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Enhancing Judicial Impartiality in Ecuador: A Fuzzy Cognitive Map Approach Using Neutrosophic Logic and Fuzzification

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Abstract. Fuzzy Cognitive Map (FCM) approach, with neutrosophic logic and fuzzification applied to assign weights to the relationships between key concepts. Through expert consensus, eight critical factors were identified: Judicial Independence, Transparency, Corruption, Judicial Training, Accountability, Access to Justice, Procedural Guarantees, and Supervision and Control. Centrality analysis revealed that Judicial Independence and Transparency are the most influential, while Judicial Training has the lowest impact. The use of neutrosophic logic and fuzzification allowed for a flexible and accurate representation of causal relationships, accounting for uncertainty within the system. The findings highlight the need for reforms focused on enhancing judicial independence and transparency, as well as addressing corruption and access to justice. Future research should incorporate dynamic simulations and machine learning to further improve predictive capabilities and deepen the understanding of policy impacts on judicial impartiality.

Keywords: Judicial impartiality, fuzzy cognitive maps, expert knowledge, Neutrosophic Logic fuzzification.

1. Introduction

The issue of judicial impartiality in Ecuador is a critical and multifaceted challenge, reflecting the ongoing difficulties within the nation's legal system. Despite numerous efforts to reform and strengthen the judiciary over recent decades, doubts persist regarding the genuine autonomy of the courts. A significant barrier to achieving full impartiality lies in the persistent political interference in administrative procedures, particularly in the appointment of judges. Such interventions compromise public confidence in the fairness of judicial decisions, as many citizens perceive rulings to be influenced by external political agendas rather than legal principles [1].

An additional and severe obstacle is the pervasive corruption at various levels of the Ecuadorian government, including the judiciary itself. Corrupt practices within the judicial system severely undermine both the actual and perceived fairness of court rulings, leading to doubts about the integrity of judges and the outcomes of legal processes. Although efforts to combat corruption have been implemented, they have been insufficient in eradicating the issue. Stronger oversight and enforcement mechanisms are urgently needed to restore public trust in the judicial system [2].

Another contributing factor to the erosion of judicial impartiality is the lack of resources and inadequate training for judges. Heavy workloads and limited access to specialized training often result in biases or insufficient decision-making processes. Particularly in complex cases requiring technical expertise, the absence of continuous education and infrastructure support poses significant challenges. Addressing these deficiencies requires a comprehensive commitment to strengthening the judicial framework and providing judges with the resources necessary to carry out their responsibilities impartially [3,4].

One potential solution to these issues is the incorporation of expert information into judicial decision-making processes. In cases involving technical or scientific evidence, such as environmental or intellectual property disputes, expert participation can provide judges with the necessary specialized knowledge to make well-informed and impartial rulings. This approach reduces the likelihood of errors or biases, ensuring that judicial decisions are based on a thorough understanding of the facts [5,6].

Finally, the use of neutrosophic tools, including fuzzy cognitive maps (FCMs), offers a novel method for representing and understanding the complexities of the judicial process. These tools facilitate the depiction of uncertainty and ambiguity, which are inherent in legal decision-making. The application of neutrosophic approaches allows for a deeper understanding of the factors that affect judicial impartiality and enables the development of more effective strategies to improve transparency, fairness, and accountability in the Ecuadorian judiciary [7,8]. This study aims to explore these issues and propose solutions to enhance the efficiency and fairness of the judicial system.

2. Backgound

2.1 Fuzzy Cognitive Maps: Structure, Causality, and Integration with Neutrosophic Logic

Fuzzy Cognitive Maps (FCMs) are conceptual structures that employ feedback to describe causality. These models merge theoretical elements from cognitive maps, fuzzy logic, neural networks, semantic networks, expert systems, and nonlinear dynamic systems. This methodology allows for the representation of the system with feedback using fuzzy degrees of causality within the interval [0,1]. Each node in the diagram represents a fuzzy set or an event that occurs with a certain degree of certainty. These nodes are causal concepts that can represent events, actions, values, goals, or processes. The use of this technique provides additional advantages such as visual modeling, simulation, and predictive capability [9, 10].

In Fuzzy Cognitive Maps (FCMs), different types of relationships are established between the represented concepts. These relationships are characterized by their influence on the change of values among the associated concepts [9]. Next, the three main types of causality relationships are described[11, 12]:

1. Positive Causality: When the weight of the relationship between two concepts, represented by W_{ij}, is greater than zero ($W_{ij} > 0$), it indicates a positive causality between the concepts C_i and C_j. In other words, an increase (or decrease) in the value of concept C_i leads to an increase (or decrease) in the value of concept C_j.
2. Negative Causality: If the weight of the relationship between two concepts, W_{ij}, is less than zero ($W_{ij} < 0$), a negative causality between the concepts C_i and C_j is established. This implies that an increase (or decrease) in the value of C_i leads to a decrease (or increase) in the value of C_j.
3. Absence of Relationships: When the weight of the relationship between two concepts is null ($W_{ij} = 0$), it is concluded that there is no direct causal relationship between C_i and C_j.

A directed graph, in which nodes represent concepts and edges represent causal relationships, can be used to represent an FCM. Fuzzy values show the intensity of the causal relationship. Each step of the simulation involves calculating the values of the concepts. The initial vector will determine whether the FCM will converge to a fixed point, limit cycle, or chaotic attractor[13, 14].

In this article, the calculation will be developed as follows[15]:

1. Selection of the factors of interest
2. Elaboration of the adjacency matrix.
3. Static analysis: calculated for the absolute values of the adjacency matrix:
   - *Outdegree*, denoted by $od(v_i)$, is the sum for each row of the absolute values of a variable from the fuzzy adjacency matrix. It is a measure of the accumulated strength of the existing connections in the variable.
   - *Indegree*, denoted by $id(v_i)$, is the sum for each column of the absolute values of a variable from the fuzzy adjacency matrix. It measures the accumulated strength of input to the variable.
   - The *centrality* or *total degree* of the variable is the sum of $od(v_i)$ with $id(v_i)$, as indicated below:

$$td(v_i)= od(v_i)+id(v_i) \quad (1)$$

Finally, the variables are classified according to the following criteria, see[14]:

a) The transmitting variables are those with $od(v_i) > 0$ and $id(v_i) = 0$.
b) The receiving variables are those with $od(v_i) = 0$ and $id(v_i) > 0$.
c) Ordinary variables satisfy both $od(v_i) \neq 0$ and $id(v_i) \neq 0$.

They are ordered in ascending order according to the degree of centrality.

The adjacency matrix is created using an aggregation operator, such as the arithmetic mean, when a set of experts (k) is involved. The simplest method is to calculate the arithmetic mean of each connection for each expert. The final adjacency matrix of the FCM (E) for k experts is obtained as [16]:

$$E = \frac{(E_1+E_2+\cdots+E_k)}{k} \quad (2)$$

The creation of collective mental models is relatively easy thanks to this aggregation ease.

The relationships in fuzzy cognitive maps can be expressed using many-valued logic, such as computing with words, hesitant, and neutrosophic logic [17, 18, 19]. Neutrosophic logic, in particular, allows for greater flexibility by incorporating the notions of truth, indeterminacy, and falsity, making it suitable for dealing with uncertainty and hesitation in decision-making processes. Using neutrosophic logic in fuzzy cognitive maps enhances the ability to model complex, real-world systems with a more nuanced representation of uncertainty and conflicting information[20, 21].

3. Materials and Methods

This study utilized a Fuzzy Cognitive Map (FCM) to analyze the factors influencing judicial impartiality in Ecuador. The methodology was based on the consensus of a panel of experts who identified the key concepts impacting impartiality in the Ecuadorian judicial system.

A group of 12 specialists in law and justice, including judges, academics, and lawyers with experience in the Ecuadorian judicial system, were selected. These experts participated in structured interviews and workshops to identify the most relevant factors related to judicial impartiality.

The experts provided a list of key concepts through a modified Delphi process, involving rounds of discussion and review. The agreed-upon concepts were: judicial independence, corruption, transparency, judicial training, accountability, access to justice, procedural guarantees, and supervision and control. Using these concepts, the FCM was constructed with the Mental Modeler software.

The procedure is as follows:

1. Construction of the Fuzzy Cognitive Map

The Fuzzy Cognitive Map was built using an Adjacency Matrix, which describes the influences between the identified concepts. Each cell in the matrix contains a value representing the magnitude and direction of influence between pairs of concepts, as assessed by the experts. In this case, the weights are expressed using linguistic terms and then represented as singlevalued neutrosophic numbers according to the scale shown in Table 1.

Table 1: Linguistic Terms and Corresponding Neutrosophic Values

Linguistic Term	Neutrosophic Values $\left(TA(x), IA(x), FA(x)\right)$
Strong Negative Influence	(0,0,-1)
Negative Influence (NI)	(0.25, 0,0)
Neutral (N)	(0.5, 0.5, 0.5
Positive Influence (PI)	(0.75, 0,0.25)
Strong Positive Influence (SPI)	(1,0,0)

The function presented in [22] transformed for the fuzzification process. Given $AN = \{x, \left(TA(x), IA(x), FA(x)\right): x \in X\}$ a NS. Its equivalent fuzzy membership set is defined as $AF = \{\left(x, \mu A(x)\right): x \in X\}$,where $\mu A(x) = s\left(\left(TA(x), IA(x), FA(x)\right), (1,0,0)\right)$. So, using the similarity equation proposed in [22],

$$\mu A(x) = T_A(x) - \max\{I_A(x), F_A(x)\} \quad (3)$$

The range of the similarity measure function is in the interval [-1,1], μA (x) ∈ [-1,1] for all x ∈ X. Therefore, the membership function of the derived fuzzy set belongs to [-1, 1] and satisfies the property of a membership function of a fuzzy cognitive map.

2. Centrality Analysis

A centrality analysis was performed for each concept within the FCM, calculating "Indegree" (incoming influences) and "Outdegree" (outgoing influences) values. Centrality was determined as the sum of both values, helping to assess the overall importance of each node in the system.

3. Nodes Calsification

In a fuzzy cognitive map, nodes are classified into three categories:

- Receivers: Nodes that only receive influences, with outdegree = 0.
- Ordinary: Nodes that both receive and emit influences, with indegree and outdegree greater than 0.
- Transmitters: Nodes that primarily emit influences, with low or zero indegree, and high outdegree.

This classification helps to understand the flow of influences within the system.All analyses were conducted using Mental Modeler software, which facilitated both the construction of the cognitive map and the calculations for centrality and weighted sum. This software is particularly suited for modeling complex systems with qualitative and fuzzy variables, as is the case with judicial impartiality.

4. Results

From the consensus among the experts, eight relevant concepts for an individual cognitive map centered on judicial impartiality in Ecuador were determined. Below the reasons for their relevance are explained and listed.

1. Judicial independence: The independence of the judiciary is fundamental to ensure that judges can make decisions free from external influences, contributing to the impartiality of the judicial system.
2. Corruption: Corruption can undermine judicial impartiality by compromising the integrity of judges and the judicial process, negatively affecting public trust in the judicial system.
3. Transparency: Transparency in the judicial system is crucial to maintaining public confidence and ensuring that judicial decisions are made fairly and impartially.
4. Judicial training: Proper training of judges and judicial personnel is essential to ensure they can perform their duties impartially and effectively.
5. Accountability: Holding judges accountable for their actions is important to ensure responsibility and integrity in the exercise of their duties, contributing to the impartiality of the judicial system.
6. Access to justice: Ensuring equitable access to justice for all citizens is essential to maintain the impartiality of the judicial system and prevent unfair discrimination.
7. Procedural guarantees: Procedural guarantees, such as the right to a fair trial and due process of law, are fundamental to protecting individual rights and ensuring impartiality in the judicial system.
8. Supervision and control: Effective supervision and control of judicial activities are important to prevent abuses of power and ensure that the judicial system operates impartially and transparently.

These concepts are fundamental to understanding and addressing the challenges related to judicial impartiality in Ecuador, as well as to promoting a fair, transparent, and effective judicial system (Figure 1) and (Tables 2 and 3).

Table 2: Adjacency Matrix.

	Judicial independence	Transparency	Accountability	Access to justice	Corruption	Procedural guarantees	Supervision and control	Judicial training
Judicial independence	(0.5, 0.5, 0.5) **N**	(0.75, 0, 0.25) PI	(0.75, 0, 0.25) PI	(0.75, 0, 0.25) PI	(0.75, 0, 0.25) PI	(0.75, 0, 0.25) PI	(0.75, 0, 0.25) PI	(0.5, 0.5, 0.5) **N**
Transparency	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**	(0.75, 0, 0.25) **PI**	(1, 0, 0) **SPI**	1, 0, 0) **SPI**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**
Accountability	(0.25, 0, 0.75) **NI**	(0.75, 0, 0.25) **PI**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**
Access to justice	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N** 0	(0.5, 0.5, 0.5) **N** 0	(0.5, 0.5, 0.5) **N**	(0.25, 0, 0.75) **NI**	(0.75, 0, 0.25) **PI**	(0.5, 0.5, 0.5) **N**	(0.75, 0, 0.25) **PI**
Corruption	(0.5, 0.5, 0.5) **N**	(0, 0, 1) **SNI**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**	(0.25, 0, 0.75) **NI**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**
Procedural guarantees	(0.75, 0, 0.25) **PI**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**	(0.75, 0, 0.25) **PI**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**
Supervision and control	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**	(0.75, 0, 0.25) **P**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**
Judicial training	(0.5, 0.5, 0.5) **N** 0	(0.5, 0.5, 0.5) **N** 0	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**	(0.5, 0.5, 0.5) **N**

Fuzzification of the values occur cording to (3) graphically equation 3.

Table 3: Adjacency Matrix associated after de fuzzification process.

	Judicial independence	Transparency	Accountability	Access to justice	Corruption	Procedural guarantees	Supervision and control	Judicial training
Judicial independence	0	0.5	0.5	0.5	0.5	0.5	0.5	0
Transparency	0	0	0.5	1	1	0	0	0
Accountability	-0.5	0.5	0	0	0	0	0	0
Access to justice	0	0	0	0	-0.5	0.5	0	0.5
Corruption	0	-1	(0	0	0	-0.5	0	0
Procedural guarantees	0.5	0	0	0.5	0	0	0	0
Supervision and control	0	0	0.5	0	0	0	0	0
Judicial training	0	0	0	0	0	0	0	0

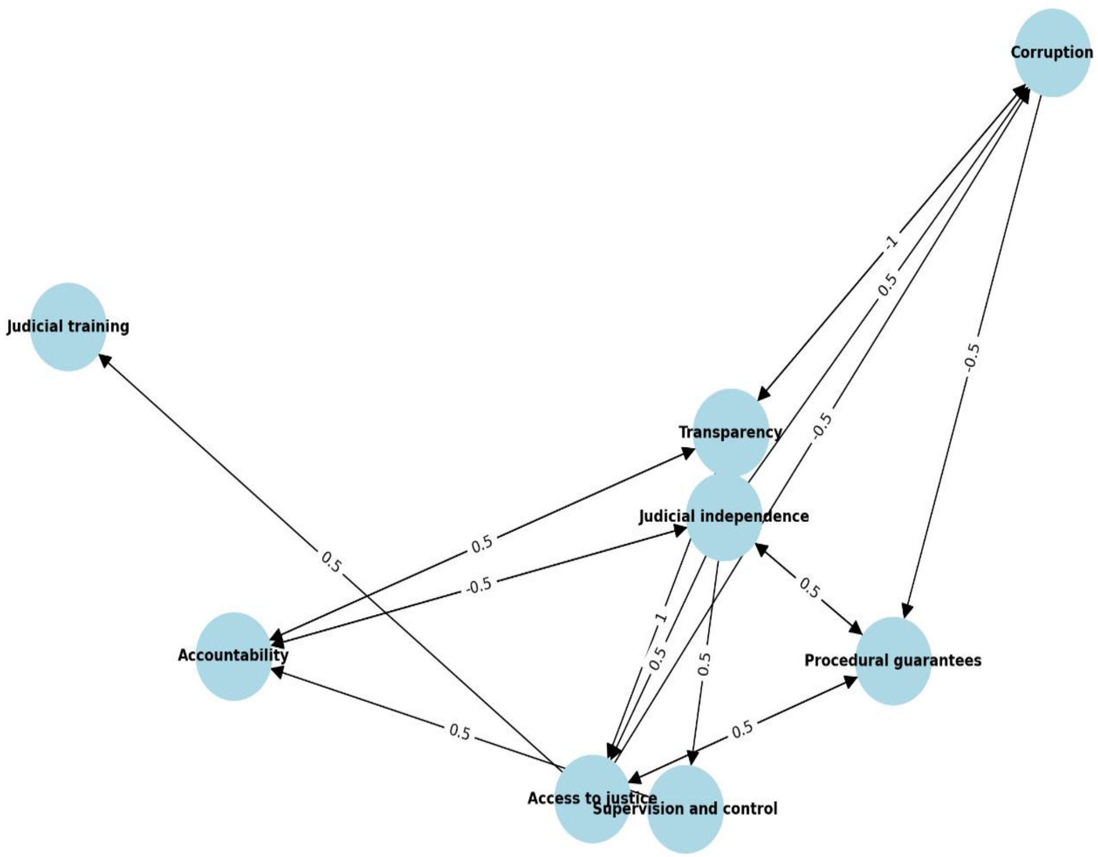

Figure 1. Fuzzy Cognitive Map of the Judicial System

The centrality analysis for each element is presented in the following table:

Table 4: Centralized Analysis. Note: Mental Modeler software was used for method execution. Source: own elaboration.

Components	Indegree	Outdegree	Centrality	Type
Judicial independence	3	1	4	Ordinary
Transparency	2	2.5	5.5	Ordinary
Accountability	1.5	1	2.5	Ordinary
Access to justice	2	1.5	3.5	Ordinary
Corruption	2	1.5	3.5	Ordinary
Procedural guarantees	1.5	1	2.5	Ordinary
Supervision and control	0.5	0.5	1	Ordinary
Judicial training	0.5	0	0.5	Ordinary

The centrality analysis of the judicial system components reveals the following key insights:

- Judicial independence and Transparency emerge as the most influential nodes, with high centrality values (4 and 5.5, respectively). Both nodes exhibit strong incoming and outgoing influences, classifying them as Ordinary nodes.
- Access to justice, Corruption, and Procedural guarantees hold moderate centrality values (between 2.5 and 3.5), indicating their importance within the system. These are also classified as Ordinary.
- Accountability and Supervision and control display lower centrality but remain Ordinary nodes due to their capacity to both influence and be influenced.
- Judicial training has the lowest centrality (0.5) and outdegree = 0, indicating its limited role in the system, although it is classified as Ordinary.

This classification helps to highlight the varying degrees of influence and importance among the different components within the system.

Conclusion

This study provides valuable insights into the factors influencing judicial impartiality in Ecuador, using a Fuzzy Cognitive Map (FCM) to model the relationships between key concepts. The centrality analysis highlights the prominence of Judicial Independence and Transparency as the most influential factors, suggesting that these areas are crucial for enhancing impartiality. Corruption, Access to Justice, and Procedural Guarantees also hold significant importance, while Judicial Training is identified as having a lesser impact. These results emphasize the need for targeted interventions in these areas to improve the judicial system's effectiveness and public trust.

Additionally, this research has applied neutrosophic logic and fuzzification techniques to determine the weights of the arcs in the FCM, allowing for a more flexible and accurate representation of the relationships between concepts. Future research should further refine this approach by incorporating more dynamic simulations and expanding the range of stakeholders involved. Additionally, integrating machine learning and expert systems with FCMs could enhance predictive capabilities and improve decision-making processes within the judiciary.

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