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Neutrosophic Logic to Navigate Uncertainty of Security Events in Mexico

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Abstract: A significant degree of uncertainty surrounds security events in Mexico because of the interaction of multiple socioeconomic and political elements. Conventional probabilistic and logical approaches frequently fall short of properly handling this uncertainty. To effectively navigate and manage security incidents in Mexico, this study suggests applying neutrosophic logic, an extension of classical logic that allows for indeterminacy and partial knowledge. Neutrosophic logic provides a more adaptable framework for making decisions in uncertain contexts by simultaneously handling true, false, and indeterminate values. In this study, we have created a neutrosophic-based model that includes metrics like social unrest, economic instability, and crime rates to provide a thorough evaluation of the security environment. When the model is put to the test using actual data from different parts of Mexico, it outperforms conventional techniques in terms of prediction and interpretation of security occurrences. The findings demonstrate how neutrosophic logic helps security analysts and policymakers make more thoughtful and nuanced judgments by offering insightful information about the ambiguous nature of security occurrences. The ability to foresee and address possible risks is much improved when neutrosophic logic is incorporated into security event analysis. This not only improves overall security management but also creates new opportunities for its application in other sectors where uncertainty is crucial.

Keywords: Neutrosophic Logic, Security Events, Uncertainty, Mexico, Decision-Making, Predictive Analysis, Crime Rates, Socio-Economic Factors, Indeterminacy

1. Introduction

Mexico's security landscape has long been fraught with complexities, shaped by a convergence of organized crime, drug trafficking, violence, political corruption, and social instability. In recent decades, the country has faced escalating security threats, particularly from powerful drug cartels, transnational criminal organizations, and increasing levels of violent crime. The unpredictability of these threats presents a daunting challenge to government agencies, security forces, and policymakers who must continuously adapt to an evolving and uncertain environment [1]. Traditional approaches to security management, which often rely on deterministic models and binary logic, struggle to effectively handle the complexity and uncertainty intrinsic to these events. The crux of the problem lies in the uncertainty surrounding security events. Security analysts and decision-makers are frequently confronted with incomplete, contradictory, or imprecise information [2].

For example, intelligence reports may be based on conflicting sources, and the outcomes of potential interventions may be difficult to predict due to rapidly changing circumstances. In such scenarios, the ability to incorporate and reason with uncertainty is crucial for making informed decisions. Traditional binary logic—where a statement is either true or false—fails to account for the nuances of real-world data, where information may be partially true, indeterminate, or evolving [3].

To address this gap, neutrosophic logic offers a novel approach. Introduced by Florentin Smarandache in the late 1990s, neutrosophic logic extends classical and fuzzy logic by introducing three distinct components: truth (T), indeterminacy (I), and falsity (F). These parameters allow for a more flexible interpretation of reality, where propositions are not simply true or false, but can also include elements of uncertainty or contradiction. This is particularly relevant in security contexts, where data can often be incomplete, unreliable, or fluid. Neutrosophic logic provides the tools to model these ambiguities, allowing for better decision-making under uncertain conditions. In the context of Mexico's security challenges, neutrosophic logic can be a powerful tool for navigating the complex, uncertain, and rapidly changing landscape. By offering a more comprehensive framework for understanding and responding to security threats, neutrosophic logic can assist in areas such as crime prediction, risk assessment, and strategy formulation. This logic allows decision-makers to model not just the known elements of a security event, but also the unknowns and contradictions that often accompany them. This paper aims to explore the application of neutrosophic logic to security events in Mexico, focusing on how it can provide a structured approach to handling uncertainty. We will begin by examining Mexico's current security environment, highlighting the unpredictable nature of crime and violence in the country. Next, we will introduce the principles of neutrosophic logic and discuss its theoretical foundations. Finally, we will present practical examples of how this logic can be applied to real-world security scenarios in Mexico, offering insights into how it can improve decision-making and policy formulation in the face of uncertainty [4].

1.1. Security Events

The incidents or occurrences that pose a risk to the safety, stability, and well-being of a nation, its citizens, and its institutions are referred to as security events. These events can range from organized crime, terrorism, and political unrest to cyber-attacks, natural disasters, and civil disobedience. Security events may involve both internal and external threats, such as domestic violence, insurgencies, cross-border conflicts, or cyber warfare. In the context of Mexico, for instance, security events often include cartel violence, kidnappings, organized crime, extortion, and widespread corruption. However, security events aren't limited to criminal activity; they can also include mass protests, economic instability leading to civil unrest, and even natural disasters like earthquakes or hurricanes, which can destabilize regions and strain government resources [5].

The significance of security events lies in their profound impact on a nation's stability, governance, and quality of life. These events, such as violence, terrorism, organized crime, and political unrest, directly threaten public safety, erode trust in institutions, and destabilize economies. In countries like Mexico, the persistence of security events, particularly driven by drug cartels and organized crime, affects social cohesion, disrupts daily life, and hinders economic growth by deterring investment and tourism. Security issues also undermine the rule of law, leading to impunity and weakening democratic governance. Addressing these events is critical for protecting citizens, preserving social order, and ensuring long-term national development [6]. A secure environment enables not only the physical safety of individuals but also promotes political stability, economic prosperity, and international standing, all essential for the betterment of a country. Determinate factors are the underlying causes or contributors that shape and influence the occurrence of security events. These factors can vary based on geographical, socio-economic, political, and historical contexts, but they generally include elements such as crime, corruption, poverty, governance failures, and social inequality. Understanding these determinate factors is crucial for identifying the root causes of security issues and developing effective strategies to prevent and mitigate violence. For the current study, they are considered as determinate factors throughout this paper. These are as follows[7], [8], [9]:

- Drug Trafficking and Organized Crime (Df1)
- Corruption and Weak Governance (Df2)
- Poverty and Social Inequality (Df3)
- Weak Rule of Law and Impunity (Df4)
- Availability of Firearms (Df5)
- Territorial Control and Fragmentation of Cartels (Df6)
- Migration and Human Trafficking (Df7)
- Political Instability and Social Unrest (Df8)

The rest of the paper is divided into 5 sections. Section 2 and Section 3 present extensive literature and methodology respectively. Section 4 is focused on results and discussion whereas Section 5 presents the conclusion of the present work.

2. Literature Survey

Many studies focus on analyzing the root causes of violence and insecurity in Mexico. For instance, Astorga (2020) explores the roles of political corruption, social inequality, and the weakness of the rule of law as key contributors to the rise of organized crime in the country. Similarly, Buscaglia (2018) provides a comprehensive analysis of how the lack of government control in certain regions has allowed criminal organizations to flourish, leading to greater uncertainty about security outcomes [10].

However, despite the extensive body of work on the causes of security issues in Mexico, there is relatively little research on how to manage the uncertainty that these security threats produce. This gap presents an opportunity to apply advanced logical frameworks, such as neutrosophic logic, to better understand and address the unpredictable nature of security events in the country.

Neutrosophic logic has gained traction in recent years for its applications in decision-making processes, particularly in fields that involve uncertainty, such as engineering, medicine, and economics. One notable example is the use of neutrosophic sets in multi-criteria decision-making (MCDM) frameworks. These frameworks are often employed in situations where decision-makers must choose between multiple alternatives based on incomplete or uncertain information. In a study by Ye, neutrosophic logic was applied to assess risks in industrial processes, demonstrating its effectiveness in environments characterized by uncertain and indeterminate conditions. Other research has focused on using neutrosophic logic to improve decision-making in medical diagnosis, where conflicting data can lead to ambiguous results. These applications suggest that neutrosophic logic could similarly be applied to the complex decision-making processes involved in security events in Mexico, where risks must be assessed under conditions of uncertainty and incomplete information [11]. The potential of neutrosophic logic for risk assessment has been demonstrated in several studies. For instance, Smarandache applied neutrosophic models to security risk analysis in infrastructure systems, proving its effectiveness in handling indeterminate situations where traditional logic failed to provide conclusive outcomes. Given the complexity of security threats in Mexico, this approach could be highly relevant, as it would allow for more comprehensive risk assessments that take into account not only known threats but also the uncertainties surrounding those threats. Indeterminacy, or the presence of uncertain, ambiguous, or incomplete factors, plays a significant role in the perpetuation of violence, particularly in complex environments like Mexico's security landscape. Indeterminate factors make it difficult to predict or fully understand the dynamics behind violent events, complicating efforts to devise effective responses [12]. For instance, inconsistent or unreliable intelligence reports, fluctuating alliances between criminal organizations, and blurred lines between corrupt officials and law enforcement contribute to an indeterminate environment. Additionally, the role of external influences, such as illegal arms trafficking and international drug markets, adds another layer of unpredictability to the situation. These indeterminate factors exacerbate the uncertainty faced by policymakers and law enforcement, making it harder to implement sustainable security solutions. The unpredictability of violence in Mexico, driven by a combination of socio-economic, political, and international variables, underscores the need for flexible decision-making frameworks like neutrosophic logic that can accommodate and navigate such indeterminacies.

Many researchers have emphasized the assessments happening in institutions for the successful implementation of educational models. Black and Wiliam analyze various assessment techniques and their effects on learning [13].

They highlight that the effectiveness of assessments depends on their design, implementation, and students' perceptions. The impact of assessment techniques is indeterminate due to differences in assessment types, teacher practices, and student responses to assessments.

There are as follows as are termed as indeterminate or uncertain throughout the study [14], [15], [16], [17], [18], [19]:

- Exposure to Violence (Idf1)
- Family Dynamics (Idf2)
- Socioeconomic Conditions (Idf3)
- Brain Abnormalities (Idf4)
- Immediate Stressors (Idf5)
- Provocation (Idf6)
- Substance Abuse (Idf7)

3. Methodology

The proposed solution to indeterminacy uses the concept of Neutrosophic Cognitive Map (NCMs). It is a technique in Neutrosophy introduced by W. B. Vasantha Kandasamy [20]. The concept of Neutrosophic logic introduced by Florentine Smarandache [21], which is a merger of the fuzzy logic together with the inclusion of indeterminacy. When data under scrutiny contains concepts which are indeterminate, we are not able to formulate mathematical expression. Presentation of Neutrosophic logic by Florentine Smarandache [22] has put forward a panacea to this problem. It is the reason Neutrosophy has been introduced as an additional notion for evaluation educational models. Fuzzy theory evaluates the existence or non-existence of associateship but it has failed to attribute the indeterminate relations among concepts and most data collected in educational setup has much indeterminate and uncertain concepts. Therefore we have employed Neutrosophic Cognitive Maps (NCMs) in place of Fuzzy Cognitive Maps (FCMs) to show the significance of indeterminate factors of violence in Mexico.

3.1. Neutrosophic Concepts

3.1.1. Neutrosophic Sets:

Neutrosophic sets are an extension of classical sets and fuzzy sets that handle uncertainty, indeterminacy, and contradiction in data. A classical set only allows elements to be either fully part of the set or not (0 or 1). Fuzzy sets extend this by allowing partial membership (values between 0 and 1), but neutrosophic sets go further by introducing three components:

1. Truth (T): The degree to which a statement is true.
2. Indeterminacy (I): The degree to which it is uncertain or indeterminate.
3. Falsity (F): The degree to which a statement is false.

In a neutrosophic set, each element has a degree of truth, indeterminacy, and falsity, all ranging from 0 to 1, and they don't have to sum to 1 (unlike fuzzy sets). This flexibility allows for more nuanced representation of uncertainty and contradictory information.

3.1.2. Neutrosophic Cognitive Maps (NCMs)

3.2. FCM Adjacency Matrix

An **FCM Adjacency Matrix** is a mathematical tool used to represent the relationships between concepts in a Fuzzy Cognitive Map (FCM). It is a square matrix where each row and column corresponds to a concept in the system, and the entries in the matrix reflect the strength and type of influence one concept has on another. The values in the matrix typically range from -1 to 1, where positive values indicate a positive influence, negative values signify a negative influence, and zero means there is no direct influence between the concepts. This matrix helps to model complex systems by showing how changes in one concept can affect others, enabling the analysis and simulation of dynamic behaviors. The FCM adjacency matrix is particularly useful for studying decision-making processes, forecasting, and understanding the interactions in systems with interdependent factors, such as social, economic, or environmental systems.

Let's consider a system with 3 concepts: C1C_1C1 (Economic Growth), C2C_2C2 (Employment Rate), and C3C_3C3 (Public Spending). The FCM adjacency matrix could look like this:

$$\begin{pmatrix} 0 & 0.6 & -0.2 \\ 0.7 & 0 & 0.3 \\ 0 & -0.4 & 0 \end{pmatrix}$$

- w_12=0.6 means that "Economic Growth" has a positive influence on "Employment Rate".
- w_13 means that "Economic Growth" negatively affects "Public Spending".
- w_21=0.7 means that "Employment Rate" positively affects "Economic Growth".
- w_23=0.3 means that "Employment Rate" positively influences "Public Spending".
- w_32=−0.4 means that "Public Spending" negatively influences "Employment Rate"
- Diagonal entries are typically 0 because a concept does not directly influence itself.

3.3. NCM Adjacency Matrix

The **NCM Adjacency Matrix** is an extension of the Fuzzy Cognitive Map (FCM) adjacency matrix, used to represent the relationships between concepts in a **Neutrosophic Cognitive Map (NCM)**. Unlike FCMs, where each connection between concepts is represented by a single value (indicating positive or negative influence), the NCM adjacency matrix incorporates three components to account for the uncertainty and indeterminacy in relationships. Each entry in the NCM adjacency matrix consists of three values: **Truth (T)**, **Indeterminacy (I)**, and **Falsity (F)**.

Example:

Consider a system with 3 concepts: C1C_1C1 (Economic Stability), C2C_2C2 (Inflation Rate), and C3C_3C3 (Employment Levels). The NCM adjacency matrix could look like this:

$$\begin{pmatrix} (0,0,0) & (0.6,0.2,0.1) & (0.4,0.3,0.1) \\ (0.5,0.3,0.2) & (0,0,0) & (0.7,0.1,0.1) \\ (0.3,0.4,0.2) & (0.6,0.2,0.2) & (0,0,0) \end{pmatrix}$$

- The relationship between "Economic Stability" and "Inflation Rate" is (0.6,0.2,0.1)(0.6, 0.2, 0.1)(0.6,0.2,0.1), meaning there is a 60% positive influence, 20% uncertainty, and 10% negative influence.
- The relationship between "Inflation Rate" and "Employment Levels" is (0.7,0.1,0.1)(0.7, 0.1, 0.1)(0.7,0.1,0.1), indicating a strong positive influence with little uncertainty and falsity.

Neutrosophic Cognitive Maps (NCMs) are an advanced extension of Fuzzy Cognitive Maps (FCMs), designed to model complex systems where uncertainty, indeterminacy, and contradiction play a significant role. Like FCMs, NCMs consist of concepts representing variables within a system, connected by edges that depict the influence between these concepts. However, in NCMs, each connection is characterized by three components: truth (T), indeterminacy (I), and falsity (F), allowing for a more nuanced understanding of relationships. This structure helps capture not just the positive or negative influence between concepts but also the uncertainty and incomplete information that might exist in real-world scenarios. NCMs are particularly useful for dynamic, evolving systems—such as social, economic, or environmental models—where information is often ambiguous or contradictory, providing a more flexible and realistic framework for analysis and decision-making.

In the following NCM diagram, each node represents a concept such as "Economic Stability" or "Inflation Rate," and each directed edge between nodes represents the influence one concept has on another. The relationships between nodes are described by three values: Truth (T),

Indeterminacy (I), and Falsity (F), are displayed as labels on the edges.

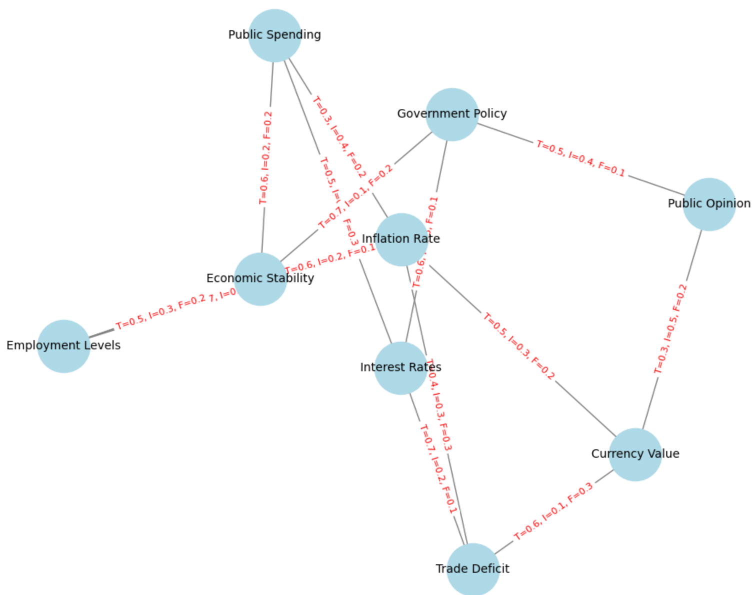

Figure 1: Neutrosophic Cognitive Maps for Economic Stability

4. Results

After taking all these factors & their relationship to violence, we must model the condition of violence based on the concept of Neutrosophic Cognitive Maps. This is the graph for mapping the condition of factors related to violence. Nodes denote factors and edges denote the relationship from node to node or from node to factors. Some nodes have representation like *Df*1, *Df*2, *Df*3, ………, and *Df*7 known as Determinate Factors, and other nodes have representation like *Idf*1, *Idf*2, *Idf*3, ………*I*df8 known as Indeterminate Factors. The edges have weight "1" represent known or determinate edges and the edges having representation "*I*" represent Indeterminate edges. The graph contains two types of edges, the first type of edge is the complete edge as we have seen in the normal graph, this edge shows determinacy and another type of edge is a dotted edge which represents indeterminacy. We took Blue color for showing Determinate Factors and Red color for showing Indeterminate Factors respectively as we have in Figure 2. The straight simple line shows the relationship between Determinate Factors and dotted lines show the relationship between Indeterminate Factors. The edges have

weight "*I*" representing known or determinate edges and the edges having representation "*I*" represent Indeterminate edges. We have formulated the adjacency matrix given in Table 1 for the graph(Figure 2).

4.1 Determinate and Indeterminate Factors| for Affecting Violence

The literature review identified numerous factors that contribute to shaping the conditions of violence. Table 1 presents the factors categorized as determinate, while Table 2 highlights those considered indeterminate.

Table 1. Determinate Factors

S. No.	Determinate Factors	Presentations
1	Drug Trafficking and Organized Crime	Df1
2	Corruption and Weak Governance	Df2
3	Poverty and Social Inequality	Df3
4	Weak Rule of Law and Impunity	Df4
5	Availability of Firearms	Df5
6	Territorial Control and Fragmentation of Cartels	Df6
7	Migration and Human Trafficking	Df7

Table 2. Indeterminate Factors

S. No.	Indeterminate Factors	Presentations
1	Exposure to Violence	Idf1
2	Family Dynamics	Idf2
3	Socioeconomic Conditions	Idf3

S. No.	Indeterminate Factors	Presentations
4	Brain Abnormalities	Idf4
5	Immediate Stressors	Idf5
6	Provocation	Idf6
7	Substance Abuse	Idf7
8	Political Instability and Social Unrest	Df8

4.2 NCM graph of factors

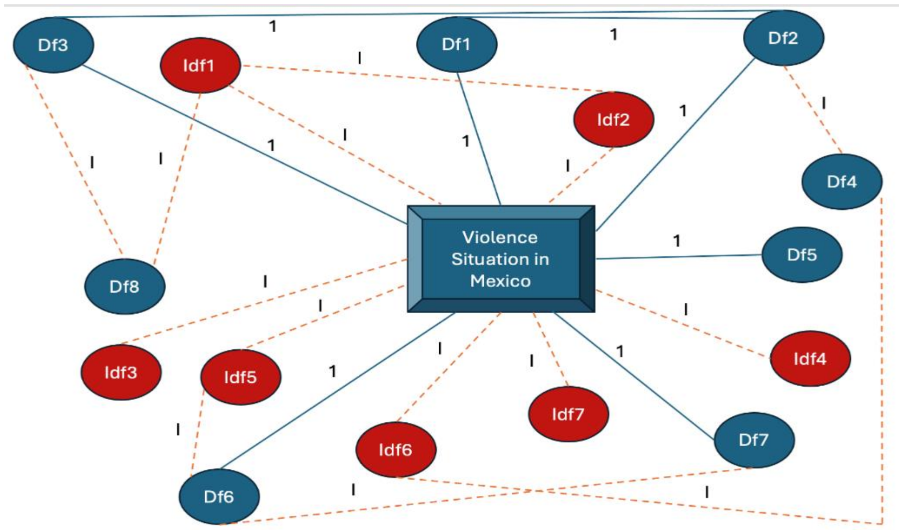

Figure 2: Neutrosophic Cognitive Map based on determinate and indeterminate factors affecting violence in Mexico

4.3 Adjacency matrix

Table 3. AdjecencyMarix

	VSI_ M	**Df 1**	**Idf 1**	**Df 2**	**Idf 2**	**Df 3**	**Idf 3**	**Df 4**	**Idf 4**	**Df 5**	**Idf 5**	**Df 6**	**Idf 6**	**Df 7**	**Idf 7**	**Df 8**
VSI_ M	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**
Df1	**1**	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Idf1	**0**	0	0	0	I	0	0	0	0	0	0	0	0	0	0	I
Df2	**1**	0	0	0	0	0	0	I	0	0	0	0	0	0	0	0
Idf2	**0**	0	I	0	0	0	0	0	0	0	0	0	0	0	0	0
Df3	**1**	0	0	1	0	0	0	0	0	0	0	0	0	0	0	I
Idf3	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Df4	**1**	0	0	I	0	0	0	0	0	0	0	I	0	0	0	0
Idf4	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Df5	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Idf5	**0**	0	0	0	0	0	0	0	0	0	0	0	I	1	0	0

	VSI_M	Df1	Idf1	Df2	Idf2	Df3	Idf3	Df4	Idf4	Df5	Idf5	Df6	Idf6	Df7	Idf7	Df8
Df6	**1**	0	0	0	0	0	0	0	0	I	0	0	0	I	0	0
Idf6	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Df7	**1**	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Idf7	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Df8	**1**	0	I	0	0	I	0	0	0	0	0	0	0	0	0	0
Idf8	**0**	0	0	I	0	I	0	0	0	0	I	0	0	0	0	0

Now, this Neutrosophy Adjacency Matrix will be evaluated to show the significance of factors causing violence. We will take vector FA as an "ON" state i.e. the state vector is given as input. Based on the methodology mentioned above following iterations are carried out. These iterations are performed till we obtain a limit cycle.

This limit cycle is also referred to as a constant state vector. The Limit cycle shows hidden patterns that are used in mapping inferences. These inferences are used to show the joint effect of interacting knowledge. To get the current result we used NCM which shows that when a crime is in an ON state all the factors. All these factors show that they have a direct effect on crime.

4.4 Iterative Process

Now, this Neutrosophy Adjacency Matrix will be evaluated to show the significance of factors causing violence. We will take vector FA as an "ON" state i.e. the state vector is given as input. Violence in Mexico (VM) = (100000000000000000) and the combined system is VM1*N(E) The symbol → denotes that the resultant vector is updated and threshold. Based on the methodology mentioned above following iterations are carried out. These iterations are performed till we obtain a limit cycle. This limit cycle is also referred to as a constant state vector. The first iteration starts by keeping the critical thinking state as ON rest all other factors are considered null at this time. So, the Initial State becomes,

$$S(0) = [1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0]$$

The iterations for both FCM and NCM are done separately. The further iterations are carried out using the formula mentioned below. Iterations for FCM:

Iteration 1: S(1)=S(0)×WS(1)=S(0)×W

Iteration 2: S(2)=S(1)×WS(2)=S(1)×W

Iteration 1: S(1)=S(0)×WFCMS(1)=S(0)×WFCM

Iteration 2: S(2)=S(1)×WFCMS(2)=S(1)×WFCM

Combining the intermediate results of iteration, we get the final state vector (1,1,0,1,0,0,0,1,0,1, I,1,0,1,0,0). This clearly shows the presence of I mentioning the importance of indeterminate factors in crime analysis which was absent in the final result obtained by the FCM.

Conclusion

The crime situation in Mexico has seen an unprecedented change due to prevailing uncertainty surrounding security events. This is due to the complex mix of social, economic, and political factors. Traditional methods struggle to handle this uncertainty effectively. Therefore, this study proposes the use of neutrosophic logic, which can deal with uncertainty by considering true, false, and indeterminate values present in any security event captioning. By creating a model based on neutrosophic logic, we can assess factors like social unrest, economic instability, and crime rates more accurately. Our results show that this approach predicts and interprets security events better than traditional methods, helping analysts and policymakers make better decisions in uncertain situations.

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