ 0.0000\ \ \ B_2\ 0.0827\ \ 0.0000\ 0.0364\ 0.0290\ 0.0815\ \ \ B_3\ 0.0463\ \ B_4\ 0.0537$$

Figure 1: Matrix of degrees of preference (Pn) for each criterion. Source: Own elaboration

Using equation (6), the integral priority index is obtained, as shown in figure 2 , from which the inflow, outflow and net flows of each alternative are obtained, as shown in table 4.

$$\Pi = |B_1\ B_1\ 0.000\ \ B_2\ 0.000\ \ B_3\ 0.005\ \ B_4\ 0.005\ \ B_5\ 0.000\ \ \ B_2\ 0.062\ \ 0.000\ 0.022\ 0.030\ 0.026\ \ \ B_3\ 0.057\ \ B_4\ 0.049\ \ B_5\ 0.049\ \ \ 0.013$$

Figure 2: Integral priority index of the Bi scheme relative to Br. Source: Own elaboration

Table 4: Input, output and net flows of the alternatives. Source: Own elaboration

	□□	□□	□
ATS	0	1,000	-1,000
MTS	1	0.000	1,000
STS	0.691	0.036	0.654
ESI	0.555	0.167	0.388
CTAS	0.703	0.150	0.553

The positive and negative flows in this type of analysis indicate the degrees of preference and non-preference over other alternatives. In this sense, from the results achieved by the analysis, it can be observed that the MTS system has a higher preference over the other triage systems. Its superiority over the other systems is absolute. It is closely followed by CTAS and STS, the ATS system being the one with the least preference over the rest. On the other hand, when analyzing the negative flows obtained, it can be observed that ATS is the one with the highest degree of non-preference with respect to the other systems. In this case, all the systems present similar levels of non-preference, except the MTS, which in this case is the lowest of the values.

The net flows confirm the data produced by the negative and positive flows and show that the analysts' most preferred method in decision-making was the MTS system, placing the STS and CTAS systems in second and third place. It is noted that for this case, the ATS method was the least preferred by analysts.

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6. Conclusions

Due to the successive increase in patients who come to the emergency services, it is important to use an adequate triage system for their classification and timely care. The triage system appropriate to the characteristics and needs of any hospital entity will allow the adequate distribution of resources for optimal patient care depending on the degree of urgency.

In the present study, the main triage systems were analyzed by applying multicriteria methods to solve the problem. The use of the method demonstrates the efficiency of these methods in solving complex problems in real life and in different fields of society, particularly medicine.

Using single-valued neutrosophic sets, it was possible to solve the proposed problem by eliminating the uncertainties and vagueness of reality. Furthermore, the analysis carried out made it possible to determine the superiority of the MTS triage system compared to the other systems analyzed.

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