Neutrosophic Sets in Investigating the Right to Genetic Information: A Study using Fuzzy Cognitive Maps and D-OWA

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Abstract

This article provides a comprehensive view of the evolution and ethical implications of genetics, from its historical origins to modern advancements like the Human Genome Project. It emphasizes the importance of genetic information in disease prediction and understanding human diversity while highlighting the need to address associated ethical and privacy issues. It introduces Fuzzy Cognitive Maps (FCM) and the Dependent OWA (D-OWA) aggregation operator as innovative tools for analyzing the complex landscape of the Right to Genetic Information (RGI) in an international context, identifying key factors such as legal frameworks, technological advancements, access to health, culture, ethics, and commercial interests. The research reveals that while legal framework and technology are predominant, other factors also play significant roles in managing RGI. The application of D-OWA provides additional insights, confirming that conventional centrality assessments adequately reflect the priorities and influence of factors in RGI. It concludes by underlining the need for specific strategies to address these challenges, such as strengthening the legal framework, promoting ethics in genetics, improving public education, and respecting cultural diversity, to protect individual rights while leveraging the benefits of genetics for society.

Keywords: Neutrosophic sets; D-OWA technique; Fuzzy Logic; Genetics; right to genetic information; dependent aggregation operator.

1. Introduction

The exploration of hereditary elements has been an ongoing concern throughout the history of humanity, from ancient Babylonian clay tablets that displayed diagrams on the expected inheritance of traits in animals to the most recent developments in the 20th century, such as the discovery of the DNA structure by Watson and Crick in 1953. As genetic science advanced, ethical and legal questions about the manipulation and management of people's genetic information emerged [1]. Events such as the conference on Genetics, Man, and Society organized by the American Association for the Advancement of Science in 1972, along with documents published in subsequent years that established the concept of genetic responsibility, highlighted the importance of regulating genetic testing and its associated information [2][3].

I'm sorry for the oversight. Let's correct that:

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At the same time, public consciousness was imbued with hopes and fears regarding this science. Literary and cinematic works began to explore issues related to genetic manipulation, privacy, and the impact on people's lives. An iconic example of this was the 1997 movie "Gattaca," where the protagonist's life was determined by predictions based on his genetic profile.

The Human Genome Project, completed in 2003, was a milestone in genetic knowledge and brought changes in research. Four important elements were highlighted: international collaboration in research, the culture of sharing and reusing results and data, technological advances in the acquisition of genetic information, and the broader focus on genomics [4].

Genetic information, fundamental for understanding human biology, provides essential data on a wide range of aspects related to health and individual development [5]. From predicting predispositions to diseases to understanding phenotypic variability, genetic analysis offers a unique window into the complexity of human biology. Additionally, it allows for the investigation of the genetic diversity of populations, as well as the identification of biomarkers that can be used in disease diagnosis and treatment. Figure 1 illustrates some of the types of information that can be identified from genetic analysis.

Figure 1: Elements that can be obtained from genetic analysis. Source: own elaboration based on[5].

Every individual possesses a unique genetic configuration that acts as personal identification [6]. The comparison of genetic markers can identify an individual with high probability, although it does not reveal the entire genetic structure. The inherited genetic information facilitates determining the kinship between individuals, allowing us to establish if they are related and to what degree. Although in certain circumstances, genetic similarities may suggest belonging to a specific ethnic group, this type of analysis is uncertain and can generate discrimination issues. Phenotyping enables the prediction of aspects and other observable physical characteristics of an individual from a biological sample analysis. Genetic testing provides information about a person's current and future health status, including the detection of genetic diseases and predispositions to certain conditions [7]. Although behavioral genetics investigates individual differences in behavior and their causes, currently, genetic analysis only provides predispositions and probabilities, not certainties.

It's worth noting that genetic information is often subject to uncertainty due to its dependence on an interaction between genetic, environmental, and social factors. Likewise, understanding an individual's genetic information can carry implications for their relatives and related groups, raising ethical considerations and privacy protection issues [5].

1.1. FCM

A fuzzy cognitive map (FCM) is a modeling tool used to represent knowledge and causal relationships between different concepts in a complex system. Unlike traditional cognitive maps, FCMs incorporate the uncertainty and vagueness that characterize many real-world systems. They consist of nodes (concepts or variables), arcs (causal relationships), and weights (intensity of the relationships) [8].

In the following figure, the essential elements that define FCMs are illustrated:

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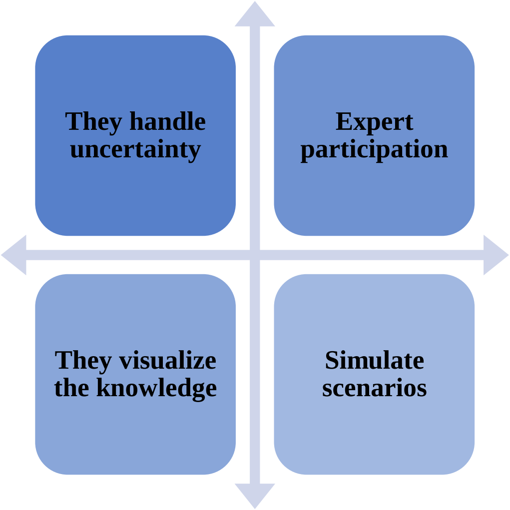

Figure 2: Key Features of FCMs. Source: own elaboration.

- ✓ Manage uncertainty: they allow for the representation of uncertainty in causal relationships through the use of fuzzy weights.
- ✓ Allow expert participation: they can be built with the collaboration of experts in different areas, facilitating the integration of different perspectives and knowledge.
- ✓ Visualize knowledge: they represent knowledge graphically, which facilitates understanding of the different factors influencing a system and their causal relationships.
- ✓ Simulate scenarios: they can be used to simulate different scenarios and evaluate the impact of different decisions on a system.

FCMs are emerging as a highly useful tool for analyzing the factors that influence the Right to Genetic Information (RGI) in the international context [9]. The complexity of the subject, the diversity of actors and perspectives, the uncertainty, and the vagueness inherent to this fundamental right, make FCMs an ideal tool to address it in a comprehensive and effective manner.

Their ability to handle uncertainty and vagueness allows FCMs to represent the complexity of RGI more accurately than traditional analysis methods. By incorporating the multiplicity of interdependent factors, causal relationships, and divergent perspectives, FCMs offer a holistic view of the international landscape of RGI.

The possibility of constructing FCMs with the participation of experts from various areas, such as genetics, law, ethics, and bioinformatics, facilitates the integration of different knowledge and perspectives in the analysis. This enriches the debate and understanding of RGI, allowing the identification of relevant factors that might be overlooked with other methods.

1.2. D-OWA

OWA (Ordered Weighted Averaging) operators are a specific type of aggregation operator used to combine information from multiple sources, taking into account both the value of the information and its relative importance. These operators integrate traditional decision-making criteria in the presence of uncertainty into a single model. Specifically, this integration encompasses the optimistic, pessimistic, Laplace, and Hurwicz criteria in a single formulation [10].

The dependent OWA operator is an extension of the standard OWA operator that allows the weights of the inputs to vary depending on certain parameters or conditions. In other words, instead of assigning fixed weights to each input, the weights are determined based on some specific characteristic or criterion. It is a specific type of OWA operator used to combine information from multiple sources. Like the classic OWAs, D-OWAs take into account both the value of the information and its relative importance. However, D-OWAs introduce an additional concept: weight degradation [11].

Procedure:

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1. Starting from a set of values $a_1, a_2, ..., a_n$ representing the information to be combined.

2. Weights $w_1, w_2, ..., w_n$ are assigned to each value, where the sum of all weights equals 1.

3. The values are ordered in ascending or descending fashion (depending on the type of D-OWA operator).

4. A degradation function is applied to the initial weights to obtain degraded weights. The degradation function reduces the value of the weights as one progresses in the ordering, giving greater importance to the values with higher weights in the original ordering.

5. The weighted average is calculated using the ordered values and the degraded weights.

RGI is a fundamental human right recognized by various international instruments. However, its effective exercise is affected by a series of factors that vary in different international contexts.

The ongoing research aims to determine the factors that influence RGI in the international arena, using an FCM model with the D-OWA aggregation operator. Furthermore, the study seeks to examine how these factors interrelate and their impact on decision-making related to genetic information in diverse communities and cultural contexts. It also aims to offer a deeper understanding of the ethical, legal, and social dynamics underlying the access and management of genetic information at a global level.

FCMs and the D-OWA operator are tools that, when integrated, allow a deeper and more accurate analysis of the factors influencing RGI in the international arena. The integration of FCMs with D-OWA represents a robust methodological strategy that enhances the analysis of the determinants of RGI. These tools, when unified, not only enable a deeper assessment of the complex network of influences impacting this field but also allow greater precision in understanding the interactions among the different elements that affect the guarantee of this right. By combining the capabilities of FCMs to model perception and subjective knowledge with the flexibility of the D-OWA operator to handle uncertainty and variability, a more detailed and comprehensive analysis of the dynamics inherent to genetic information in a global context is opened.

2. Methodology

For processing the information, FCMs are used, which are an extension of Cognitive Maps to the fuzzy domain in the interval [-1, 1] to indicate the strength of causal relationships. In this article, the calculation will be developed as follows:

1. Selection of relevant causes.
2. Preparation of the adjacency matrix.
3. Static analysis: calculated for the absolute values of the adjacency matrix:

Outdegree, denoted by $od(vi)$, is the sum of the absolute values of a variable in the fuzzy adjacency matrix for each row. It measures the accumulated strength of the outgoing connections from the variable.

Indegree, denoted by $id(vi)$, is the sum of the absolute values of a variable in the fuzzy adjacency matrix for each column. It measures the accumulated strength of incoming connections to the variable.

The centrality or total degree of the variable is the sum of $od(vi)$ and $id(vi)$, as follows:

$$td(vi) = od(vi) + id(vi) \tag{1}$$

Finally, the variables are classified according to the following criteria, see [8]:

The transmitting variables are those with $od(v_i) > 0$ and $id(v_i) = 0$.

The receiving variables are those with $od(v_i) = 0$ and $id(v_i) > 0$.

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.

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When a set of individuals (k) participates, the adjacency matrix is formulated through an aggregation operator, such as the arithmetic mean. The simplest method consists of finding the arithmetic mean of each of the connections for each expert. For k experts, the final FCM adjacency matrix (E) is obtained as follows:

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

This aggregation facility allows for the creation of collective mental models with relative ease.

Additionally, the D-OWA operator is integrated, which allows weighting of the importance of each factor in different international contexts, considering cultural, economic, legal, and ethical diversity. It is a generalization of the classic OWA operator that introduces weight degradation [12]. This degradation allows modeling the decrease in the importance of information as one advance in the ordering of the input values.

Mathematical function:

$$\boldsymbol{F(x) = \Sigma w_i * d_i * a_i} \tag{3}$$

Where:

- $\boldsymbol{F(x)}$: Output value of the D-OWA operator.
- $\boldsymbol{w_i}$: Original weight associated with the i-th input value.
- $\boldsymbol{d_i}$: Degradation factor of the i-th input value.
- $\boldsymbol{a_i}$: i-th input value ordered in ascending or descending order.
- n: Number of input values.

Degradation factors $\boldsymbol{d_i}$ are calculated from a degradation function D(i), which defines how the importance of the information is reduced as one progresses in the ordering.

Common degradation functions:

- Linear degradation function:

$$\boldsymbol{D(i) = 1 - \frac{i-1}{n-1}} \tag{4}$$

- Exponential degradation function:

$$\boldsymbol{D(i) = \exp\left(-k * \frac{i-1}{n-1}\right)} \tag{5}$$

- Sigmoid degradation function:

$$\boldsymbol{D(i) = 1 - \left(1 + \exp\left(-k * \frac{i-1}{n-1}\right)\right)} \tag{6}$$

Where k is a parameter that controls the shape of the degradation curve.

A composite centrality metric is used, generated through the D-OWA operator, which amalgamates a set of previously selected measures. The adoption of this operator facilitates the integration of the various centrality metrics, considering the degree of compensation during the calculation of the composite metric. The activities of the model are detailed below:

1. Select measures: It is recommended to determine measures for the following aspects: how strongly a node is connected (5), the importance of the flow of information (6), and the speed in the dissemination of information (7). Finally, the selected measure(s) is (are) calculated.
2. Calculate composite measure: A composite centrality measure is calculated. The aggregation of the values of the normalized measures is performed using the D-OWA operator.

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3. Order nodes: In this activity, nodes are ordered taking into account their importance in the model, according to the value obtained from the selected measure(s). Additionally, the graph can be visualized for better analysis.

The measures used are defined below:

- Degree centrality (C(v)) indicates how strongly a node is related to others from its direct connections. It is calculated as indicated in Equation 1.
- Intermediation: it is calculated using the following expression:

$$\boldsymbol{CB(v)} = \sum_{s \neq v \neq t \in V} \frac{\sigma_{(st)(v)}}{\sigma_{st}} \tag{7}$$

Where σst(v) represents the number of shortest paths from node s to node t passing through node v, and σst is the total number of shortest paths from s to t. This indicates the importance of a node in the flow of information [13].

- Proximity: defined as:

$$\boldsymbol{Cc(V)} = 1 - \sum_{t \in V, t \neq v} \boldsymbol{dG(v,t)} \tag{8}$$

Where t ≠ v and dG(v, t) is the shortest path between v and t. This measure provides information on how quickly information spreads from a node throughout the network [13].

3. Results and Discussion

For the development of the research, surveys were conducted separately with people from different interest groups (see Figure 3), aiming to achieve a more complete and diverse understanding of the factors influencing RGI in the international context.

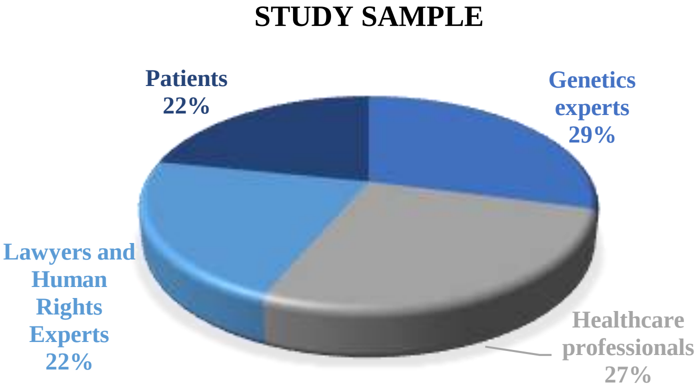

Figure 3: Description of the study sample. Source: own elaboration.

Genetics experts, including researchers, scientists, and genetics professionals, offer an informed perspective on the application and study of genetic information globally. Health professionals, such as doctors and clinical geneticists, provide insights into the management and access to genetic information in clinical and public health settings. On the other hand, lawyers and human rights experts provide information about the legal and ethical frameworks that regulate access to genetic information globally. Patients and advocacy groups, who have directly experienced issues related to access to genetic information, offer valuable perspectives on the challenges and barriers faced by individuals in practice.

Following the conduct of surveys and the analysis of participants' responses, the following factors were identified:

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- ✓ Legal Framework: Laws and regulations related to privacy, data protection, and bioethics vary significantly from one country to another, affecting access to and control of genetic information internationally.
- ✓ Ethics and Human Rights: Ethical considerations and human rights play a crucial role in access to and the use of genetic information. Issues such as informed consent, genetic discrimination, and equity in access to genetic information need to be addressed.
- ✓ Technological Advances: Advances in genetic technology, such as DNA sequencing and genetic testing, increase the availability and accuracy of genetic information but also raise challenges in terms of privacy and data security.
- ✓ Access to Healthcare: The availability and quality of healthcare influence individuals' ability to access genetic information and receive appropriate genetic counseling.
- ✓ Culture and Traditions: Cultural differences and beliefs affect attitudes towards genetic information and health-related decision-making.
- ✓ Commercial Interests: Commercial interests in the genetic industry influence the availability and use of genetic information, raising questions about equity in access and ownership of genetic data.

Below are the adjacency matrices (Tables 1-5), obtained with criteria derived from the results, for each study group.

Table 1: Adjacency Matrix (Patient Group).

	Legal	**Ethics**	**Technological**	**Medical**	**Cultural**	**Commercial**
Legal	0	0.7	0.8	0.6	0.4	0.5
Ethics	0.7	0	0.6	0.5	0.3	0.4
Technological	0.8	0.6	0	0.7	0.5	0.6
Medical	0.6	0.5	0.7	0	0.4	0.5
Cultural	0.4	0.3	0.5	0.4	0	0.3
Commercial	0.5	0.4	0.6	0.5	0.3	0

Table 2: Adjacency matrix (Genetics Expert Group).

	Legal	**Ethics**	**Technological**	**Medical**	**Cultural**	**Commercial**
Legal	0	0.6	0.9	0.8	0.5	0.6
Ethics	0.6	0	0.5	0.5	0.2	0.3
Technological	0.9	0.4	0	0.4	0.4	0.5
Medical	0.4	0.5	0.7	0	0.4	0.5
Cultural	0.4	0.3	0.5	0.4	0	0.3
Commercial	0.5	0.4	0.6	0.5	0.3	0

Table 3. Adjacency matrix (Health Professionals Group).

	Legal	**Ethics**	**Technological**	**Medical**	**Cultural**	**Commercial**
Legal	0	1	0.9	0.8	1	0.6
Ethics	0.6	0	0.5	0.5	0.2	0.3
Technological	0.9	0.4	0	0.4	0.4	0.5
Medical	1	0.5	0.7	0	0.4	0.5
Cultural	0.4	0.3	0.5	0.4	0	0.6
Commercial	0.5	0.4	0.3	0.5	1	0

Table 4: Adjacency matrix (Lawyers and Human Rights Experts Group).

	Legal	**Ethics**	**Technological**	**Medical**	**Cultural**	**Commercial**
Legal	0	0.8	0.8	0.6	0.4	0.5
Ethics	0.8	0	0.6	0.5	0.3	0.4
Technological	0.8	0.6	0	0.7	0.5	0.6
Medical	0.6	0.5	0.7	0	0.4	0.5
Cultural	0.4	0.3	0.5	0.4	0	0.3
Commercial	0.5	0.4	0.6	0.5	0.3	0

Table 5: Joint adjacency matrix.

	Legal	**Ethics**	**Technological**	**Medical**	**Cultural**	**Commercial**
Legal	0	0.775	0.85	0.7	0.575	0.55
Ethics	0.675	0	0.55	0.5	0.25	0.35
Technological	0.85	0.5	0	0.55	0.45	0.55
Medical	0.65	0.5	0.7	0	0.4	0.5
Cultural	0.4	0.3	0.5	0.4	0	0.375
Commercial	0.5	0.4	0.525	0.5	0.475	0

Table 5 shows the values obtained after averaging those of Tables 1-4, for which Equation 2 was applied.

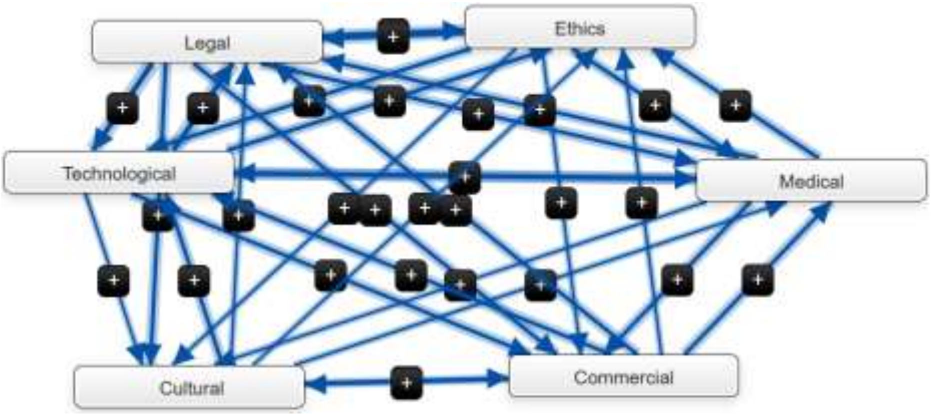

Figure 4: Fuzzy Cognitive Map using the joint adjacency matrix. Source: own elaboration.

Table 6: Joint static analysis.

Node	***od(vi)***	***id(vi)***	***td(vi)***
Legal	3,075	3.45	6,525
Ethics	2,475	2,325	4.8
Technological	3,115	2.9	6,015
Medical	2.65	2.75	5.4
Cultural	2.15	1.9725	4.1225
Commercial	2.3225	2.39	4.7125

In the static analysis through the fuzzy cognitive map, a clear hierarchy of nodes based on their centrality within the network is observed. The legal framework factor emerges as the most influential node, highlighting its role as a central axis in the dissemination of information and decision-making.

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It is closely followed by technological advances, which also play a significant role in the network as a key driver of change and innovation. Access to healthcare is in an intermediate position, acting as an important connector that is considered vital for the flow of specific information in RGI. The factor of commercial interests, with moderate influence, and aspects of culture and traditions, a bit further behind, suggest that these factors, although not the most central, have their own sphere of influence that should not be overlooked. The theme of ethics and human rights is perceived as the least central, reflecting a more isolated or specialized role within the network.

From the three previously defined centrality measures, aggregated through the D-OWA operator, a new static analysis is carried out. The results are shown in the following table.

Table 7: Centrality of factors and D-OWA.

Node	**Cc(v)**	**Cb(v)**	**Cc(v)**	**D-OWA**
Legal	0.206487	0.206487	0.153257	0.188744
Ethics	0.151899	0.151899	0.208333	0.17071
Technological	0.190665	0.190665	0.166251	0.182527
Medical	0.170886	0.170886	0.185185	0.175652
Culture	0.130538	0.130538	0.242571	0.167882
Commercial	0.149525	0.149525	0.212202	0.170417

When applying the D-OWA operator to the centrality table, an interesting reconfiguration in the order of influence of the different factors is denoted. In this context, the legal framework, which might be expected to hold a predominant position, sees its preeminence diminished, suggesting that when other centrality measures are taken into account in a weighted manner, its role is important but not dominant. Technological advances emerge with significant influence, reflecting their crucial role in the dynamics of the network and possibly their impact on driving changes and connections within it.

Healthcare also presents itself as an influential factor, highlighting its relevance and the impact it has on the system. This aspect is especially critical in contexts where health is a priority or is at the center of policies and decisions. Culture and traditions, despite receiving the lowest weighting initially, experience an increase in their relative importance with the application of D-OWA, which is interpreted as an acknowledgment of their essential role in shaping identity and decisions within the network, beyond what a simple centrality measure by distance reveals.

Commercial interests and ethics are positioned similarly in terms of influence. This suggests that both factors, although not the most central, have considerable impact and contribute significantly to the network's structure and operation, especially when considering qualitative and contextual aspects that may affect their relevance.

Based on the reconfiguration observed after applying the D-OWA operator, a fuzzy cognitive map is visualized that reflects this new hierarchy of influences among the different factors. This fuzzy map not only illustrates the direct connections between the nodes but also highlights how the relative importance of each changes when considering more complex centrality measures.

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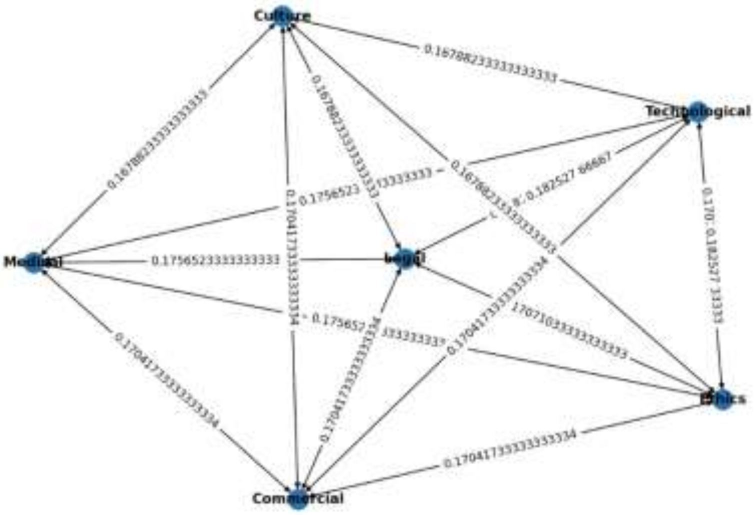

Figure 5: FCM using centrality measures with D-OWA. Source: own elaboration.

Applying the D-OWA operator provides a more complex perspective than simply adding distances or degrees of connectivity, which could change the interpretation of the importance of nodes in a way that is more informed by the specific context and the underlying decision criteria of the analyzed network.

In the particular case of determining the factors influencing RGI internationally, the application of the D-OWA operator, while providing a powerful tool for evaluating the network from a more nuanced and contextual perspective, surprisingly does not alter the hierarchy or order of importance of the initially established nodes. This result suggests that, in this specific context, traditional centrality measures already adequately reflect the priorities and relative influence of the involved factors.

The consistency in the order of factors, both before and after applying D-OWA, underscores that the network's inherent structure and the interactions among its components are intrinsically aligned with the deeper valuations that the operator attempts to capture. This indicates that, for the RGI domain internationally, connectivity considerations, whether through degrees of outdegree or indegree or the sum of distances, are consistent with the more sophisticated evaluations that consider dynamic weightings and contextual criteria.

The invariance in the order of importance reveals that critical factors such as the legal framework, technological advances, and access to healthcare already occupy appropriate priority positions reflecting their fundamental role in shaping access to and control of genetic information. This observation is particularly relevant in international debates where clarity and consensus on which factors should be prioritized are essential for formulating effective policies and regulations. The consistency in the hierarchy of factors, therefore, facilitates a common understanding among stakeholders about the key areas of focus and action.

To mitigate the influence of the factors identified and previously evaluated, several strategies focused on both the legal and institutional framework and the education and participation of society can be considered. These strategies might include:

- ✓ Strengthening the Legal Framework: Develop and update legislation related to genetic information to protect individuals' privacy and autonomy, ensuring any use of genetic information is done with the individual's informed consent.

- ✓ Clear Regulations for Genetic Research: Establish specific ethical and legal guidelines for genetic research that respect the rights of participants, including confidentiality, anonymity, and appropriate use of genetic data.

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- ✓ Creation of a Regulatory Body: Institute an independent authority responsible for overseeing the collection, use, and storage of genetic information, ensuring adherence to ethical and legal standards.

- ✓ Promotion of Ethics in Technological Advances: Integrate ethical considerations into the development and application of genetic technologies, ensuring technological advances positively contribute to society without compromising individual rights.

- ✓ Education and Public Awareness: Implement education programs that increase awareness about the importance of genetic information, its potential benefits and risks, and individuals' rights concerning their genetic data.

- ✓ Inclusion of Cultural and Traditional Perspectives: Recognize and respect cultural diversity and traditions in the management of genetic information, especially in a multicultural country like Ecuador, to ensure policies and practices are culturally sensitive and appropriate.

- ✓ Promotion of International Collaboration: Engage in international dialogues and agreements to establish global standards in the handling of genetic information, allowing Ecuador to align its policies with best international practices.

- ✓ Encouragement of Citizen Participation: Involve communities and civil society in the debate on the management of genetic information to ensure policies reflect the values and needs of the population.

4. Conclusions

The article addresses the complexity and challenges of RGI in the international context, utilizing advanced analytical tools such as FCMs and the D-OWA aggregation operator to identify and evaluate influential factors. The research highlights the importance of ethical, legal, technological, medical, cultural, and commercial considerations in accessing and managing genetic information, offering a detailed perspective on how these elements interact and affect the exercise of RGI.

The methodology employed, combining FCMs and D-OWA, allows for a detailed analysis and visualization of the relationships and relative importance of the various factors, reflecting the inherent complexity of the subject. The research underscores the centrality of the legal framework and technological advances as the most influential factors, followed by access to healthcare, while commercial interests, cultural issues, and ethical considerations also play significant roles, albeit to a lesser extent. This approach highlights how the combination of analytical tools enables a deeper understanding of the network of factors impacting RGI, overcoming the limitations of traditional methods.

The consistency observed in the hierarchy of importance of the factors, both before and after applying the D-OWA operator, reflects an intrinsic alignment between traditional centrality valuations and more complex, contextualized evaluations. This suggests that conventional measures already adequately capture the priorities and relative influence of the elements involved in RGI internationally. However, the use of D-OWA provides an additional layer of analysis, dynamically considering importance and context, enriching the understanding of the subject.

Finally, the implementation of specific strategies, including strengthening the legal framework, promoting ethics in technological advances, public education, and recognizing cultural diversity, is crucial for effectively managing genetic information. These strategies emphasize the importance of a balanced and respectful approach that protects individual rights while leveraging the benefits of genetic research for society.

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