Analysis of operational risks of electricity distribution network based on the fuzzy cognitive map approach

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One of the most essential development factors in any country is the quality of electricity supply and distribution. Energy consumers seek electricity supply at a very high safety level. Considering the sensitivity of electronic devices and the dependence of most activities on electricity, providing sustainable energy in urban systems is critical. Unscheduled shutdowns are the leading cause of disruption in the continuity of electricity supply and reduce the quality of power delivered to customers. Operational risks are potential events that result in unplanned outages in the network. In the current research, the fuzzy cognitive map (FCM) method has been used to investigate the relationships between risks and to reach a comprehensive solution for the simultaneous control and management of several risks. Accordingly, extracting the effect of operational risks on each other and how to draw them in the form of a FCM is analyzed and represented. The results emphasize that adverse weather conditions are the most influential with the highest degree of output and equipment failure is the most influential with the highest degree of input in operational risks. The highest value of the sum of input and output degrees (centrality) is the breakdown in the transformer, which has the highest value. The analysis of managerial and practical perspectives shows that the operators, by focusing on forecasting weather conditions and retrofitting network structures and technical management of transformers, reach a convergent and sustainable solution to manage operational risks and ultimately reduce unplanned shutdowns.

Keywords: *Operational risk, power distribution network, unplanned outage, fuzzy cognitive map.*

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1. Introduction

The supply chain of power generation, transmission and distribution network is a critical structure that combines processes, from the supply of primary fuel sources to the consumption of electricity. One of the most essential factors of economic-social development in any country is the quality of electricity sources. The electricity industry has experienced significant changes worldwide in the last two decades. Energy consumers seek electricity supply at a very high safety level from producers. Considering the sensitivity of electronic devices and the dependence of most activities on electricity, providing sustainable energy in the urban system is vital. Unscheduled shutdowns are the leading causes of disruption in the continuity of electricity supply, reducing the quality of power delivered to electricity subscribers, which causes public dissatisfaction and the occurrence of adverse social consequences [1]. Therefore, a comprehensive perspective and suitable approach towards the power distribution network is precious to prevent any power loss in all processes. On the other hand, the occurrence of incidents in the system is not independent and affects each other. Disruptions in the electricity distribution network can be caused by factors such as the threat of natural disasters (storms, floods, earthquakes, etc.), special economic and political conditions, incidents and terrorist attacks, and expose the network to all kinds of risks and disruptions. Accordingly, due to the extraordinary significance of the electricity sector in the economy of countries and various government policies, a risk-resistant electricity distribution network can be of great help in saving and reducing costs in the electricity industry. During its ups and downs, the world's electricity industry has been involved with crises that in order to be resilient, risks must be carefully identified, evaluated and prioritized depending on the political, economic, and social conditions of each region. When big storms or incidents cause severe damage to the electricity supply network, responding quickly to risks or reducing them reduces all types of damage [2]. This brings the importance of the issue that the correct management with the most negligible error is one of the day's needs for the sustainable supply of electricity.

Theoretically, risk means the possibility of deviation from achieving the desired goal. In risk theory, terms such as uncertainty, unknown situations, and conditions of unreliability about the future are also used as equivalent to the term risk. In general, every effort and every human movement involves risks. Daily, we sometimes encounter changing situations that often include unknown, unexpected, pleasant or unpleasant and often unpredictable factors.

The AS/NZS-4360 standard defines risk as: "the chance of something happening that will affect the objectives". According to ISO/IEC Guide 73, risk is represented as a combination of the probability of an event and its consequences [3]. According to the PMI definition, risk is announced as follows: an uncertain incident or situation that, if it happens, it will affect the project objective positively or negatively. Risk has a reason, and if it happens, an experience will be gained from it [4]. Risk can be defined as any unpleasant thing that happens. For managers, the risk is a threat that disrupts their activities or plans. The reason for risk is the uncertainty about the future.

In the following, the review of the literature and the background of the research and the types of applications of the FCM to determine the relationships of system risks are represented in Section 2. In Section 3, the research method is explained. Numerical results, including the list of exploitation risks and their priority number, and the results of investigating the relationships of risks in the form of a FCM are presented in Section 4. The conclusion and future suggestions are described in Section 5.

2. Literature Review

Many studies have been done in risk management and its various methods, including the FCM method. A case study in the current research is the operational risks of the electricity distribution network in Yazd city. Studies related to them are reviewed and represented here.

In reference [5] used a combined method based on FCM and multi-step PFMEA to rank the failure of production procedures in the drinks industry. In their method, failures are ranked due to the impact of each failure on other failures as well as the value of the three factors of occurrence, detection, and severity (PFMEA priorities). This prioritizes risks by examining the relationships between production process failures. Accordingly, the prioritization of possible failures is due to RPN index criteria and causal relationships between failures. Their approach has been implemented using the multi-stage cognitive mapping algorithm due to the developed delta law. The results of implementing their approach in a company active in the drinks industry represent that the prioritization of failures is closer to reality and provides a complete prioritization compared to approaches such as basic RPN. [5]. In a recent study, published by Napoles et al., a FCM approach has been presented to quantify implicit deviation in predetermined datasets and clarify a new reasoning mechanism structured with a normalization-like transfer function [6]. Ozinga and Ikki (2022) considered the food waste chain in Italian urban society and modeled its factors using the FCM. In their study, to propose a more complete approach of the complex system, the FCM method has been used [7]. Sang bar et al. (2019) discussed that fuzzy cognitive mapping, as one of the methods proposed in the structure of soft modeling can structure the ambiguous and complex nature of issues in the form of stochastic relationships and propose a quantitative consideration of the issue for professional experts. They aim to consider the practical components in achieving sustainable SCM in the petrochemical industry applying the fuzzy cognitive mapping approach [8]. A FCM is one of the research approaches in the field of problem structuring in soft operations, which can create a hierarchical image of risks, factors and present their consequences by extracting the mental map of experts, and in this way, by preparing a risk map, realize the main goals of the risk identification stage. In addition, by discovering the relationships between mapping elements and creating the possibility of scenario development to investigate the effect of changes in risk-generating factors, it turns risk mapping into a more efficient tool for identifying operational risk [9]. Unlike other decision-analyzing techniques, FCM is a suitable approach for formulating expert ideas. For example, dynamic systems formulations, despite describing and modeling the dynamic behavior of systems, have limitations in such situations where the required data is limited or unavailable [10]. Although structural equation formulating is useful for examining stochastic relationships between variables, it does not have the ability to identify and formulate. In complex subjects, these techniques are highly dependent on the experts' opinions and cannot apply an unbounded number of variables. However, FCM does not have such restrictions in the cases mentioned [11].

The results of the investigations show that blackouts in the field of electricity distribution are divided into two categories: unplanned blackouts (accidental) and planned blackouts, the first category of which occurs as a result of technical and non-technical events in the electricity distribution networks and is cut off without the will of the company and electricity workers, and is very critical [12]. Due to the low voltage level and high current, distribution networks have very high losses and high voltage drops, which has always contributed the most to losses and reduced reliability of the electricity distribution network [13]. The statistical study conducted on the failure events of Khorasan regional electricity transmission and super distribution substations for sixteen years (2000-2016) has been helpful in comprehensive planning for the maintenance and repair of substation equipment [14]. In a research conducted by the group of intelligent systems and control engineering of the city of Girona, Spain, using the method of multi-layer principal component analysis, a strategy to clarify unusual operating conditions on weak pressure system data has been presented [15].

Network equipment information is critical in asset management decisions. These data should be provided to power company decision-makers as input to asset management decision making processes. By extracting and preparing the required information, analysis and evaluation will be possible [16]. In a research conducted on electricity demand data in one of Japan's regions, the amount of load consumed at different times was predicted by the SARIMAX method; This issue shows the importance of examining the data available in electricity distribution companies [17]. Many electric utilities in developing countries are investing in renewing and installing electric distribution system (EDS) components, such as switching devices, cables, and overhead lines, to improve EDS reliability and cope with rapidly increasing load demand. A comprehensive formulation for predicting power distribution system reliability is presented, which is made up of two separate parts of power distribution system failure models and planned outages [18].

Optimal use of electricity distribution networks requires proper monitoring and maintenance. Also, in recent years, the increase of unplanned blackouts in Iran's electricity distribution networks has been noticeable. The risks of operating the electricity distribution network in the maintenance and operation systems sector are the main cause of unplanned shutdowns. On the other hand, the impact of these risks on each other leads to the complexity of the causes and manner of failure in the system. The innovation of this research has been done in prioritizing the operational risks of the electricity distribution network by considering the relationships and influence between them. Fuzzy Cognitive Map (FCM) has been used to consider the relationships between risks. Also, with high priority risk management, the impact on other operational risks can be seen and checked.

3. Research Method

The cognitive mapping approach is a procedure in which a network of components and relationships of a complex system is shown as a diagram or map and as a formulation that represents how the system works [10]. In 1986, Cusco applied fuzzy tools to draw a graphical cause or cognitive map and effect formulations and determined FCM methods [19]. FCMs are hybrid models that, based on some definitions, are between neural networks and fuzzy systems [20]. Creating a FCM needs a set of inputs that are derived from the experiences and knowledge of subject matter experts. This method consists of concepts or nodes (C) connected by weighted arcs. Each connection among two nodes Ci and Cj has a W_{ij} (weight between node *i* and node *j*) representing stochastic relationships. The value of the weight of each concept can be extracted from the direct knowledge of the users, in this research, using the BWM and FMEA method, the values of the nodes are entered into the cognitive map and modeling is done.

$$A_i^{(t+1)} = f(\sum_{\substack{j\neq i\\ j=1}}^{N} A_j^{(t)}.W_{ij}) \qquad (1)$$

In the above equation, $f(\cdot)$ represents a non-decreasing uniform function to connect the activation number of each concept to the allowable interval. Many functions have been applied in the reviewed articles in Section 2, the most important of which is used in FCM Expert software is the sigmoid function (Equation 2). If the network can converge, the system will produce the same results finally. Accordingly, the degree of activation of the nodes remains unchanged (or undergoes infinitesimal changes).

$$f = \frac{1}{1+e^{-\lambda x}} \qquad (2)$$

In the above equation, $f(\cdot)$ represents a non-decreasing uniform function until the activation number is updated by using the above two rules to deduce the values of the nodes and the relationships between them. It reaches convergence by determining the acceptance limit or the number of iterations. According to the [21], the value of λ equals 2. The main steps of the proposed FCM approach in the current study are carried out according to Figure 1.

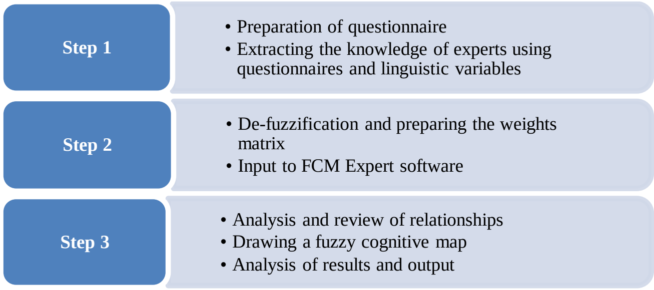

Figure 1: The main steps of the proposed FCM approach

4. Numerical Analysis

To analyze the operational risks of the electricity distribution network, first, the type and intensity of the relations are determined through linguistic variables. Then it is de-fuzzified and the relationship matrix is determined with the obtained values. Cartography is drawn from it and analyzed.

4.1. Defining the type of stochastic relationships among concepts

As mentioned, FCM is due to imprecise fuzzy phrases to explain the interrelationships in the presented concepts. The experts are requested to clarify the relationship among two concepts with a fuzzy rule that describes the cause and effect. Accordingly, using the linguistic concept, they infer the influence of one concept on the other. Using this approach, decision makers are forced to analyze about and explain the definable relationships among concepts. Finally, the influence of one concept on another is determined as "negative" or "positive" and then the degree of influence is evaluated by applying a five-point Likert language variable " very high, high, medium, low, very low". The experts' answers are converted into numbers in the interval using fuzzy logic. The fuzzy spectrum used in the current study is according to Table 1 to calculate the penetration intensity of the indicators. The occurrence of any failure in the system does not lead to the improvement of other failures, so all relationships between operational risks are considered positive.

As mentioned, a questionnaire was applied to collect data, and the type and the number of causal relationships between risks were determined by forming a matrix of paired comparisons. Linguistic variables have been converted into fuzzy numbers based on Table 1.

Table 1: Fuzzy numbers for the penetration intensity of nodes

Verbal expression	Impact				
	Very high	high	Medium	Low	No impact
Fuzzy number	(0.75,1,1)	(0.5,0. 5,1)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0,0.25)

Defuzzification is an essential step in fuzzy systems. Therefore, the results of approximate reasoning are typically determined as one or more fuzzy sets. In these cases, it is essential to convert the fuzzy output of the system into a normal (non-fuzzy) number. There are several methods for this task, including the surface center method, the center of gravity method, the maximum center method, the total center method, and the weighted average method of centers [22]. In this research, the surface center method is used for de-fuzzification (Equation 3). If a triangular fuzzy number is considered as (U, M, L), its de-phased value is calculated as follows.

$$DF = \frac{\lfloor (U-L)+(M-L) \rfloor}{3} + L \qquad (3)$$

After collecting the experts' opinions according to Table 1, using equation 3, the intensity values of risk communication were defuzzified. In the next part of the matrix, the severity of the impact of operational risks on each other is specified.

After gathering experts' opinions due to Table 1, using equation 3, the risk communication intensity values were defuzzified. Then, the impact of operational risks on the project is presented as a matrix.

4.2. Estimation of the severity of causal relationships

Obtaining the intensity of relationships was done by completing the questionnaire by experts and in a comparative manner. Thus, it is first considered that an operational risk has occurred; Then, its impact on the occurrence of other risks is determined through linguistic variables. After collecting the opinion of each expert and defuzzifing the matrix of comparisons, we influence the weight of each expert's opinion in numbers and obtain the final matrix for drawing a cognitive map (Tables 2 and 3). In the answers to the questions of the questionnaires, some of the values of the cells were empty, and their values were considered as absolute zero. The order of nodes (columns and rows) is the same as the table of risk definition.

Also, in the FCM, the mutual influence of the nodes on themselves has been ignored. In the analysis of the state of operational risks, as the concepts of the map, adverse effects have not been considered because no risk has been observed whose increase will reduce another risk. To facilitate the analysis and reduce the high complexity in the FCM, the complexity of the map has been slightly reduced by removing the values of W_{ij}≤0.083, which indicates the concept of no influence.

Table 2: Relationship estimation matrix (Part A)

	C1	**c2**	**c3**	**c4**	**c5**	**C6**	**c7**	**c8**	**c9**	**c10**	**c11**
c1	-	0.095	0.25	0.453	0	0.235	0	0	0	0.235	0.235
c2	0.285	-	0.902	0.471	0.25	0.235	0.75	0	0	0.25	0
c3	0	0	-	0.25	0	0.235	0.902	0	0	0.75	0.431
c4	0.75	0	0.25	-	0	0.5	0.25	0	0	0.25	0.231
c5	0.753	0	0.25	0.661	-	0.25	0	0.231	0	0.325	0.201
c6	0.528	0	0	0.5	0	-	0	0	0	0.25	0.231
c7	0.113	0.25	0.25	0.238	0.25	0.25	-	0	0	0.25	0.453
c8	0.234	0.102	0.25	0.238	0.25	0.25	0	-	0	0.25	0.231
c9	0.234	0.45	0.89	0.703	0.75	0.765	0.917	0.75	-	0.75	0.675
c10	0.235	0	0	0	0	0.098	0.25	0	0	-	0.231
c11	0.224	0.25	0.25	0.25	0.25	0.235	0.5	0	0	0.235	-
c12	0.224	0.102	0	0	0	0	0.25	0	0	0.235	0.25
c13	0.728	0.102	0	0	0.75	0	0	0	0	0.25	0.25
c14	0	0.102	0.478	0	0.5	0.221	0	0.25	0	0.098	0.266
c15	0	0.102	0.518	0	0.75	0	0	0.25	0	0.098	0.266
c16	0	0.114	0.728	0.25	0	0.098	0	0	0	0.098	0.5
c17	0.75	0.114	0	0.478	0.478	0.235	0	0	0	0.098	0.528
c18	0.75	0.095	0.25	0.478	0.478	0.235	0.25	0	0	0.25	0.25
c19	0.917	0.095	0.25	0.25	0.098	0.25	0	0	0	0	0.5
c20	0.5	0.25	0	0	0	0	0.5	0	0	0	0.5
c21	0.25	0	0	0.235	0	0	0	0	0	0	0.5

Table 3: Relationship estimation matrix (Part B)

	c12	**c13**	**c14**	**c15**	**c16**	**c17**	**c18**	**c19**	**c20**	**c21**
c1	0	0.5	0	0	0	0.25	0.25	0.25	0	0
c2	0.5	0.75	0.5	0.5	0	0.5	0.5	0	0	0
c3	0.5	0.484	0.917	0.5	0	0.75	0.75	0.25	0	0
c4	0.25	0.094	0.25	0	0	0.5	0.25	0.25	0.463	0
c5	0.463	0.641	0.5	0	0	0.226	0.377	0.405	0.25	0.129
c6	0.25	0.326	0.25	0	0	0.5	0.25	0.5	0.5	0.129
c7	0.522	0.75	0.25	0.5	0	0.288	0.75	0.75	0.902	0.129
c8	0.235	0.902	0.25	0	0.094	0.5	0.917	0.917	0.5	0.596
c9	0.75	0.75	0.917	0.25	0.094	0.712	0.75	0.5	0.75	0.596
c10	0.25	0.25	0	0	0.094	0.11	0.25	0	0.75	0
c11	0	0	0.25	0.25	0.25	0.266	0.5	0.25	0.5	0
c12	-	0	0.25	0	0.094	0.266	0.25	0.25	0.25	0
c13	0.25	-	0.25	0	0.094	0.11	0.917	0.5	0	0.098
c14	0	0.25	-	0.25	0.473	0.11	0.5	0	0	0.115
c15	0	0	0.25	-	0.239	0.11	0.5	0.5	0	0.144
c16	0.75	0.25	0.5	0.25	-	0.5	0.25	0.5	0	0.144
c17	0.25	0.5	0	0	0.5	-	0.5	0.5	0	0.25
c18	0.5	0.266	0.25	0	0.5	0.25	-	0	0	0.112
c19	0.25	0.094	0	0	0.25	0.25	0.25	-	0	0.233
c20	0	0.094	0.25	0.25	0	0.5	0.5	0.25	-	0
c21	0.25	0.25	0	0	0.25	0.75	0	0.75	0	-

The data matrix was prepared for drawing a cognitive map and implementing algorithms, using Excel software and converting to CSV format, for input into FCM Expert software. Tables 2 and 3 show the final matrices for drawing the FCM (presented in two parts due to the limitation of page width).

All calculations were done in Excel software. With a little attention on row 9 (unfavorable atmospheric conditions), it is clear that this node (concept) has the most impact on others. After any adverse weather conditions, other operational risks increase significantly. The second part of the relationship estimation matrix is represented as part B.

4.3. Integrative FCM

By integrating the opinions of the experts in the two matrices of the previous section (Tables 2 and 3) and using Excel software, the weight values of the effect of operational risks on each other have been calculated. It is converted into CSV format and entered into the FCM Expert software. Accordingly, the initial FCM is drawn so that other analyzes can be performed on it. Figure 2 shows the FCM without the initial numbers of the nodes.

As shown in Figure 2, the nodes that represent the concepts of the model (operational risks of the supply chain of the electricity distribution network) have the same values and are connected to other nodes only by a series of relationships. Other studies receive the initial values of the nodes, which are between zero and one, directly from the expert. After entering the initial values (Figure 3), the indicators of the cognitive map are calculated and the proposed formulation is evaluated by analyzing the convergence and implementing the patterns with supervision.

4.4. FCM indicators

Kosko (1986) described centrality as a constraint to determine node importance in FCM. In a cognitive map, the centrality of a node (C_j) is calculated by the sum of the number of intrusions on the node. In FCM, the number, as well as the degree of influence of cause and effect relationships, can be considered to provide a more detailed view of the centrality concept [22]:

$$C(C_i) = IN(C_i) + OUT(C_i) \qquad (4)$$

In relation (4), $IN(C_i)$ is the sum of the weight of the causal relations, which includes all the connecting paths from the nodes C_j, ($i \neq j$) to the node C_j, calculated from the following relation.

$$IN(C_i) = \sum_{j=1}^{N} w_{ji} \qquad (5)$$

In relation (6) $OUT(C_i)$ is the sum of the weight of the stochastic relations, which includes the connecting paths from the nodes C_i, to all the nodes C_j, ($i \neq j$), which is calculated from the following relation.

$$OUT(C_i) = \sum_{j=1}^{N} w_{ij} \qquad (6)$$

4.5. The conceptual model

Using the standard function provided by Kosko (Equations 4-8) with a slope of λ=2 and a degree of deviation of 0.05 and a stop criterion of 0.001, convergence has been analyzed and Figure 4 has been obtained. Figure 4 shows that the values of the nodes have converged from the second step onwards and no noticeable change is observed. However, from the fourth step onwards, the conditions are stopped and the calculations are not repeated (Table 5).

The final values of each concept indicate the result of its penetration and effectiveness in the system; The existence of other nodes and their relationships with that node has caused the final values to equal one. The lowest value is related to node number 9 (adverse atmospheric conditions). This node is a sending node and is not affected by other nodes, and its controllability with other risks is very low. Table 5 shows how much the centrality value of each node will be in each step of the implementation of the convergence algorithm on the nodes.

As shown in Table 5, in the implementation of Step 4 (the map is converged according to the acceptance limit), many values of nodes are equal to one. Therefore, the values of the Step 1 are applied for prioritization. After the convergence of the cognitive map for evaluation, it is possible to check the validation of the model using data-monitored algorithms.

As a summary of managerial views and practical results, it can be concluded that the limited power sources, the high consumption of electricity in the world and the high cost of electricity production means that an accident in the electricity distribution network causes damage to the network and subscribers. When an incident occurs in the network, in addition to the cost of network repairs, subscribers will be without electricity for a while and the network will prevent the sale of electricity. From an economic point of view, these incidents cause losses and loss of economic resources and reduce competitiveness in this field. Therefore, evaluating, prioritizing and managing operational risks by considering the relationships between them helps network management to improve reliability. By providing solutions for high-impact risks in the network, in addition to the direct reduction of unplanned shutdowns, indirect reduction through other risks can be achieved. Investigating and predicting network weather conditions can help reduce casualties during natural disasters. Also, the results showed that transformer failures increase during peak load consumption and other failures.

existing risks and is not affected by other risks. The highest degree of influence reaches node number 18 because it has the highest input from other nodes. Also, the degree of centrality for the three risks of failure in fittings, failure in transformers, and failure in the foundations of the power distribution network has the highest centrality value than the others, which indicates the importance of these nodes in the system.

To present the final proposed model, the convergence of the checked map and the converged values of the nodes need to be presented. Convergence is done in a FCM with different functions provided by researchers.

Step 1: Separation of data

5. Conclusions

Considering the sensitivity of electronic devices and the dependence of most activities on electricity, providing sustainable energy in the urban system is critical. Therefore, a comprehensive perspective and efficient approach towards the factors causing disruption in the electricity distribution network is precious to prevent any electricity losses. In the current study, unplanned shutdowns were considered as the operational risks of the electricity distribution network. The analytical results show us how to manage other significant risks by controlling highly influential risks. Analysis of the status of each node was investigated and analyzed according to its role in the model. The reason for using the FCM for risk management is that by examining the relationships between risks, it is possible to provide a convergent and reliable approach for controlling and managing multiple risks simultaneously. To pay attention to risks independently only by using FMEA results, the approach provided to reduce one risk may increase other risks. The results showed that adverse weather conditions are the most significant (node output value: 12.953), and equipment failure is the most influential (node input value: 8.461) in operational risks. Failure in the transformer has a high centrality number. By focusing on predicting weather conditions and retrofitting network structures, and technical management of transformers, operators reach a convergent and sustainable solution to manage operational risks and ultimately reduce unplanned shutdowns. Accordingly, unplanned outage time data was used for evaluation, and to eliminate the effect of network expansion, the ratio of time to network length can be applied for analysis in future research. Also, the developed approach has been prepared using the data and opinions of the experts of the electricity distribution network of Yazd City. Researchers can investigate and analyze using the data of other networks in other cities.

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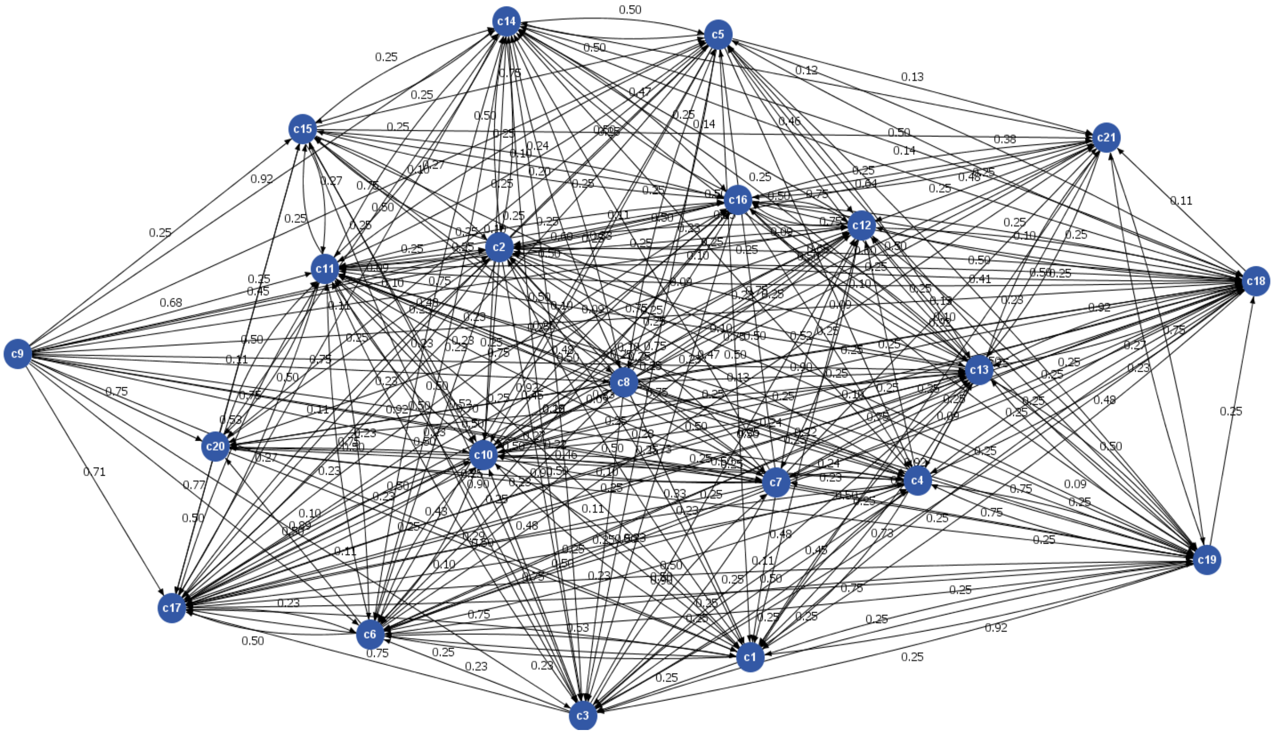

Figure 2: Fuzzy cognitive map without initial values of nodes

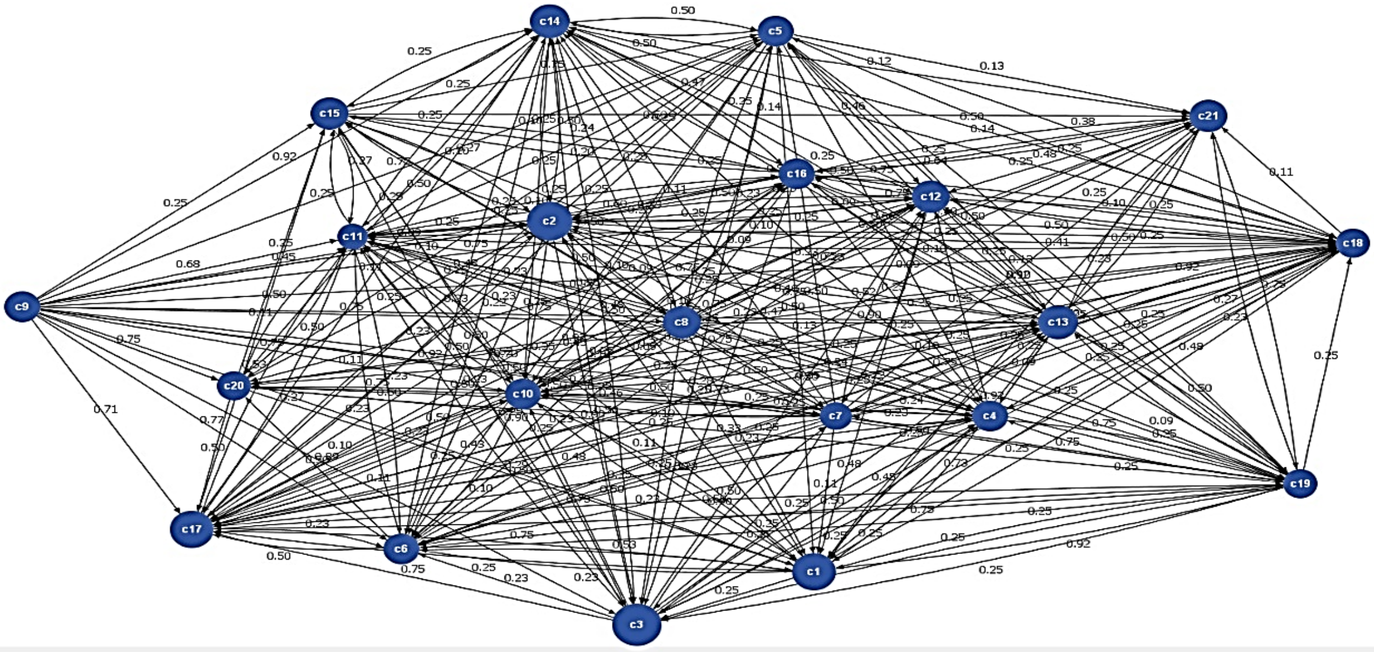

Figure 3: Fuzzy cognitive map with initial values of nodes

Table 4: FCM indicators

Node	Operational risk	Input	Output	Centerality
c1	Transitory defect	7.475	2.753	1.228
c2	The collision of foreign objects (such as the collision of cars, construction equipment, trees, etc.)	2.223	6.393	8.616
c3	Failure in network foundations (concrete, wooden, and metal)	5.516	6.719	12.235
c4	Failure in cut-out fuse	5.455	4.288	9.743
c5	Network conductors hitting each other or the fuselage	4.804	5.662	1.466
c6	Failure in circuit breakers (recloser, sectionalizer, etc.)	4.92	4.214	8.306
c7	Human error (wrong maneuver or power cut during hotline operation)	4.569	6.895	11.464
c8	Birds collision	1.481	6.716	8.197
c9	Adverse weather conditions	0.0	12.953	2.953
c10	Failure in the Lightning arrester	4.672	2.518	7.19
c11	Failure in the internal network of subscribers	6.729	4.46	1.189
c12	failure in the electrical jumper	5.97	2.421	8.391
c13	Failure in pin insulator	7.151	4.299	11.45
c14	Rupture wire	2.75	3.613	6.363
c15	Self-maintained cable breakage	2.75	3.727	6.477
c16	Theft of network equipment	2.932	4.932	7.864
c17	Failure in the transformer	7.448	5.181	12.629
c18	Failure in fittings	8.461	4.802	13.263
c19	Failure in electrical substations	7.322	3.687	11.9
c20	Electrocution	4.865	3.594	8.459
c21	Failure in the above distribution equipment	2.675	3.235	5.91

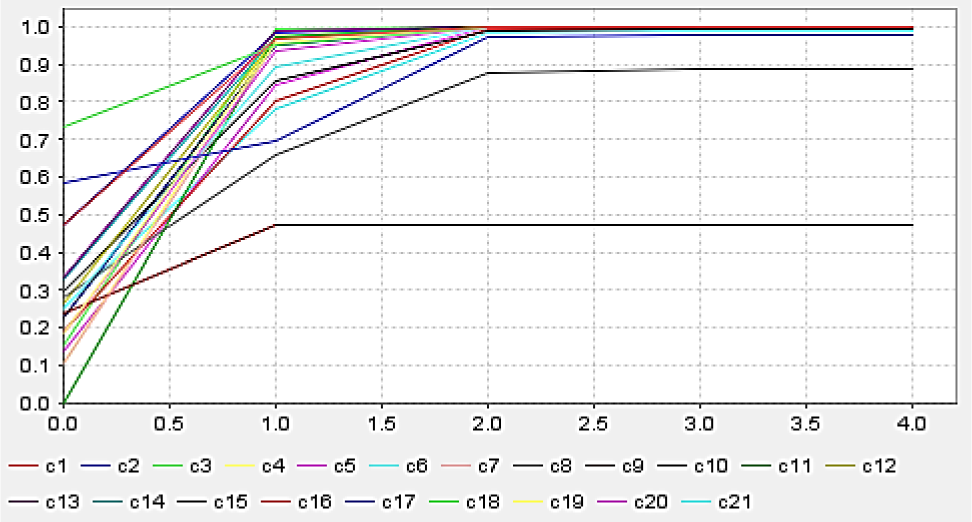

Figure 4: Convergence diagram of the FCM

Table 5: The results of the implementation steps of the convergence algorithm

Node	Initial values (RPN)	Step 1	Step 2	Step 3	Step 4
c1	0.732	0.9687	1	1	1
c2	0.582	0.6966	0.9731	0.9791	0.9791
c3	0.472	0.9532	0.9998	0.9999	0.9999
c4	0.470	0.9575	0.9999	1	1
c5	0.336	0.9329	0.9997	0.9998	0.9998
c6	0.328	0.8955	0.9988	0.9993	0.9993
c7	0.296	0.9562	0.9993	0.9997	0.9997
c8	0.281	0.6577	0.8763	0.8879	0.8881
c9	0.263	0.475	0.475	0.475	0.475
c10	0.256	0.9533	0.9996	0.9998	0.9998
c11	0.246	0.9728	1	1	1
c12	0.237	0.9657	1	1	1
c13	0.228	0.9891	1	1	1
c14	192	0.9744	0.9999	1	1
c15	187	0.8539	0.9895	0.994	0.994
c16	185	0.804	0.9952	0.9964	0.9964
c17	153	0.986	1	1	1
c18	138	0.9957	1	1	1
c19	108	0.9776	1	1	1
c20	104	0.8467	0.9997	0.9998	0.9998
c21	0.85	0.7786	0.9826	0.9887	0.9889