RESEARCH ARTICLE

Fuzzy and Neutrosophic Cognitive Maps Analysis of the Emergence of COVID-19 Post-vaccination

Norarida Abd Rhani[a]*, Nurul Eylia Maisarah Mazlan[b], Nur Amani Izzati Mohd Azhan[c], Siti Nurul Fitriah Mohamad[a], Suriana Alias[a]

[a]School of Computing and Mathematics, College of Computing, Informatics and Mathematics, Universiti Teknologi MARA, 18500 Machang, Kelantan, Malaysia; [b]AEM Enersol Sdn Bhd, West Block, Wisma Golden Eagle Realty,142C, Jalan Ampang, 50450 Kuala Lumpur, Malaysia; [c]Hospital Sultan Ismail Petra KM6, Jalan Kuala Krai-Gua Musang, 18000 Kuala Krai, Kelantan, Malaysia

Abstract After several years of the spread of coronavirus disease 2019 (COVID-19) around the world occurred, World Health Organization (WHO) has stimulated great efforts to develop a vaccine against the COVID-19. Therefore, all of citizen is obliged to take the vaccine for precaution. However, the vaccine is only one step to reduce the spreadness of COVID-19, where the appearance of COVID-19 can occur after vaccination. Some peoples do not understand the vaccine function where it is used to prevent spreading COVID-19. This research analysed the emergence of COVID-19 post-vaccination by using the method of fuzzy and neutrosophic cognitive maps. The collected data from an interview with two experts called as a concept and from there the directed graph and adjacency matrix are constructed. Multiplication between vectors and matrices are repeated until the fixed point in finding the hidden pattern for all the concepts for COVID-19 post-vaccination obtained. The results obtained from this study are useful to all to know the factors caused of the epidemic after vaccinated as well as the procedures to be followed to protect from this disease.

Keywords: Covid-19 post-vaccination, fuzzy cognitive maps, neutrosophic cognitive maps, neutrosophic set.

Introduction

Every human in this world is looking back to a new disease that has been spread across the globe called as coronavirus disease 2019 (COVID-19). This disease has created a big issued in the world, affecting people's lives and causing many deaths. In late 2019, an unknown virus that related to severe acute respiratory syndrome (SARS) emerged in Wuhan, China. According to Elengoe [1] the virus was named at severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). SARS-CoV-2 caused COVID-19 and expanded from Wuhan and was exported to almost all countries around the world.

In March 2020, the World Health Organization (WHO) declared this virus as a pandemic. Reported illnesses have ranged from mild symptoms like fever, cough, tiredness, loss of taste or smell and other too severe illness and death for confirmed COVID-19 cases. As a precaution, all countries have declared lock down, continuous hand washing, always wearing a mask especially in a crowded place, social distancing and so on. The virus is easily transmitted via respiratory droplets and contact.

In early 2021, scientists found vaccines to reduce the number of cases. Safe and effective vaccines help ensure that COVID-19 does not result in severe disease and death. Vaccination protects against COVID-19 and reduces the likelihood of new variants from emerging.

*For correspondence:
norarida@uitm.edu.my

In the context of medical diagnosis, it involves a degree of uncertainty and needs to consider the clinical parameters, the illness context, and the experts' knowledge to determine the diagnosis. Fuzzy cognitive maps (FCM) have the simplest method that can be analysed by directed graphs and connection matrices.

The term "cognitive maps" have been coined by Tolman [2] and introduced that an internal spatial representation or mental map of the environment move in is referred to as a cognitive map. A cognitive map is a collection of nodes linked by some arc. A cognitive map is usually drawn as short pieces of text linked with unidirectional arrows to link them. Chen [3] used the new method based on the cognitive map decision analysis where negative-positive-neutral (NPN) logic applied.

Kosko [4] introduced the notion of FCM as an extension of the cognitive maps theory developed by [2] in 1973. In FCM, there are three possible types of relations between concepts: positive relation, negative relation, or non-existence of relations. A directed graph represents a causal relationship between concepts where events are denoted as nodes and causalities denoted as edges. This model has been used in various applications such as in economics which models mathematical relationships, in medical, engineering and others. In the medical field, FCM can be applied in model systems to provide diagnosis or medical assessment. However, FCM have the limitation of not considering the indeterminacy relations between concepts [5]. In this regard, Smarandache [6] introduced the neutrosophic theory, making possible the representation of indeterminacy [7]. Such characteristic is helpful for modelling decision-making problems [8] since it considers all aspects of decision such as agree, not sure, and disagree [9].

FCM applied the key features of fuzzy logic and neural processors to imprecise and uncertain descriptions. Kandasamy and Smarandache [10] in the year 2003 extend the theory of FCM to neutrosophic cognitive maps (NCM) to make sure that NCM can overcome the drawback presented in traditional FCM because this theory is not representing the indeterminacy relations between the concepts. NCM is a neutrosophic directed graph in which at least one edge is an indeterminacy denoted by dotted lines with concepts like policies, events etc., as nodes and causalities or indeterminates as edges. The concept of NCM can be applied in modelling supervisory systems in the design of hybrids. Several local studies investigated the issue about the factors in the spread of pandemics COVID-19 in the country. The previous study that has been conducted by Cepeda *et al.* [11] who investigated a causal analysis of the determinants of childhood and adolescent obesity in post-COVID-19 by using NCM. Besides, Zafar and Wajid [12] surveyed that the role of uncertain and indeterminate factors in spread of pandemics COVID-19 in India using NCM. Also, Ramalingam *et al.* [13] used the method of NCM to analyse the COVID-19 before vaccination since it involves indeterminacy.

In year 2023, a comparative study is made by Murugesan *et al.* [14] on different parameters related to omicron and delta variants such as travelling behavior, prevention measures for the disease, blood pressure, cancer patient, loss of taste and smell, brain fog and many others. The authors made a comparison between FCM and NCM among the COVID-19 variant parameters.

The aim of this research is to analyse the emergence of COVID-19 post-vaccination based on different parameters related to COVID-19 such as fever or chills, cough, and shortness of breath, maintaining social distance, wearing mask etc. These parameters are analysed through the FCM and NCM by considering any "1" as ON state.

The results obtained from this research are helpful to the community to know the influenced factors of the emergence of COVID-19 after vaccinated as well as the actions to be followed to protect from this disease.

The remaining paper is structured as follows: section two describes some preliminary studies needed for this research. In section three, some methods involved in this research are discussed. In section four, analysis of the emergence COVID-19 using both methods of FCM and NCM are presented. The paper ends with the conclusion of the proposed work in section five.

Preliminary Concepts and Notations

Some basic concepts and definitions extracted from [10] related to FCM and NCM are as follows:

Definition 1. [10] FCM (NCM)
A fuzzy weighted directed graph involving concepts like policies, events etc. as nodes and the edge connecting them represent the causal relationship between the concepts is an FCM. NCM is differ when at least one edge is an indeterminacy denoted by I .

Definition 2. [10] Simple FCM (NCM)
FCM with edge weights or causalities from the set {-1, 0, 1} are called simple FCM. NCM is said to be simple if the edge weights are taken from the set $\{-1, 0, 1, I\}$.

Definition 3. [10] The Adjacency Matrix of FCM (NCM)
Let $(C_1, C_2, ..., C_n)$ be the nodes of the FCM. Using this node, the directed graph is drawn with edge weight $e_{ij} = \{-1, 0, 1\}$. Define the adjacency matrix, $E = (e_{ij})$ for FCM ($N(E) = (e_{ij})$ for NCM). Here e_{ij} is the weight of the corresponding edge C_iC_j . Similarly, by using the same nodes with FCM, the directed graph of NCM is drawn with edge weight $e_{ij} = \{-1, 0, 1, I\}$. Here for both FCM and NCM, $e_{ij} = 1$ means positive causality between the nodes. In other way increase (or decrease) to the corresponding increase (or decrease) in the other and vice-versa for $e_{ij} = -1$. If the nodes have no relation indicates $e_{ij} = 0$ and $e_{ij} = I$ in NCM means the relation between the nodes is indeterminate and it is denoted by dotted line in the directed graph.

Definition 4. [10] Instantaneous State Vector of FCM (NCM)
Let $(C_1, C_2, ..., C_n)$ be the nodes of FCM (NCM). The instantaneous state vector $M = (m_1, m_2, ..., m_n)$ where $m_i = \{0, 1, I\}$ represent the on-off-indeterminate state position of the node. If $m_i = 0$ means OFF, $m_i = 1$ means ON and $m_i = I$ means indeterminate for $i = 1, 2, 3, ..., n.$

Definition 5. [10] Cyclic, Acyclic of FCM (NCM)
If the edges form a directed cycle, then FCM (NCM) is said to be cyclic, otherwise acyclic.

Definition 6. [10] Feedback in FCM (NCM)
FCM (NCM) with cycles is said to have feedback.

Definition 7. [10] Dynamical System of FCM (NCM)
If the FCM (NCM) has feedback, i.e., when the causal relations flow through a cycle in a revolutionary way, then the FCM (NCM) is called a dynamical system.

Definition 8. [10] Hidden Pattern in FCM (NCM)
Let $\overline{C_1C_2}, \overline{C_2C_3}, ..., \overline{C_{n-1}C_n}$ be a cycle. The dynamical system goes round and round if the concept C_i is ON and if the causality passes through the edges of the cycle and again causes C_i . This is true for any C_i for $i = 1, 2, 3, ..., n.$ The hidden pattern is the equilibrium state of the dynamical system.

Definition 9. [10] Equilibrium State
If the equilibrium state is a unique state vector, then it is fixed point or limit cycle.

Definition 10. [10] Limit Cycle of FCM (NCM)
If the FCM (NCM) settles down with a state vector repeating in the form, $M_1 \rightarrow M_2 \rightarrow ... \rightarrow M_i \rightarrow M_1$ then this equilibrium is called a limit cycle of the FCM (NCM).

Methodology

This research was conducted to analyse the emergence of COVID-19 post-vaccination by using the method of FCM and NCM. Specifically, the collected data are obtained from an interview with two experts who worked as medical officers. This data is called a concept and from this data, some directed graphs and adjacency matrices are constructed. The results obtained from this study are useful to all to know the factors caused of the epidemic after vaccinated as well as the procedures to be followed to protect from this disease.

Below are some steps involved in this research.

Step 1: Collect the data from the medical experts. Based on their opinions the following conceptual nodes are identified.

Table 1 shows the collected data obtained from interviews with the medical experts. The collected data will be considered as the concepts for the proposed work. Some explanation of the concepts can be found as in the following.

Table 1. Concepts for the proposed work

Concepts	Explanation
C_1	Fever or chills, cough, and shortness of breath
C_2	No symptoms
C_3	Hand washing, mask wearing, and social distancing
C_4	High blood pressure, diabetes, tuberculosis, cancer patient, and elder people
C_5	Travelling behavior
C_6	Possibility of COVID-19.
C_7	High risk factor for getting COVID-19.
C_8	Prevention of COVID-19.

Step 2: Construct the directed graph, neutrosophic directed graph through experts' opinion, also the corresponding adjacency matrix E ($N(E)$ for NCM).

Step 3: Take any concept $C_i\left(i = 1, 2, 3, ..., n\right)$ in ON state.

Step 4: To discover the hidden pattern of $C_i\left(i = 1, 2, 3, ..., n\right)$ the input vector $M_i = \left(m_1, m_2, ..., m_n\right)$ is described as a $m_1 = 1$ for $i = 1$ and other $m_i's = 0$. The dynamical system goes round and round if the concept C_i is ON and if the causality passes through the edges of the cycle and again causes C_i. This is true for any C_i for $i = 1, 2, 3, ..., n$.

Step 5: Multiply vector M_1 with matrix E ($N(E)$ for NCM) then the row vector is namely as $\left(h_1, h_2, ..., h_n\right)$. The new

operation is called a threshold operation and denoted by the symbol $'\rightarrow'$. When the operation is done, $h_1 = 1$ is put to the corresponding on state concept C_i for $i = 1, 2, 3, ..., n$ and 0 for remaining h_i, a new vector as M_2 is obtained.

Step 6: Multiply vector M_2 with matrix E ($N(E)$ for NCM), then repeat the same procedure until the fixed point is obtained. The same procedure will be followed to find the hidden pattern for all the concepts of COVID-19.

Step 7: Compare which method gives the best result in analysing COVID-19 post-vaccination, take all the results from FCM and NCM and see the difference from both methods.

Results and Discussion

In this section, FCM and NCM are analyzed based on experts' opinions. Since the data will be influenced by the way the experts answered the question, in terms of the position that the experts in, the expert's experience in handling the case of the emergence COVID-19 post-vaccination or the difference in where the data have been collected.

For both methods, the iteration processes are repeated until a constant vector or limit cycle is obtained. The constant vector is the basis for interpreting the outcomes. Notice that further iteration is not required when a limit cycle is achieved, i.e $X_n = X_n +1$. The result of final iteration is a constant vector or fixed point or a limit cycle. The limit cycle is extremely important since it reveals a hidden pattern that is used to form a conclusion.

FCM And NCM of the First Expert

Figure 1 presents the directed graph of FCM based on the first expert.
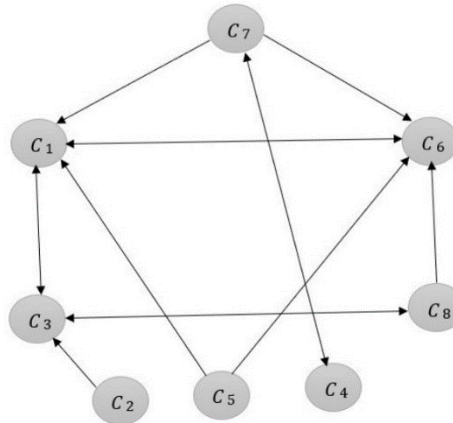
Figure 1. Fuzzy Cognitive Maps by the first expert of COVID-19 post-vaccination

The corresponding matrix, E_1 is related to the graph in Figure 1 is given below:

$$E_1 = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \\ C_8 \end{array} \begin{array}{c} \begin{array}{cccccccc} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 \end{array} \\ \left(\begin{array}{cccccccc} 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \end{array} \right) \end{array}$$

For Case-1 by first expert in FCM, the concept of C_1 i.e fever or chills, cough, and shortness of breath are considered as ON state. Take $M_1 = (1, 0, 0, 0, 0, 0, 0, 0)$

$$\begin{aligned} M_1 E_1 &= (0, 0, 1, 0, 0, 1, 0, 0) \\ &\to (1, 0, 1, 0, 0, 1, 0, 0) \\ &= M_2 \end{aligned}$$

$$\begin{aligned} M_2 E_1 &= (2, 0, 1, 0, 0, 1, 0, 1) \\ &\to (1, 0, 1, 0, 0, 1, 0, 1) \\ &= M_3 \end{aligned}$$

$$\begin{aligned} M_3 E_1 &= (2, 0, 2, 0, 0, 2, 0, 1) \\ &\to (1, 0, 1, 0, 0, 1, 0, 1) \\ &= M_4 \end{aligned}$$

Here, $M_3 = M_4$.

The last two iterations' values are obtained as the same, so that the iteration process may stop, and it shows that, when the C_1 parameter is taken as ON state then the parameters C_3, C_6 and C_8 are obtained

as ON state. Thus, factors such as fever or chills, cough, and shortness of breath and hand washing, mask wearing, and social distancing are all have the possibility of getting COVID-19 post- vaccination even they practiced the prevention of COVID-19.

For Case-2 by first expert of FCM, the concept of C_2 i.e no symptoms are considered. Take $M_1 = (0,1,0,0,0,0,0,0)$. The influence of M_1 on E_1 is given by

$$M_1E_1 = (0,0,1,0,0,0,0,0)$$
$$\rightarrow (0,1,1,0,0,0,0,0)$$
$$= M_2$$

$$M_2E_1 = (1,0,1,0,0,0,0,1)$$
$$\rightarrow (1,1,1,0,0,0,0,1)$$
$$= M_3$$

$$M_3E_1 = (1,0,3,0,0,2,0,1)$$
$$\rightarrow (1,1,1,0,0,1,0,1)$$
$$= M_4$$

$$M_4E_1 = (2,0,3,0,0,2,0,1)$$
$$\rightarrow (1,1,1,0,0,1,0,1)$$
$$= M_5$$

Here, $M_4 = M_5$.

The last two iterations' values are obtained as the same, so that the iteration process may stop, and it shows that, when the C_2 parameter is taken as ON state then the parameters C_1, C_3, C_6 and C_8 are obtained as ON state. Thus, factors such as fever or chills, cough, and shortness of breath, no symptoms, hand washing, mask wearing, and social distancing are all have the possibility of getting COVID-19 post-vaccination even they practiced the prevention of COVID-19.

The results of the last two iteration of FCM for Case-4 (i.e high blood pressure, diabetes, tuberculosis, cancer patient, and elder people) and Case-5 (i.e the traveling history) are obtained to be same which is $M_4 = M_5$, where the factors such as fever or chills, cough, and shortness of breath, no symptoms, hand washing, mask wearing, and social distancing are all have the possibility of getting COVID-19 post-vaccination even they practiced the prevention of COVID-19.

Figure 2 shows the neutrosophic directed graph with the same nodes.
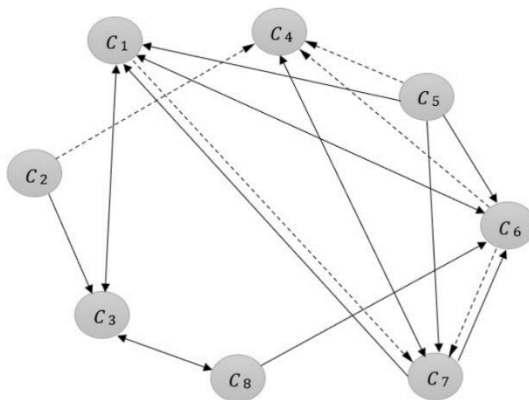
Figure 2. Neutrosophic Cognitive Maps by the first expert of COVID-19 post-vaccination

The corresponding neutrosophic adjacency matrix, $N_1(E)$ related to the neutrosophic directed graph is found as in the following:

$$N_1(E) = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \\ C_8 \end{array}
\begin{array}{c} \begin{array}{cccccccc} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 \end{array} \\
\begin{pmatrix}
0 & 0 & 1 & 0 & 0 & 1 & I & 0 \\
0 & 0 & 1 & I & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
1 & 0 & 0 & I & 0 & 1 & 1 & 0 \\
1 & 0 & 0 & I & 0 & 0 & I & 0 \\
1 & 0 & 0 & 1 & 0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 1 & 0 & 0
\end{pmatrix}
\end{array}$$

For Case-1 by first expert in NCM, the concept of C_1 i.e fever or chills, cough, and shortness of breath are considered. Take $M_1 = (1,0,0,0,0,0,0,0)$. The influence of M_1 on $N_1(E)$ is given by

$$M_1 N_1(E) = (0,0,1,0,0,1,I,0)$$
$$\rightarrow (1,0,1,0,0,1,I,0)$$
$$= M_2$$

$$M_2 N_1(E) = (I+2,0,1,2I,0,I+1,2I,1)$$
$$\rightarrow (1,0,1,I,0,1,I,1)$$
$$= M_3$$

$$M_3 N_1(E) = (I+2,0,2,2I,0,I+2,3I,1)$$
$$\rightarrow (1,0,1,I,0,1,I,1)$$
$$= M_4$$

Here, $M_3 = M_4$.

The iteration process may be stopped when the current iteration seems as same. The above iteration process gives that when the C_1 parameter is taken as ON state then expect the parameters C_3, C_6 and C_8 are obtained as ON state and the parameters C_4 and C_7 as I state. According to the expert the factors such as persons having fever or chills, cough, and shortness of breath, hand washing, mask wearing, and social distancing and persons having chronic disease and elder people who violating C_3 are indeterminant factors to decide for the possibility of getting COVID-19 where the high risk of getting COVID-19 is also uncertain even they practiced the prevention of COVID-19.

The following cases gave the different results and can be obtained as below:

For Case-2 by first expert of NCM, the concept of C_2 i.e no symptoms are considered. Take $M_1 = (0,1,0,0,0,0,0,0)$. The influence of M_1 on $N_1(E)$ is given by

$$M_1N_1(E) = (0,0,1,I,0,0,0,0)$$
$$\rightarrow (0,1,1,I,0,0,0,0)$$
$$= M_2$$

$$M_2N_1(E) = (1,0,1,I,0,0,I,1)$$
$$\rightarrow (1,1,1,I,0,0,I,1)$$
$$= M_3$$

$$M_3N_1(E) = (I+1,0,3,2I,0,I+2,2I,1)$$
$$\rightarrow (1,1,1,I,0,1,I,1)$$
$$= M_4$$

$$M_4N_1(E) = (I+2,0,3,3I,0,I+2,3I,1)$$
$$\rightarrow (1,1,1,I,0,1,I,1)$$
$$= M_5$$

Here, $M_4 = M_5$.

The above iteration process gives that when the C_2 parameter is taken as ON state then expect the parameters C_1, C_3, C_6 and C_8 are obtained as ON state and the parameters C_4 and C_7 as I state. According to the expert the factors such as persons having fever or chills, cough, and shortness of breath, hand washing, mask wearing, and social distancing are all have the possibility of getting COVID-19 post-vaccination even they practiced the prevention of COVID-19. The person having chronic disease and elder people are indeterminant factors to decide for the possibility of getting COVID-19 where the high risk of getting COVID-19 is also uncertain even they practiced the prevention of COVID-19.

For Case-4 by first expert of NCM, the concept of C_4 i.e high blood pressure, diabetes, tuberculosis, cancer patient, and elder people are considered. Take $M_1 = (0,0,0,1,0,0,0,0)$. The influence of M_1 on $N_1(E)$ is given by

$$M_1N_1(E) = (0,0,0,0,0,0,1,0)$$
$$\rightarrow (0,0,0,1,0,0,1,0)$$
$$= M_2$$

$$M_2N_1(E) = (1,0,0,1,0,1,1,0)$$
$$\rightarrow (1,0,0,1,0,1,1,0)$$
$$= M_3$$

$$M_3N_1(E) = (2,0,I+1,0,2,2I+1,0)$$
$$\rightarrow (1,0,1,1,0,1,1,0)$$
$$= M_4$$

$$M_4N_1(E) = (3,0,1,I+1,0,2,2I+1,1)$$
$$\rightarrow (1,0,1,1,0,1,1,1)$$
$$= M_5$$

$$M_5N_1(E) = (3,0,2,I+1,0,3,2I+1,1)$$
$$\rightarrow (1,0,1,1,0,1,1,1)$$
$$= M_6$$

Here, $M_5 = M_6$.

The above iteration process gives that when the C_4 parameter is taken as ON state then expect the parameters C_1, C_3, C_6, C_7 and C_8 are obtained as ON state. Based on the expert the factors such as persons having fever or chills, cough, and shortness of breath, hand washing, mask wearing, and social distancing are all have the possibility of getting COVID-19 post- vaccination and high risk of getting COVID-19 even they practiced the prevention of this disease.

For Case-5 by first expert of NCM, the concept of C_5 i.e the traveling history is considered. Take $M_1 = (0,0,0,0,1,0,0,0)$. The influence of M_1 on $N_1(E)$ *is* given by

$$M_1 N_1(E) = (1,0,0,I,0,1,1,0)$$
$$\rightarrow (1,0,0,I,1,1,1,0)$$
$$= M_2$$

$$M_2 N_1(E) = (3,0,1,2I+1,0,3,3I+1,0)$$
$$\rightarrow (1,0,1,1,1,1,1,0)$$
$$= M_3$$

$$M_3 N_1(E) = (4,0,1,2I+1,0,3,2I+2,1)$$
$$\rightarrow (1,0,1,1,0,1,I,0)$$
$$= M_4$$

$$M_4 N_1(E) = (I+3,0,2,3I,0,I+3,2I+2,1)$$
$$\rightarrow (1,0,1,I,1,1,1,1)$$
$$= M_5$$

$$M_5 N_1(E) = (4,0,2,2I+1,0,4,3I+1,1)$$
$$\rightarrow (1,0,1,1,1,1,1,1)$$
$$= M_6$$

$$M_6 N_1(E) = (4,0,2,2I+1,0,4,2I+2,1)$$
$$\rightarrow (1,0,1,1,1,1,1,1)$$
$$= M_7$$

Here, $M_6 = M_7$.

The above iteration process gives that when the C_5 parameter is taken as ON state then expect the parameters C_1, C_3, C_4, C_6, C_7 and C_8 are obtained as ON state. It shows that '1' is a concept such as cold, cough and difficulty in breathing, hand washing, mask wearing, and social distancing, persons having chronic disease mentioned in C_4 are all have the possibility of getting COVID-19 and high risk of getting this disease even the persons practiced the precaution method in daily life.

FCM and NCM of the Second Expert

Now let's consider another expert's opinion who is first asked to give FCM model. The data will be transformed into directed graph followed by the connection of matrices.
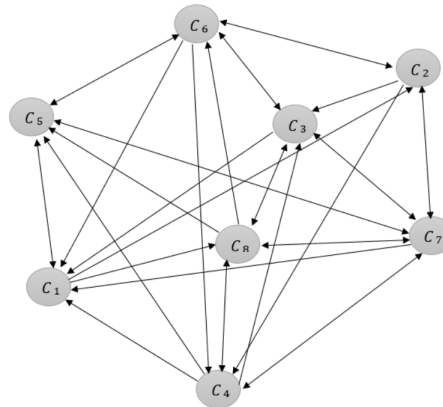
Figure 3. Fuzzy Cognitive Maps by the second expert of COVID-19 post-vaccination

There exists different causal relationship between the concepts. The edges weight causalities that have been used is {0,1} where '0' refer to no relationship or influence between two concept and '1' refer to there is relationship between two concepts. The corresponding matrix, E_2 is given by

$$
E_2 = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \\ C_8 \end{array}
\begin{array}{c}
\begin{array}{cccccccc} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 \end{array} \\
\left(\begin{array}{cccccccc}
0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 \\
0 & 0 & 1 & 1 & 0 & 1 & 1 & 0 \\
1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\
1 & 0 & 1 & 0 & 1 & 0 & 1 & 1 \\
1 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\
1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 \\
1 & 1 & 1 & 1 & 1 & 0 & 0 & 1 \\
0 & 0 & 1 & 1 & 1 & 1 & 1 & 0
\end{array}\right)
\end{array}
$$

For Case-1 by second expert in FCM, the concept of C_1 i.e fever or chills, cough, and shortness of breath are again considered. Take $M_1 = (1,0,0,0,0,0,0,0)$. The influence of M_1 on E_2 is given by
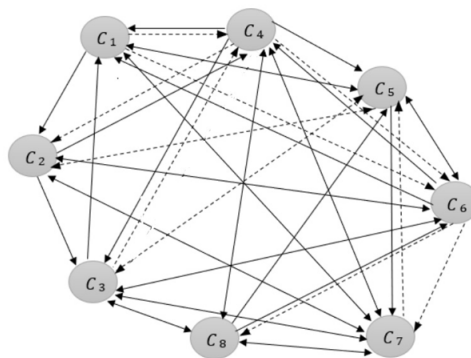
$$
\begin{aligned}
M_1 E_2 &= (0,1,0,0,1,0,0,1) \\
&\rightarrow (1,1,0,0,1,0,0,1) \\
&= M_2
\end{aligned}
$$

$$
\begin{aligned}
M_2 E_2 &= (1,1,2,2,2,3,3,1) \\
&\rightarrow (1,1,1,1,1,1,1,1) \\
&= M_3
\end{aligned}
$$

$$
\begin{aligned}
M_3 E_2 &= (5,3,5,4,5,4,5,4) \\
&\rightarrow (1,1,1,1,1,1,1,1) \\
&= M_4
\end{aligned}
$$

Here, $M_3 = M_4$.

Next, the option consists of indeterminacy in the nodes of NCM by second expert's opinion are constructed. Figure 4 shows neutrosophic directed graph followed by the connection of the square matrix.

Figure 4. Neutrosophic Cognitive Maps by the second expert of COVID-19 post-vaccination

The corresponding neutrosophic adjacency matrix, $N_2(E)$ related to the neutrosophic directed graph of Figure 4 is found as in the following:

$$
N_2(E) = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \\ C_8 \end{array}
\begin{array}{cccccccc}
C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 \\
\end{array}
\left(\begin{array}{cccccccc}
0 & 1 & 0 & I & 1 & I & 1 & 0 \\
0 & 0 & 1 & 1 & I & 1 & 1 & 0 \\
1 & 0 & 0 & I & I & 1 & 1 & 1 \\
1 & I & 1 & 0 & 1 & I & 1 & 1 \\
1 & I & I & 0 & 0 & 1 & 1 & 0 \\
1 & 1 & 1 & 1 & 1 & 0 & I & I \\
1 & 1 & 1 & 1 & I & 0 & 0 & 1 \\
0 & 0 & 1 & 1 & 1 & 1 & 1 & 0 \\
\end{array}\right)
$$

Next, Case-1 of second expert for NCM, the concept of the C_1 i.e fever or chills, cough, and shortness of breath is considered. Take $M_1 = (1,0,0,0,0,0,0,0)$. The influence of M_1 on $N_2(E)$ is given by

$$
\begin{aligned}
M_1(N)_2 E &= (0,1,0,I,1,I,1,0) \\
&\rightarrow (1,1,0,I,1,I,1,0) \\
&= M_2
\end{aligned}
$$

$$
\begin{aligned}
M_2(N)_2 E &= \left(2+2I, 2+2I+I^2, 2+3I, 2+2I, 1+4I, 1+I+I^2, 3+I+2I^2, 1+I+I^2\right) \\
&\rightarrow (1,1,1,1,1,1,1,1) \\
&= M_3
\end{aligned}
$$

$$
\begin{aligned}
M_3(N)_2 E &= (5, 3+2I, 5+I, 4+2I, 4+3I, 4+2I, 6+I, 3+I) \\
&\rightarrow (1,1,1,1,1,1,1,1) \\
&= M_4
\end{aligned}
$$

Here, $M_3 = M_4$.

By second expert opinion of FCM and NCM, noted that all the cases achieved fixed point at $M_3 = M_4 = (1,1,1,1,1,1,1,1)$. It shows that '1' is a concept such as cold, cough and difficulty in breathing, no symptoms, hand washing, mask wearing, and social distancing persons having chronic disease mentioned in C_4 violating the precaution methods, travelling from countries to countries are all have to get possibility of getting and high risk of getting this disease even the persons practiced the precaution method in daily life.

The summarized results for both experts' opinion of FCM and NCM are shown in Table 2 and 3.

Table 2. Summarized results based on first expert

ON State	FCM iteration of the first expert	NCM iteration of the first expert	Comparison Remarks
C_1	$M_3 = M_4$; (1,0,1,0,0,1,0,1)	$M_3 = M_4$; (1,0,1, I,0,1,I,1)	Changes in Parameters
C_2	$M_4 = M_5$; (1,1,1,0 ,0,1,0,1)	$M_4 = M_5$; (1,1,1,I,0,1,I,1)	No Changes
C_4	$M_4 = M_5$; (1,1,1,0 ,0,1,0,1)	$M_5 = M_6$; (1,0,1,1,0,1,1,1)	Changes in Parameters
C_5	$M_4 = M_5$; (1,1,1,0 ,0,1,0,1)	$M_6 = M_7$; (1,0,1,1,1,1,1,1)	Changes in Parameters

Table 3. Summarized results based on second expert

ON State	FCM iteration of the second expert	NCM iteration of the second expert	Comparison Remarks
C_1	$M_3 = M_4$; (1,1,1,1,1,1,1,1)	$M_3 = M_4$; (1,1,1,1,1,1,1,1)	No Changes
C_2	$M_3 = M_4$; (1,1,1,1,1,1,1,1)	$M_3 = M_4$; (1,1,1,1,1,1,1,1)	No Changes
C_4	$M_3 = M_4$; (1,1,1,1,1,1,1,1)	$M_3 = M_4$; (1,1,1,1,1,1,1,1)	No Changes
C_5	$M_3 = M_4$; (1,1,1,1,1,1,1,1)	$M_3 = M_4$; (1,1,1,1,1,1,1,1)	No Changes

Conclusions

This research is done on analysing COVID-19 post-vaccination by using FCM and NCM based on two experts' opinion where there are four different results with different limit cycle of first expert and one result from second expert. FCM and NCM play a vital role in medical field because it involves uncertainty and indeterminacy. Both methods are useful since the root cause of the epidemic is obtained and some procedures to protect from this disease to appear in the future is followed. This study helps to identify the factor with indeterminacy data having high possibilities influenced. It was found that the concept of C_4 (high blood pressure, diabetes, tuberculosis, cancer patient, and elder people) is an indeterminant factor in the emergence COVID-19 post-vaccination. The recommendation for the future research is to analyse any other diseases like Influenza A, HFMD or any other disease problem in medical field by using the same methods to compare the different of the result. This study can also be improved by using other mathematical technique to analyse COVID-19 post-vaccination. So that, the researchers develop knowledge to adapt mathematical tools in real-world problem.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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