



Multi-Criteria Evaluation of the Effectiveness of Computer Crime Disclosure Under Ecuadorian Legal Regulations

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Abstract

Decision-making based on multiple criteria is common in various contexts, recognized for its high complexity in seeking viable solutions. Computer crimes encompass any act with criminal intent that seeks to cause harm or put at risk a legally protected interest using computer tools. This study aims to determine whether residents of Santo Domingo are aware of computer crimes established in Ecuadorian legislation, employing multicriteria evaluation techniques and the TODIM and PROMETHEE methods. These methodologies are complemented by neutrosophic single-value sets, based on neutrosophic logic, to effectively manage the indeterminate and inconsistent information typical in real-world scenarios. In this way, the utility of these techniques for addressing complex problems in daily life and in various social domains is demonstrated.

Keywords: Neutrosophic logic; neutrosophic sets; computer crimes; Ecuadorian legislation; methodologies

1. Introduction

The integration of ICTs in our daily lives brings not only advancements but also challenges, notably cybercrime. This issue encompasses crimes committed via ICTs, like unauthorized data access, malware dissemination, and online fraud. Diverse terminology has arisen around cybercrime, pointing to acts that involve a computer or network element [1].

Historically, cybercrime emerged with the personal data computerization in the 1960s and has evolved significantly with the Internet's rise. These crimes are distinguished by the non-physical presence of perpetrators who can operate from remote locations. Ecuador has recognized the severity of cybercrimes by including them in its legal framework, reflecting the global movement towards more secure ICT use. The research presented here focuses on raising awareness and prevention within the Ecuadorian context [2].

Methodologically, this study leverages multicriteria decision-making (MCDM) techniques to assess the strategies for cybercrime dissemination. It specifically employs TODIM and PROMETHEE methods, enhanced by single-valued neutrosophic sets (SVNS) [3] that adeptly handle uncertainty and imprecise information. This neutrosophic approach allows for more nuanced decision-making, reflecting real-world complexities and aiding in effective strategy evaluation.

The research introduces a meticulous approach to assessing cybercrime awareness strategies in Ecuador through a neutrosophic lens. By employing a Single-Valued Neutrosophic Number Sets (SVNNs) matrix [4], the study transcends traditional decision-making models by incorporating the often-overlooked elements of uncertainty and partiality in human judgment. This innovative methodology underpins the evaluation process with a multifaceted perspective, considering not only the binary true-false criterion but also the indeterminacy that inherently characterizes human cognition and perception. Commencing with a clear definition of alternatives and attributes,

the method advances to encapsulate the subjectivity of experts' opinions by converting their linguistic assessments into neutrosophic values. This transformation results in a nuanced decision matrix that captures the full spectrum of expert knowledge, reflecting degrees of truth, indeterminacy, and falsity. By integrating these components, the study sets the stage for a comprehensive analysis of cybercrime awareness initiatives, offering a structured approach to identifying the most effective strategies within the Ecuadorian legal framework.

2. Related Work

This study addresses the application of multicriteria evaluation techniques as an approach to improve the evaluation of dissemination strategies on cybercrimes in Ecuador. Specific parameters of interest were previously established. To fulfill this objective, multicriteria decision-making methods (MCDM) are employed, which allow addressing complex real-life situations and making decisions under certain conditions through their simplification. In this way, initially posed problems can reach an effective solution [4].

Despite the variety of MCDM developed to solve problems in different areas of life and society, in traditional methods, alternatives are usually evaluated with defined values in general. However, due to the complexity of the environment and the inherent subjectivity of humans, MCDM problems are often accompanied by uncertainty, which can generate confusing or linguistic decision information.

In this article, the TODIM [6] and PROMETHEE [7] methods are presented using single-valued neutrosophic sets (SVNS). Neutrosophy, as part of philosophy, analyzes the nature of neutralities and everything related to them. Regarding neutrosophic logic and neutrosophic sets, membership functions of indeterminacy are introduced for the first time. Indeterminacy can arise due to lack of information, contradictory, inconsistent, paradoxical information, among other factors. In this study, neutrosophic sets are used to address the inability of traditional methods to handle the indeterminate and inconsistent information that is common in the real world. To improve the understanding of the information used, the preliminary aspects of neutrosophic theory and the methodology of the method used are initially presented. Then, its application proceeds, and finally, the results obtained are exposed, as well as the conclusions derived from the study.

Definition 1[7]: 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 the truth membership function $TA(x)$, the indeterminacy membership function $IA(x)$, and the falsity membership function $FA(x)$. Thus, an SVNS A can be represented by $A = \{x, TA(x), IA(x), FA(x) \mid x \in X\}$, where $TA(x), IA(x), FA(x) \in [0, 1]$ for each point x in X . Therefore, the sum of $TA(x)$, $IA(x)$, and $FA(x)$ satisfies the condition $0 \leq TA(x) + IA(x) + FA(x) \leq 3$.

Decision-making typically involves human language, commonly referred to as linguistic variables. A linguistic variable simply represents words or terms used in human language. Therefore, this linguistic variable approach is a convenient way for decision-makers to express their evaluations. Criterion ratings can be expressed using linguistic variables. Linguistic variables can be transformed into SVNSs as shown in Table 1.

Table 1: Linguistic Variable and Single-Valued Neutrosophic Numbers (SVNNs) [9].

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[10]: Let $E_k = (T_k, I_k, F_k)$ be a neutrosophic number defined for the rating of the k-th decision-maker. Then, the weight of the k-th decision-maker can be written as

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

Additionally, to achieve a favorable solution, group decision-making is important in any decision-making process. In the group decision-making process, all individual evaluations of decision-makers must be aggregated into an aggregated neutrosophic decision matrix. This can be done using the proposed single-valued neutrosophic weighted average (SVNWA) aggregation operator by Ye [11].

Definition 3. ([14]) Let $D^{(k)} = (d_{ij}^{(k)})_{m \times n}$ be the single-valued neutrosophic decision matrix of the k-th decision maker and $\psi = (\psi_1, \psi_2, \dots, \psi_p)^T$ be the weight vector of decision maker such that each $\psi_k \in [0, 1]$, $D = (d_{ij})_{m \times n}$ where

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

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. Let A = (TA, IA, FA) be a SVNN, the complement of SVNN A is:
 $A^c = (FA, 1-IA, TA)$.

6. Method

Let A = (A1, ..., Am) be the set of alternatives, and G = (G1, G2, ..., Gn) be the set of attributes. Consider W = (w1, w2, ..., wn) as the attribute weights, where $0 \leq w_j \leq 1$ and $\sum_{j=1}^n w_j = 1$. Define a_{ij} , where $i = 1, 2, \dots, m$ and $j = 1, 2, \dots, n$, as the value of attribute G_j for alternative A_i. Then, $A = (a_{ij})_{m \times n} = \langle (T_{ij}, I_{ij}, F_{ij}) \rangle_{m \times n}$ is a matrix of Single-Valued Neutrosophic Number Sets (SVNNs), where T_{ij}, I_{ij}, and F_{ij} are the degrees of membership, indeterminacy-membership degree, and non-membership degree, respectively. The procedure for conducting the analysis is detailed below:

Step 1: Identify the alternatives that will be evaluated in the decision-making process.

Step 2: Determine the weights of the decision-makers. Given the logical approach of the method, each decision-maker may have a unique and different evaluation from others, as it is based on each expert's level of knowledge about the decision at hand. The relative weights of each decision-maker are considered as linguistic variables and are expressed in Single-Valued Neutrosophic Number Sets (SVNN), which are then identified using Equation (1).

Step 3: Convert the linguistic evaluations provided by the experts into SVNN. From the individual crisp evaluation matrices obtained from the opinions of the experts, individual neutrosophic matrices of the decision-makers are constructed, following the detailed instructions in Table 1.

Step 4: Obtain the initial relationship matrix between alternatives A = (A1, ..., Am) and attributes G = (G1, G2, ..., Gn), where each a_{ij} , with $i = 1, 2, \dots, m$ and $j = 1, 2, \dots, n$, represents the value of the attribute of alternative A_i with respect to attribute G. The matrix A = (a_{ij}) of size m × n is expressed in the format of Single-Valued Neutrosophic Number Sets (SVNN), where T_{ij}, I_{ij}, and F_{ij} represent the degree of membership, the degree of indeterminacy-membership, and the degree of non-membership, respectively, according to Equation (2).

Step 5: Standardize the decision information. This involves normalizing the matrix A = (a_{ij}) of size m × n into a new matrix B = (b_{ij}) of the same size m × n. If the decision involves a cost factor, the decision information must be

transformed to its complementary set using Equation (3), whereas if it involves an efficiency factor, no changes are made.

Step 6: Construct a preference function $P_j(B_i, B_r)$ for alternative B_i in relation to B_r under attribute G_j , using Equation (5).

$$P_j(B_i, B_r) = \begin{cases} 0, & d \leq p \\ \frac{d-p}{q-p}, & p < d < q \\ 1, & d \geq q \end{cases} \quad (54)$$

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

$$w_{jr} = \frac{w_j}{w_r} = (j, r = 1, 2, \dots, n) \quad (5)$$

Step 8: Define the priority index $\pi(B_i, B_r)$ of scheme B_i relative to B_r by

$$\pi(B_i, B_r) = \frac{\sum_{j=1}^n w_{jr} P_j(B_i, B_r)}{\sum_{j=1}^n w_{jr}} \quad (6)$$

Step 9: Calculate the input flow $\Phi^+(B_i)$, the output flow $\Phi^-(B_i)$, and the net flow $\Phi(B_i)$ as follows

$$\Phi^+(B_i) = \frac{\sum_{r=1}^m \pi(B_i, B_r) - \min_{1 \leq i \leq m} \{\sum_{r=1}^m \pi(B_i, B_r)\}}{\max_{1 \leq i \leq m} \{\sum_{r=1}^m \pi(B_i, B_r)\} - \min_{1 \leq i \leq m} \{\sum_{r=1}^m \pi(B_i, B_r)\}} \quad (7)$$

$$\Phi^-(B_i) = \frac{\sum_{r=1}^m \pi(B_r, B_i) - \min_{1 \leq i \leq m} \{\sum_{r=1}^m \pi(B_r, B_i)\}}{\max_{1 \leq i \leq m} \{\sum_{r=1}^m \pi(B_r, B_i)\} - \min_{1 \leq i \leq m} \{\sum_{r=1}^m \pi(B_r, B_i)\}} \quad (8)$$

$$\Phi(B_i) = \Phi^+(B_i) - \Phi^-(B_i) \quad (19)$$

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

6. Results

To define the alternatives to be evaluated, the current regulations in the country were studied, aiming to identify and understand the main legislations that include protection for individuals against these violations:

- Constitution of the Republic of Ecuador (CRE)
- Comprehensive Organic Penal Code (COIP)
- Electronic Commerce Law, Data Message, and Electronic Signatures (LCEMFE)
- International Treaties (TI)
- Ministerial Agreement 006-2021 (AM)

The criteria for evaluating the alternatives represent the guidelines to be used in the decision-making process, using them as a source of principles for assessing regulations. In this way, the alternatives to the problem can be analyzed from the same perspectives. This study was structured with 4 evaluation criteria, which were presented to decision-makers for validation. For the analysis conducted, the analysts agreed to assign the same level of importance to each criterion (value of each weight, $w = 0.25$).

For the purposes of this research, the following criteria will be used:

1. PUBLICITY OF LAWS: refers to the process by which legal provisions, including laws, regulations, and decrees, are ensured to be accessible, understandable, and known by all citizens within a society.
2. APPLICATION OF REGULATIONS: refers to the process of implementing and complying with the regulations and legal provisions established by the competent authorities in a given jurisdiction.
3. EFFECTIVENESS OF REGULATIONS: refers to the capacity of regulations established by the competent authorities to achieve their intended objectives effectively and efficiently.
4. RESULTS OF THE APPLICATION OF REGULATIONS: refer to the consequences or effects observed after implementing specific regulations by the competent authorities.

The table below shows the evaluations provided to decision-makers according to their relative importance regarding the topic addressed.

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

Decisores	Evaluación lingüística	SVNN	Numeric value
Decisor 1	Very important	(0.9;0.1;0.1)	0.21
Decisor 2	Moderately important	(0.5;0.5;0.5)	0.17
Decisor 3	Very important	(0.9;0.1;0.1)	0.21
Decisor 4	Very	(0.9;0.1;0.1)	0.21
Decisor 5	Important	(0.75;0.25;0.20)	0.2

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

Table 3: Normal matrix of alternative decisions Note. Source: Own elaboration

	PUBLICITY	APPLICATION	EFFECTIVENESS	RESULTS
COIP	(0.61424;0.38576;0.35486)	(0.67429;0.32571;0.28374)	(0.7626;0.2374;0.2081)	(0.7257;0.2743;0.2519)
CRE	(0.55653;0.44347;0.42667)	(0.5;0.5;0.5)	(0.56731;0.43269;0.41301)	(0.5;0.5;0.5)
LCEMFE	(0.68696;0.31304;0.2988)	(0.54297;0.47088;0.45555)	(0.47187;0.54413;0.5515)	(0.6024;0.4096;0.3789)
TI	(0.69071;0.30929;0.29523)	(0.61623;0.38377;0.35244)	(0.47187;0.54413;0.5515)	(0.5673;0.4327;0.413)
AM	(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 selected criteria are classified as benefit criteria, implying that their value is sought to be maximized, except for criterion 4. Therefore, the normalized matrix obtained coincides with the normal matrix presented in Table 4. From this, the preference degree matrices $P_j(B_i, B_r)$ with respect to G_j can be derived. This process can be carried out using the linear function proposed in (4). In this context, it is assumed that $q=1$ and $p=0$, leading to the derivation of matrices P_1 to P_4 .

$$P_1 = \begin{matrix} & \begin{matrix} B_1 & B_2 & B_3 & B_4 & B_5 \end{matrix} \\ \begin{matrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{matrix} & \begin{bmatrix} 0.0000 & 0.0000 & 0.0187 & 0.0199 & 0.0000 \\ 0.0239 & 0.0000 & 0.0426 & 0.0438 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 0.0012 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0484 & 0.0245 & 0.0671 & 0.0683 & 0.0000 \end{bmatrix} \end{matrix}$$

$$P_2 = \begin{matrix} & \begin{matrix} B_1 & B_2 & B_3 & B_4 & B_5 \end{matrix} \\ \begin{matrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{matrix} & \begin{bmatrix} 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0721 & 0.0000 & 0.0102 & 0.0492 & 0.0244 \\ 0.0619 & 0.0000 & 0.0000 & 0.0390 & 0.0142 \\ 0.0229 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0476 & 0.0000 & 0.0000 & 0.0247 & 0.0000 \end{bmatrix} \end{matrix}$$

$$P_3 = \begin{matrix} & \begin{matrix} B_1 & B_2 & B_3 & B_4 & B_5 \end{matrix} \\ \begin{matrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{matrix} & \begin{bmatrix} 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0683 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.1198 & 0.0515 & 0.0000 & 0.0000 & 0.0225 \\ 0.1198 & 0.0515 & 0.0000 & 0.0000 & 0.0225 \\ 0.0973 & 0.0290 & 0.0000 & 0.0000 & 0.0000 \end{bmatrix} \end{matrix}$$

$$P_4 = \begin{matrix} & \begin{matrix} B_1 & B_2 & B_3 & B_4 & B_5 \end{matrix} \\ \begin{matrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{matrix} & \begin{bmatrix} 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0827 & 0.0000 & 0.0364 & 0.0290 & 0.0815 \\ 0.0463 & 0.0000 & 0.0000 & 0.0000 & 0.0451 \\ 0.0537 & 0.0000 & 0.0074 & 0.0000 & 0.0525 \\ 0.0012 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \end{bmatrix} \end{matrix}$$

Using equation (6), the comprehensive priority index is calculated, represented in the matrix Π , from which the input, output, and net flows of each alternative are determined, as detailed in Table 5.

$$\Pi = \begin{matrix} & \begin{matrix} B_1 & B_2 & B_3 & B_4 & B_5 \end{matrix} \\ \begin{matrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{matrix} & \begin{bmatrix} 0.000 & 0.000 & 0.005 & 0.005 & 0.000 \\ 0.062 & 0.000 & 0.022 & 0.030 & 0.026 \\ 0.057 & 0.013 & 0.000 & 0.010 & 0.020 \\ 0.049 & 0.013 & 0.002 & 0.000 & 0.019 \\ 0.049 & 0.013 & 0.017 & 0.023 & 0.000 \end{bmatrix} \end{matrix}$$

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

	□□	□□	□
COIP	0	1.000	-1.000
CRE	1	0.000	1.000
LCEMFE	0.691	0.036	0.654
TI	0.555	0.167	0.388
AM	0.703	0.150	0.553

The results of positive and negative flows in this analysis reflect the levels of preference and non-preference among the different regulatory alternatives. It is noteworthy that the Comprehensive Organic Penal Code stands out for its higher level of publicity compared to other laws, followed closely by the Constitution and the Ministerial Agreement, while the International Treaty shows the lowest degree of publicity in relation to the other regulations. Likewise, upon examining the negative flows, it is revealed that the International Treaty is the least known compared to the other laws. In general terms, all regulations present similar levels of non-preference, except for the Comprehensive Organic Penal Code, which exhibits the lowest value in this aspect in relation to cybercrimes.

6. Conclusion

The exploration into the realm of cybercrime within Ecuador's legal framework, specifically through the lens of the Comprehensive Organic Penal Code (COIP) and the 2009 Law on Jurisdictional Guarantees and Constitutional Control, unveils a complex interplay between technological advancement and legal challenges. This study embarks on a methodological journey employing multicriteria decision-making (MCDM) techniques, including TODIM and PROMETHEE methods, augmented by single-valued neutrosophic sets (SVNS), to navigate the murky waters of cybercrime dissemination and prevention strategies. The employment of a neutrosophic approach allows for a refined analysis that embraces the uncertainty and imprecision of information, reflecting the real-world complexity of cybercrime phenomena. By applying these innovative methodologies, the research aims to develop a comprehensive understanding of the various dimensions influencing cybercrime in Ecuador, providing a foundation for informed and nuanced decision-making in the fight against this modern menace. Furthermore, the study's application of Single-Valued Neutrosophic Number Sets (SVNNS) facilitates a groundbreaking assessment of cybercrime awareness strategies, transcending conventional decision-making models by addressing the inherent uncertainty and partiality in human judgment. This nuanced decision matrix not only captures the breadth of expert knowledge but also offers a structured approach to identifying and prioritizing effective strategies within the Ecuadorian context. Through this advanced analytical framework, the research highlights the critical importance of a multifaceted approach to cybercrime prevention, suggesting that the integration of diverse perspectives and the acknowledgment of the complexities involved are essential for crafting effective legal and policy measures. Consequently, this study contributes significantly to the ongoing discourse on cybersecurity and legal adaptation, pointing towards a future where informed and agile responses to cyber threats become a cornerstone of national security strategy.

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