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Prioritization of Software Requirements Using Neutrosophic TOPSIS

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Abstract. Prioritizing software requirements is one of the most significant and complex tasks for software developers. It involves a multi-criteria decision process to balance the benefit of each requirement and its cost, considering different factors and dimensions, many of which are qualitative. Although numerous prioritization methods have been developed to date, the appropriate treatment in cases of the uncertainty and indeterminacy inherent in human decisions is limited. In the present work, the neutrosophic TOPSIS is proposed as a method of prioritizing requirements. This multi-criteria and multi-expert method uses linguistic terms associated with Single Value Neutrosophic Sets and allows the inclusion of aspects such as the importance of the criteria and the weight of expert evaluations. A case study is used to show the applicability of the proposal.

Keywords: Requirements prioritization, neutrosophic TOPSIS, SVNS, requirements engineering.

1 Introduction

The quality of the software is a fundamental element to guarantee the success of a software project, which is why it is considered an essential competitive factor in the companies that develop it [1]. The ISO/IEC 8402: 1994 standard defines software quality as the totality of characteristics that make it capable of satisfying established or implicit customer needs [7]. This concept encompasses various characteristics such as security, availability, and performance, which are usually organized under the structure of quality models, defined in turn as the specification of the required characteristics that a software system must exhibit [3].

To improve and ensure quality, it is necessary to formalize it in requirements right from the beginning. A correct definition and analysis of the requirements is one factor contributing to the success of software projects [4]. The prioritization of requirements is a complex decision-making process through which it is determined which functionalities are adequate to include in each release of the software product to be developed [10]. Numerous authors have treated it as one of the activities with the highest levels of complexity in Requirements Engineering and essential for the success of projects [5].

Requirements Engineering has been considered since the '90s as an essential process in systems development and especially in the development of software systems. Decisions made during these early stages of development are crucial and difficult since information is incomplete, imprecise, and subject to numerous changes [11]. Furthermore, these decisions are fundamental, since they will significantly influence the entire life cycle of the software system [13].

The prioritization of requirements is a complex decision-making process through which it is determined which functionalities are adequate to include in each release of the software product to be developed [10]. Projects generally have more candidate requirements than time, and cost constraints allow them to implement. The PR helps to identify the sets that are critical to the project's success, those that will be located in the first releases, leaving the trivial ones for later deliveries. This allows ordering the total set of requirements, allowing the formation of subsets and their assignment to each release [4].

In the initial stages of a software development project, the requirements are generally imprecise. As the project progresses and the understanding of the product grows, the requirements are specified in detail. Requirements prioritization is a process that can be done at different times in the life cycle, with requirements at different levels of abstraction.

The requirements are prioritized taking into account different variables, imposed by the needs and context of the organizations. According to the analyzed bibliography, we have value, importance, unfavorable effects, cost, time, risk, volatility, and customer satisfaction among the most used variables.

Although different methods have been proposed for the prioritization of requirements, among which the use of aggregation operators to merge the information [5, 10], and the techniques Numerical Assignment, MoSCoW, Priority Groups, Bubble Sort stand out. Binary Search Tree, AHP, Hundred Dollar, and Minimal Spanning Tree [6], these methods show the lack of treatment of uncertainty and the indeterminacy of human evaluations and decision-making.

This work aims to present a method for the prioritization of requirements based on the multi-criteria and multi-expert decision method TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) in its neutrosophic variant [2, 8]. Its effectiveness characterizes this technique and the simplicity of its principle in solving multi-criteria decision problems where the selection is based on finding the alternative closest to the ideal solution and moves further away to the worst solution.

The neutrosophic variant of TOPSIS is based on Neutrosophy. Neutrosophy is the branch of philosophy that studies the origin, nature, and scope of neutralities. Logic and neutrosophic sets constitute generalizations of Zadeh's logic and fuzzy sets of Atanassov's intuitionist logic [9]. Incorporating the neutrosophic sets into TOPSIS ensures that uncertainty and indeterminacies are taken into account. Experts will evaluate in linguistic rather than numerical terms, which is a more natural form of measurement for humans.

A case study is used to demonstrate the applicability of the Neutrosophic TOPSIS for the prioritization of software requirements.

2 Materials and methods

This section details the main concepts and techniques that will be used in this study. Let X be a universe of discourse, a Single Value Neutrosophic Set (SVNS) A over X has the following form [12-24]:

$A = \{\langle x, u_a(x), r_a(x), v_a(x)\rangle : x \in X\}d$ (1)

Where $u_a(x): X \rightarrow [0,1], r_a(x): X \rightarrow [0,1]\ y\ v_a(x): X \rightarrow [0,1]$

With $0 \leq u_a(x), r_a(x), v_a(x) \leq 3, \forall\ x \in X$

The intervals denote the memberships to true, indeterminate, and false from x in A, respectively. $u_a(x), r_a(x)$ y $v_a(x)$. For convenience a SVNS will be expressed as A = (a, b, c), where a, b, c ∈ [0.1] and satisfies 0 ≤ a + b + c ≤ 3. The SVNS arose with the idea of applying the neutrosophic sets for practical purposes. Some operations between SVNS are expressed below:

1. Let $A_1 = (a_1, b_1, c_1)$ and $A_2 = (a_2, b_2, c_2)$ ∈SVNS, the sum between A_1 y A_2 is defined by:
$A_1 \oplus A_2 = (a_1 + a_2 - a_1 a_2, b_1 b_2, c_1 c_2)$
(2)
2. Let $A_1 = (a_1, b_1, c_1)$ and $A_2 = (a_2, b_2, c_2)$ ∈ SVNS the multiplication between A_1 y A_2 is defined by:
$A_1 \otimes A_2 = a_1 a_2, b_1 + b_2 - b_1 b_2, c_1 + c_2 - c_1 + c_2)$
(3)
3. The product by a positive scalar $\lambda \in \Re$ with SVNS, A = (a, b, c) is defined by:
$\lambda A = \left(1 - (1-a)^{\lambda}, b^{\lambda}, c^{\lambda}\right)$
(4)
4. Let $\{A_1, A_2, \dots, A_n\} \in$ SVNS(x), where $A_j = (a_j, b_j, c_j)$ (j = 1, 2, …, n), then, the Single Valued Neutrosophic Weighted Average Operator is defined by:
$P_w(A_1, A_2, \dots, A_n) = \langle 1 - \prod_{j=1}^{n}\left(1 - T_{A_j}(x)\right)^{w_j}, \prod_{j=1}^{n}\left(I_{A_j}(x)\right)^{w_j}, \prod_{j=1}^{n}\left(F_{A_j}(x)\right)^{w_j}\rangle$
(5)
Where: $w = (w_1, w_2, \dots, w_n)$ is vector of $A_j (j = 1,2, \dots, n)$ such that $w_n \in [0,1]$ y $\sum w_j = 1$.
5. Let A = (a, b, c) be a single neutrosophic number, a score function S of a single-valued neutrosophic value, based on the truth-membership degree, indeterminacy-membership degree, and falsity membership degree is defined by:
$S(A) = \frac{1+a-2b-c}{2}$
(6)
Where $S(A) \in [-1,1]$
6. Let a vector SVNS such that and are vectors such that then Distance measure between and is as follows: $A^* = (A_1^*, A_2^*, \dots, A_n^*) A_j^* = (a_1^*, b_2^*, c_2^*)(j = 1,2, \dots, n)\ B_i = (B_{i1}, B_{i2}, \dots, B_{im})\ (i = 1,2, \dots, m) m B_{ij} = \left(a_{ij}, b_{ij}, \dots, c_{ij}\right)\ (i = 1,2, \dots, m)(j = 1,2, \dots, n), B_i A^*$

$$s_i = \left(\frac{1}{3}\sum_{j=1}^{n}\left\{\left(a_{ij}-a_j^*\right)^2+\left(b_{ij}-b_j^*\right)^2+\left(c_{ij}-c_j^*\right)^2\right\}\right)^{\frac{1}{2}} \quad (7)$$

The TOPSIS method for SVNS consists in that, assuming it is a set of alternatives and it is a set of criteria, the following steps will be carried out [2]: $A = \{\gamma_1, \gamma_2, \ldots, \gamma_m\} B = \{\delta_1, \delta_2, \ldots, \delta_n\}$

1. Determine the weight of the experts

To determine the weight of the experts, the selected specialists self-assess their level of knowledge on the subject according to a linguistic scale associated with SVNS values. Table 1 shows the linguistic scales to be used for the self-assessment of the experts with their associated SVNS.

Linguistic term	Evaluation	SVNS
Extremely high	EH	(1,0,0)
Very very high	VVH	(0.9, 0.1, 0.1)
Very high	VH	(0.8, 0.15, 0.20)
High	H	(0.70,0.25,0.30)
Little high	LH	(0.60, 0.35, 0.40)
Medium	M	(0.50, 0.50, 0.50)
Between low and medium	ML	(0.40, 0.65, 0.60)
Low	L	(0.30,0.75,0.70)
Very low	VL	(0.20, 0.85, 0.80)
Very very low	VVL	(0.10,0.90,0.90)
Extremely low	EL	(0; 1; 1)

Table 1. Linguistic terms and their SVNS for step 1.

If it is the SVNS corresponding to the t-th decision-maker (t = 1, 2,…, k), the weight of each expert is calculated by the following formula: $A_t = (a_t, b_t, c_t)$

$$\lambda_t = \frac{a_t + b_t\left(\frac{a_t}{a_t+c_t}\right)}{\sum_{t=1}^{k} a_t + b_t\left(\frac{a_t}{a_t+c_t}\right)} \quad (8)$$

where: $\lambda_t \geq 0$ y = $1\sum_{t=1}^{k}\lambda_t$

2. Construction of the neutrosophic decision matrix of aggregated unique values

This matrix is defined by, where, and used to aggregate all individual assessments. $D = \sum_{t=1}^{k}\lambda_t\, d_{ij} d_{ij} = \left(a_{ij}, b_{ij}, c_{ij}\right)$. According to each criterion, the expert evaluations of each decision are also made based on a scale of linguistic terms associated with SVNS. Table 2 shows the scale to use in this case.

Linguistic term	Evaluation	SVNS
Extremely important	EI	(1,0,0)
Very very important	VVI	(0.9, 0.1, 0.1)
Very important	VI	(0.8, 0.15, 0.20)
Important	I	(0.75,0.25,0.30)
Medium	M	(0.50, 0.50, 0.50)
Less important	LI	(0.40, 0.65, 0.70)
Almost nothing important	ANI	(0.25,0.75,0.80)
Not important	NI	(0; 1; 1)

Table 2. Linguistic terms and their SVNS for step 2.

Once the evaluations offered by the experts have been obtained, it is calculated as the aggregation of the evaluations given by each expert, using the weights of each one with the help of equation 5. $d_{ij}\left(a_{ij}{}^t, b_{ij}{}^t, c_{ij}{}^t\right)$

In this way, a matrix D = is obtained, where each is an SVNS (i = 1,2, .., m; j = 1,2,…, n). $\left(d_{ij}\right)_{ij} d_{ij}$

3. Determination of the Weight of the criteria

Suppose that the weight of each criterion is given by where it denotes the relative importance of the criterion. If it is the evaluation of the criterion by the t-th expert. $W = (w_1, w_2, \ldots, w_n), w_j\ \delta_j w_j^t = a_j^t, b_j^t, c_j^t \delta_j$. Then the aggregation function of equation (5) is used to add the weights. $w_j^t\ \lambda_t$

4. Construction of the neutrosophic decision matrix of the weighted mean of unique values with respect to the criteria

$D^{*} = D \otimes W$, where $d_{ij}^{*} = W_j \otimes d_{ij} = \left(a_{ij}, b_{ij}, c_{ij}\right)$ (9)

5. Calculation of the ideal positive and negative SVNS solutions

The criteria can be classified as cost type or benefit type. Let Δ_1 be the set of criteria type benefits and Δ_2 criteria type cost. The ideal alternatives will be defined as follows:

$$\gamma^{+} = \left(a_{\gamma^{+}w}(\delta_j), b_{\gamma^{+}w}(\delta_j), c_{\gamma^{+}w}(\delta_j)\right) \tag{10}$$

Denote the positive ideal solution corresponding to G_1

$$\gamma^{-} = \left(a_{\gamma^{-}w}(\delta_j), b_{\gamma^{-}w}(\delta_j), c_{\gamma^{-}w}(\delta_j)\right) \tag{11}$$

Denote the negative ideal solution, corresponding to G_2

Where

$$a_{\gamma^{+}w}(\delta_j) = \begin{cases} max_i a_{\gamma_i w}(\delta_j), & si \;\; j \in \Delta_1 \\ min_i a_{\gamma_i w}(\delta_j), & si \;\; j \in \Delta_2 \end{cases} \tag{12}$$

$$b_{\gamma^{+}w}(\delta_j) = \begin{cases} min_i b_{\gamma_i w}(\delta_j), & si \;\; j \in \Delta_1 \\ max_i b_{\gamma_i w}(\delta_j), & si \;\; j \in \Delta_2 \end{cases} \tag{13}$$

$$c_{\gamma^{+}w}(\delta_j) = \begin{cases} min_i c_{\gamma_i w}(\delta_j), & si \;\; j \in \Delta_1 \\ max_i c_{\gamma_i w}(\delta_j), & si \;\; j \in \Delta_2 \end{cases} \tag{14}$$

$$a_{\gamma^{-}w}(\delta_j) = \begin{cases} min_i a_{\gamma_i w}(\delta_j), & \text{si} \;\; j \in \Delta_1 \\ max_i a_{\gamma_i w}(\delta_j), & si \;\; j \in \Delta_2 \end{cases} \tag{15}$$

$$b_{\gamma^{-}w}(\delta_j) = \begin{cases} max_i b_{\gamma_i w}(\delta_j), & si \;\; j \in \Delta_1 \\ min_i b_{\gamma_i w}(\delta_j), & si \;\; j \in \Delta_2 \end{cases} \tag{16}$$

$$c_{\gamma^{-}w}(\delta_j) = \begin{cases} max_i c_{\gamma_i w}(\delta_j), & si \;\; j \in \Delta_1 \\ min_i c_{\gamma_i w}(\delta_j), & si \;\; j \in \Delta_2 \end{cases} \tag{17}$$

6. Calculation of the distances to the ideal positive and negative SVNS solutions

The distances to the ideal positive and negative SVNS solutions are calculated with the help of Equation (7), leaving the following expressions:

$$\mathrm{s}_{\mathrm{i}}^{+} = \left(\frac{1}{3}\sum_{\mathrm{j}=1}^{\mathrm{n}}\left\{\left(\mathrm{a}_{\mathrm{ij}} - \mathrm{a}_{\mathrm{j}}^{+}\right)^2 + \left(\mathrm{b}_{\mathrm{ij}} - \mathrm{b}_{\mathrm{j}}^{+}\right)^2 + \left(\mathrm{c}_{\mathrm{ij}} - \mathrm{c}_{\mathrm{j}}^{+}\right)^2\right\}\right)^{\frac{1}{2}} \tag{18}$$

$$\mathrm{s}_{\mathrm{i}}^{-} = \left(\frac{1}{3}\sum_{\mathrm{j}=1}^{\mathrm{n}}\left\{\left(\mathrm{a}_{\mathrm{ij}} - \mathrm{a}_{\mathrm{j}}^{-}\right)^2 + \left(\mathrm{b}_{\mathrm{ij}} - \mathrm{b}_{\mathrm{j}}^{-}\right)^2 + \left(\mathrm{c}_{\mathrm{ij}} - \mathrm{c}_{\mathrm{j}}^{-}\right)^2\right\}\right)^{\frac{1}{2}} \tag{19}$$

7. Calculation of the Proximity Coefficient (PC)

The PC of each alternative is calculated concerning the positive and negative ideal solutions.

$$\tilde{\rho}_{\mathrm{j}} = \frac{\mathrm{s}^{-}}{\mathrm{s}^{+} + \mathrm{s}^{-}} \tag{20}$$

Where: $0 \leq \tilde{\rho}_{\mathrm{j}} \leq 1$

8. Determination of the order of the alternatives

As in the classical method, the alternatives are ordered in descending order, starting with the one that most closely approximates the ideal solution (greater relative proximity). The selected case study consists of prioritizing five requirements (Ri) belonging to an information system of a software project. The criteria to be taken into account for prioritization were established as 1) technical difficulty, 2) cost, 3) risk, and 4) value for the project.

3 Results

As a result of the first step, the experts' self-assessments on their level of knowledge in software development were obtained. Their evaluations and corresponding weights are shown in table 3.

Expert	1	2	3	4	5	6	7	8	9	10
Evaluation	VVH	VH	VH	VVH	VVH	VVH	VH	EH	VVH	VH
λ_t	0.103	0.096	0.096	0.103	0.103	0.103	0.096	0.104	0.103	0.096

Table 3. Results of the experts' weight determination

The matrices of the expert evaluations of each requirement according to each criterion are shown in tables 4, 5, 6, and 7.

Requirement	Expert									
	1	2	3	4	5	6	7	8	9	10
R1	VI	VI	VI	VI	VI	VVI	VI	VI	VVI	I
R2	VI	VI	VI	I	VI	VI	VI	VI	VVI	VI
R3	VI	VI	VI	I	I	VI	VI	VI	I	VI
R4	VI	VI	VI	VVI	VVI	VI	VVI	VI	VI	VI
R5	VI	VI	VI	VI	VI	VVI	VI	VI	VI	VI

Table 4. Evaluation of requirements by experts in terms of the criterion *Technical difficulty*

Requirement	Expert									
	1	2	3	4	5	6	7	8	9	10
R1	VI	VI	VVI	VI	VI	VI	VVI	VI	VI	I
R2	I	I	M	I	I	I	I	VI	I	VI
R3	VI	VVI	VI	VI	VI	VI	VI	VI	VI	VI
R4	VI	VI	VVI	VI	I	VI	VI	VI	VI	VI
R5	I	I	VI	I	I	VI	I	I	I	I

Table 5. Evaluation of requirements by experts in terms of the criterion *Cost*

Requirement	Expert									
	1	2	3	4	5	6	7	8	9	10
R1	VI	VI	VI	VI	VI	VI	VVI	VI	VVI	VVI
R2	I	I	I	I	I	I	I	I	VI	I
R3	VI	VI	VI	VI	VI	I	VI	VVI	VI	VI
R4	VI	I	VI	VI	VI	VI	I	VI	VI	VVI
R5	VI	VVI	VI	VVI	VI	VVI	VI	VI	VI	VI

Table 6. Evaluation of requirements by experts in terms of the criterion *Risk*

Requirement	**Expert**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
R1	VVI	VVI	VVI	VI	VI	VVI	VVI	VI	VVI	VVI
R2	I	M	I	I	I	I	I	I	I	I
R3	VI	VVI	VVI	VI	VI	VI	VI	VVI	I	VI
R4	VI	VI	I	VI	VI	I	VI	VI	VI	VI
R5	VI	I	VI	VI	VI	VI	VI	VI	VI	I

Table 7. Evaluation of requirements by experts in terms of the criterion *Value to the project*

From the SVNS associated with the linguistic variables used, the evaluations given by the experts were added to each requirement according to each criterion (See table 8).

Requirement	**Criterion**			
	Technical difficulty	***Cost***	***Risk***	***Value to the project***
R1	(0.823, 0.145, 0.18)	(0.821, 0.146, 0.182)	(0.837, 0.133, 0.163)	(0.876, 0.113, 0.124)
R2	(0.809, 0.152, 0.194)	(0.745, 0.241, 0.291)	(0.756, 0.237, 0.288)	(0.733, 0.267, 0.315)
R3	(0.786, 0.176, 0.227)	(0.813, 0.144, 0.187)	(0.81, 0.152, 0.194)	(0.833, 0.14, 0.17)
R4	(0.838, 0.133, 0.162)	(0.808, 0.152, 0.195)	(0.805, 0.159, 0.202)	(0.791, 0.166, 0.217)
R5	(0.814, 0.144, 0.186)	(0.761, 0.226, 0.277)	(0.838, 0.133, 0.162)	(0.791, 0.165, 0.216)

Table 6. Neutrosophic decision matrix of single aggregated values

The weight of the criteria was then determined. The weight that the experts assigned to each criterion appears in Table 9.

Criterion	Expert									
	1	2	3	4	5	6	7	8	9	10
Technical difficulty	VI	VVI	VI	VI	VI	VI	VI	VI	I	VI
Cost	I	VI	I	VI	I	I	I	I	I	VI
Risk	VI	VI	VI	VVI	VI	VI	VI	VI	VI	VVI
Value to the project	I	I	VI	VI	M	I	I	I	I	I

Table 9. Evaluation of the weight of each criterion according to the experts

Through aggregation, the weight of the criteria expressed in SVNS was calculated, as shown in Table 10.

Criterion	Weight (SVNS)
Technical difficulty	(0.81, 0.15, 0.2)
Cost	(0.77, 0.22, 0.27)
Risk	(0.83, 0.14, 0.17)
Value to the project	(0.74, 0.24, 0.29)

Table 10. Weight of criteria

The neutrosophic decision matrix was constructed from the weighted mean of unique values with respect to the criteria (step 4), as shown in Table 11.

Requirement	Criterion			
	Technical difficulty	*Cost*	*Risk*	*Value to the project*
R1	(0.665, 0.265, 0.34)	(0.558, 0.429, 0.454)	(0.691, 0.253, 0.309)	(0.651, 0.328, 0.38)
R2	(0.654, 0.281, 0.351)	(0.57, 0.404, 0.479)	(0.624, 0.343, 0.412)	(0.545, 0.445, 0.515)
R3	(0.635, 0.301, 0.378)	(0.623, 0.328, 0.404)	(0.668, 0.269, 0.335)	(0.619, 0.349, 0.412)
R4	(0.677, 0.265, 0.326)	(0.619, 0.335, 0.409)	(0.664, 0.275, 0.341)	(0.588, 0.368, 0.445)
R5	(0.658, 0.274, 0.345)	(0.583, 0.392, 0.469)	(0.692, 0.253, 0.308)	(0.588, 0.368, 0.445)

Table 11. Weighted aggregate decision matrix.

The ideal positive and negative SVNS solutions calculated in step 5 are shown in Table 12.

Criterion	Positive ideal value	Negative ideal value
Technical difficulty	(0.677, 0.265, 0.326)	(0.635, 0.301, 0.378)
Cost	(0.623, 0.328, 0.404)	(0.558, 0.429, 0.479)
Risk	(0.692, 0.253, 0.308)	(0.624, 0.343, 0.412)
Value to the project	(0.651, 0.328, 0.38)	(0.545, 0.445, 0.515)

Table 12. SVNS positive and negative ideal solutions by criteria.

The distances to the ideal positive and negative SVNS solutions, as well as the Proximity Coefficient (PC) and the resulting order of the requirements, are shown in table 13.

Requirement	d +	d-	Pc	Order
R1	0.075656582	0.153348908	0.330370169	4
R2	0.165651411	0.027118707	0.859321001	1
R3	0.043823603	0.08169519	0.349139776	3
R4	0.005244914	0.088172458	0.056144951	5
R5	0.147150174	0.140844952	0.51094675	2

Table 11. Distances to ideal solutions, proximity coefficient, and order of alternatives

The order of priority resulting from the requirements is, therefore: R2> R5> R3> R1> R4.

Conclusions

Requirements prioritization is used to define the order of execution of requirements based on their priority or importance with respect to the points of view of all interested parts. Researchers have proposed many requirements prioritization techniques, and there is no single technique that can be used for all types of projects. For an adequate adjustment to the uncertainty and indeterminacy of human decision-making, the use of TOPSIS in its neutrosophic variant is proposed.

With the application of neutrosophic TOPSIS, it is possible to efficiently estimate the order of priority of the requirements based on the selected criteria. The assessment of each requirement according to each criterion, the weighting of each evaluation of the expert according to their level of knowledge on the subject, as well as the weighting of the experts of the importance of each criterion, is carried out through linguistic terms associated with SVNS, which allows the treatment of uncertainty and indeterminacy.

In the selected case study, five software requirements were analyzed under the criteria of technical difficulty, cost, risk, and value for the project. It was determined that the order of priority of the requirements should be: 1) R2, 2) R5, 3) R3, 4) R1 and 5) R4.

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