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RESEARCH ARTICLE

Evaluation of Vital Parameters Influencing Oxygen Demand with Pythagorean Neutrosophic-Fuzzy Cognitive Map

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Abstract

Objectives: The primary goal is to provide a novel idea known as the Pythagorean neutrosophic fuzzy cognitive map. A multi-objective goal programming issue with a set of objectives and constraints is solved using PNCM. **Methods**: Linguistic variables are transformed into crisp values using a score function and the Pythagorean neutrosophic quantification scale. The linear combinations of crisp values and factors yield the goal and constraint equations. **Findings:** To enhance decision-making in emergency situations like COVID-19, the implications of the novel PNCM concept were utilized to examine the variables influencing oxygen demand. **Novelty:** Fuzzy cognitive mapping combined with Pythagorean Neutrosophic can improve the modelling and analysis of real-world issues with imprecise data.

Keywords: Pythagorean Neutrosophic set (PNs); Fuzzy Cognitive Map (FCM); Goal programming; Oxygen Demand; Multiobjective Optimisation

1 Introduction

The need for oxygen is a significant issue that the majority of people faced during COVID-19 encounter. Patients who have severe infections in particular require oxygen support to maintain their oxygen saturation levels, which raises their oxygen demand. The COVID-19 pandemic spurred research into novel approaches to address the oxygen shortage. The increasing need for medical oxygen was examined by Malik VS et al.[(1)].Mirza M. et al. discussed how to respond to the rise in oxygen demand during the COVID-19 epidemic.[(2)]

Smarandache gave the concept of the Neutrosophic set and Yager gave the Pythagorean fuzzy set. Pythagorean fuzzy sets and neutrosophic sets are combined to create PNs. The dependent components of PNs are membership and non-membership degrees, and the independent component is indeterminacy degrees. In the year 1986, Bart Kosko gave the idea of a Fuzzy Cognitive Map. FCM is a mathematical modelling technique used to depict and study complicated systems having ambiguous and imperfect links between concepts. FCM is a directed graph in which the concepts and their relationship is represented by the vertices and edges respectively. Relationship values between vertices fall within the range of[1]. Multi-objective optimization includes goal programming as a subfield. This method was first presented by Charnes, Cooper and Ferguson in 1955. The topic of time series forecasting using fuzzy cognitive maps was covered by Omid Orang et al.[3].A survey of the uses and developments of fuzzy cognitive maps in systems risk analysis was given by Bakhtavar et al.[4].Akilashri PSS and Nithya G presented an improved fuzzy cognitive map for the diagnosis of COVID-19[5].Apostolopoulos ID et al. have applied FCM to medical applications[6].Hajek et al. combined the IFCM with the topsis approach for decision-making[7].For the supply chain issue, Dursun M and Gumus G. presented an intuitionistic fuzzy cognitive map[8].Hajek P et al. discussed about the intuitionistic fuzzy grey cognitive maps for time series forecasting[9].Obbineni JM et al. talked about the use of the neutrosophic cognitive map in therapeutic decision-making in mental health[10]. A comparative analysis of fuzzy cognitive map and neutrosophic cognitive map on COVID-19 variations was conducted by Murugesan R et al.[11]. Obbineni J et al. talked about the Neutrosophic cognitive map and SWOT analysis for organic farming in India[12]. Using NCM, Raúl DC et al. talked about how social factors affect homelessness[13]. Rojas HE et al. examined the causes of violence using NCM[14]. The influence of ambiguous and unpredictable elements in the spread of pandemics like COVID-19 is analyzed by Zafar A et al. using NCM[15]. NCM was utilized by Reyes Salgado LN et al. to diagnose autism[16]. With the aid of NCM, Vasantha WB et al. talked about children's imaginative play[17]. Shakil MT et al. discussed the health deteriorating factors using a neutrosophic cognitive map[18]. Martin N discussed risk factors for lifestyle diseases using a linguistic neutrosophic fuzzy cognitive map[19]. Ramalingam S et al. presented a Neutrosophic Cognitive Map (NCM) to analyze the COVID-19 pandemic[20]. The effects of adverse childhood experiences on schoolchildren's learning were examined by Merlin MM et al. utilizing PCM[21]. To manage technological waste, F X Edwin Deepak introduced the idea of a Pythagorean cognitive map[22]. For the Pythagorean neutrosophic set, algebraic procedures were provided by Jamiatun Nadwa Ismail et al.[23].

The Pythagorean Cognitive Map establishes links between geometry and cognition; nevertheless, additional research is required to support the theories behind the map and to determine its practical applications in understanding human cognition. Some cognitive events cannot be covered by Pythagorean cognitive map, especially those that are difficult to describe in geometric terms. To overcome these limitations Pythagorean neutrosophic cognitive map has been introduced. This study presents a novel idea: Pythagorean neutrosophic cognitive map, which is the combination of fuzzy cognitive map and Pythagorean neutrosophic sets. PNCM provides a framework for modelling complicated systems with inconsistent information. This approach provides enhanced comprehension for making decisions when faced with uncertainty.

The following are the catalogues for the article:

- Section 2 presents some fundamental concepts regarding PNFs.
- The technique and an explanation of the factors impacting oxygen demand are provided in Section 3.
- The Pythagorean Neutrosophic Cognitive Map (PNCM) and its implementation are covered in Section 4.
- Section 5 provides results and discussions.
- Section 6 contains the conclusion.

2 Preliminaries

2.1 Fuzzy Cognitive Map (FCM)[24]

An FCM is a directed graph with concepts like policies, events etc. as nodes and causalities as edges. It represents the causal relationship between concepts. The directed links that define the relationships between concepts can be positive or negative taking values between [−1,1].

2.2 Pythagorean Neutrosophic Set[25]

Let X be a universe of discourse. A Pythagorean neutrosophic set (PN) N on X is defined as

$$N = \{\langle x, \Phi_N(x), \Psi_N(x), \Pi_N(x)\rangle | x \in X\}$$

where $0 \leq \Phi_N^2(x) + \Psi_N^2(x) + \Pi_N^2(x) \leq 2$ and $\Phi_N(x), \Psi_N(x), \Pi_N(x) \in [0,1]$

$\Phi_N(x), \Psi_N(x), \Pi_N(x)$ denotes degree of membership, degree of non-membership and degree of indeterminacy.

2.3 Score function[25]

Let $A = \{\Phi_A, \Psi_A, \Pi_A\}$ be a PN set, then the score is defined as $S_A = \Phi_A^2 - \Psi_A^2 - \Pi_A^2$,
Where $-1 \leq S_A \leq 1$.

2.4 Pythagorean Neutrosophic Cognitive Map (PNCM)

PNCM can be assumed as a directed graph with nodes which represent characteristics and the weights of the causality as edges.

3 Methodology

This section outlines a method for applying PNCM to handle multi-objective goal programming problems. To accumulate the pairwise relationship between variables influencing oxygen interest, a study is conveyed, and the responses are assembled.

Step 1: Consider the elements that impact oxygen supply and address their relationship with the assistance of linguistic variables.

Step 2: Convert the linguistic variables into a Pythagorean neutrosophic number.

Step 3: Convert the Pythagorean neutrosophic number into a crisp value using the score function (Definition 2.2). Take This crisp value as the weight of the curves of the PNCM.

Step 4: Recognize the constraints and goals among the given variables.

Step 5: Find the connection between objectives and constraints by the accompanying condition $F_n = \sum_{i=1}^{n} W_{in} \times F_i$ (I=1,2…, n)

Where W_{in} - weight of the curve and F_i - Factors.

Step 5: Solve the equation by considering objective factors as the goals to achieve under the given constraints using TORA software.

3.1 Factors affecting oxygen demand

There are certain factors that could influence oxygen demand in emergency settings such as COVID-19. Some factors that could be used in PNCM to model oxygen demand during COVID-19 are given in Table 1. Below is an explanation of how these factors impact oxygen demand.

Table 1. Factors Influencing Oxygen Demand

Factors	Explanation
F_1	Patient's severity
F_2	Rate of Infection
F_3	Population density
F_4	Healthcare infrastructure
F_5	Hospitalization percentage
F_6	Ventilator usage
F_7	Vaccination rate
F_8	Public awareness
F_9	Equitable distribution
F_{10}	Timely response

1. Patient's seriousness: The patient's oxygen request is most certainly impacted by the seriousness, as the patient might require oxygen support.

2. Rate of infection: Request will ascend as the quantity of positive cases rises

3. Population density: A high populace expands the possibilities of spread, which influences the requirement for oxygen.

4. Healthcare infrastructure: The demand for oxygen will be affected by sufficient medical services framework, like the arrangement of oxygen and the accessibility of clinical help.

5. Hospitalization rate: The requirement for oxygen will ascend as more Coronavirus patients are owned up to clinics.

6. Ventilator usage: Patients with Extreme diseases might require ventilator help, which raises the requirement for oxygen in patients.

7. Vaccination rate: Expanded inoculation rates lower contamination rates, which influences oxygen demand

8. Public awareness: Public mindfulness about mask usage and social distancing will slow the spread of diseases, which will influence the interest in oxygen.

9. Equitable distribution: Even-handed conveyance of clinical offices and oxygen will forestall deficiencies, which influence the demand for oxygen.

10. Timely response: The opportune arrangement of help to those in need will influence the demand for oxygen.

3.2 Formulation of objectives and constraints

Following is the rationale behind choosing Timely response and Equitable distribution as objectives to be achieved and the other factors as constraints.

Goal 1: Access to healthcare services for the entire population, free from economic and geographic discrimination, will be made easier by the equitable distribution of healthcare necessities.

Goal 2: Timely response is crucial for the management of COVID-19 patients and early-stage prediction, leading to a decrease in severity and hospitalization rates.

Constraints 1: The severity of a patient is regarded as a constraint since it influences the need for basic healthcare supplies. We can control the distribution of healthcare necessities and improve patient outcomes with the aid of equitable distribution and timely response.

Constraints 2: Timely responses, such as vaccination drives and awareness campaigns, can help control the infection rate, which will cause a decrease in the spread.

Constraints 3: The virus may spread more quickly in densely populated places, which raises the need for oxygen and other critical healthcare supplies. We can control the distribution of resources by taking population density into account as a Constraint.

Constraints 4: Counting the amount of hospital beds, ventilators, and volunteer staff as limits related to the healthcare infrastructure. This will influence how people react to the rise in instances and required medical care.

Constraints 5: It's important to keep patient hospitalization rates within the bounds in order to control resource usage.

Constraints 6: Patients with severe infections should use ventilators. We can guarantee that any patient in need of a ventilator will receive one through equitable distribution.

Constraints 7: Getting vaccinated will slow down the rate of spread. By taking timely responses, like holding immunization drives, vaccination rates can rise.

Constraints 8: A rise in virus transmission could be caused by a lack of public knowledge. The spread can be controlled by prompt action, such as advising people to wear masks and avoiding social situations.

3.3 Implementation of the proposed method

Step 1: The opinions of the experts were gathered, and Table 2 presents the linguistic link between the factors. Figure 1 shows a PNCM with factors and their relationship by nodes and double-sided arrows.

Table 2. Linguistic Link Between Factors

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}
F_1	VL	M	H	VH	H	H	L	VL	H	VH
F_2	M	VL	H	H	H	VH	VH	H	L	M
F_3	H	H	VL	M	M	H	M	VL	VH	H
F_4	VH	H	M	VL	VH	H	H	VH	H	VH
F_5	H	H	M	VH	VL	H	VL	H	VH	VH
F_6	H	VH	H	H	H	VL	VL	VL	VH	H
F_7	H	VH	H	H	H	M	VL	M	VH	M
F_8	VL	H	VL	VH	H	VL	M	VL	M	M
F_9	H	L	VH	H	VH	VH	VH	M	VL	VH
F_{10}	VH	M	H	VH	VH	H	M	M	VH	VL

Step 2: Table 3 is used to translate linguistic variables into Pythagorean neutrosophic numbers.

Step 3: Using the score function, the Pythagorean neutrosophic number is transformed into a crisp value and is displayed in Table 4.

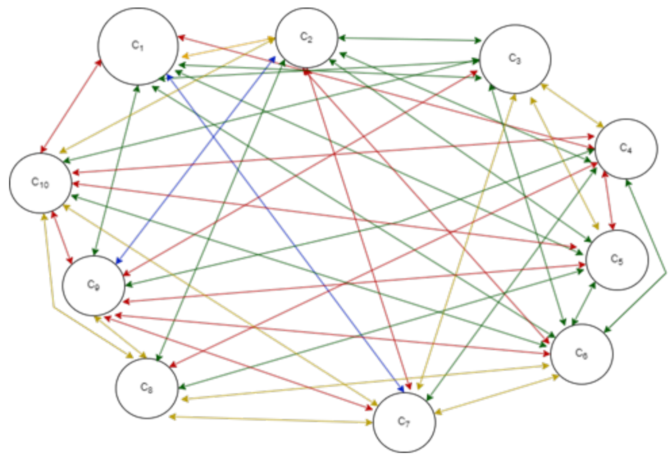

Fig 1. PNCM on Factors Influencing Oxygen Demand

Table 3. Pythagorean Neutrosophic Quantification of Linguistic Variables

Linguistic variable	Pythagorean Neutrosophic Quantification	Crisp value
Very High (VH)	(0.95,0.02,0.05)	0.9
High (H)	(0.9,0.12,0.15)	0.8
Moderate (M)	(0.8,0.2,0.3)	0.51
Low (L)	(0.7,0.3,0.4)	0.24
Very Low (VL)	(0,0,0)	0

Table 4. Weights (Score value) of the Arcs in PNCM

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}
F_1	0	0.51	0.8	0.9	0.8	0.8	0.9	0.24	0.8	0.9
F_2	0.24	0	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.9
F_3	0.8	0.9	0	0.51	0.8	0.8	0.9	0	0.9	0.8
F_4	0.51	0.8	0	0	0.9	0.8	0.8	0.9	0.8	0.9
F_5	0.9	0.8	0.8	0.9	0	0.8	0.8	0.8	0.9	0.9
F_6	0.9	0.8	0.8	0.9	0.9	0	0	0	0.9	0.8
F_7	0.8	0.9	0.8	0.8	0.8	0.51	0	0.51	0.9	0.51
F_8	0	0.8	0	0.8	0.8	0.51	0.9	0	0.51	0.8
F_9	0	0	0.8	0.8	0.51	0.8	0.51	0.51	0	0.9
F_{10}	0	0	0	0.8	0	0	0.51	0.8	0.9	0

Step 4: F_9 and F_{10} are considered as goal variables among the provided variables, while the remaining variables are considered the constraints.

Step 5: The connection between objectives and constraints is given below

Mathematically the problem can be represented as –

Goal Programming Problem:

Goal 1: Maximize F_9 =0.8 F_1+0.8 F_2+0.9F_3+0.8F_4+0.9F_5+0.9F_6+0.97F_7+0.51F_8

Goal 2: Maximize F_{10}= 0.9 F_1+0.9 F_2+0.8F_3+0.9F_4+0.9F_5+0.8F_6+0.51F_7+0.8F_8

Subject to

F_1= 0.24 F_2 + 0.8 F_3 + 0.51 F_4 + 0.9 F_5 + 0.9 F_6 + 0.8 $F_7 \leq 1$

F_2 =0.51F_1+0.9 F_3+0.8 F_4+0.8 F_5+0.8 F_6+0.9 $F_7 + 0.8\ F_8 \leq 1$

F_3=0.8F_1+0.8 F_2+0.8 F_5+0.8 F_6+0.8 $F_7 \leq 1$

F_4=0.9 F_1+0.8 F_2+0.51 F_3+ 0.9 F_5+0.9 F_6+0.8 $F_7 + 0.8\ F_8 \leq 1$

F_5=0.8 F_1+0.8 F_2+0.8 F_3+ 0.9 F_4+0.9 F_6+0.8 $F_7 + 0.8\ F_8 \leq 1$

F_6=0.8 F_1+0.9 F_2+0.8 F_3+0.8 F_4+ 0.8 F_5+0.51 $F_7 + 0.51 \leq 1$
F_7=0.9 F_1+0.9 F_2+0.9 F_3+0.8 F_4+ 0.8 $F_5 + 0.9\, F_8 \leq 1$
F_8= 0.24 F_1+0.8 F_2+0.9 F_4+ 0.8 $F_5 + 0.51\, F_7 \leq 1$
$F_1,\ F_2, F_3, F_4,\ F_5, F_6, F_7, F_8 \geq 0$
Step 6: Using Tora software, the aforementioned issue has been resolved.

4 Results and Discussion

Result 1: We obtained the maximization of goal 1 (Equitable distribution) = 1.34 by taking Goal 1 into consideration and all other relations as constraints. In Table 5 the first column displays outcomes for goal 1.

Result 2: We obtained the maximization of goal 2 (Timely response) = 1.38 by taking Goal 2 into consideration and all other relations as constraints. In Table 5 the second column displays outcomes for goal 2.

From Table 5 we conclude that to maximize the equitable distribution and timely response we have to concentrate more on the rate of infection, healthcare infrastructure, hospitalization rate and ventilator usage.

Table 5. Results of the goal programming problem using TORA software

Factors	Results for goal 1	Results for goal 2
F_1	0.04	0.05
F_2	0.24	0.27
F_3	0.00	0.00
F_4	0.34	0.38
F_5	0.38	0.38
F_6	0.32	0.29
F_7	0.01	0.00
F_8	0.00	0.00

4.1 Comparative analysis

This section offers a comparison between our suggested strategy and other approaches that have been documented in the literature. The purpose of this analysis is to clarify the benefits of the suggested approach above earlier research. Numerous studies have looked into using different fuzzy sets to apply fuzzy cognitive maps to real-world issues. Numerous researchers investigated the concepts of intuitionistic fuzzy cognitive maps (ICM), neutrophilic fuzzy cognitive mappings (NCM), and Pythagorean fuzzy cognitive maps (PCM). These fuzzy collections, however, offer unique challenges when it comes to managing uncertainty. ICM did not adequately address the ambiguity that exists between true and false values. NCM reacts quickly to even minute changes in input data. A strong understanding of Pythagorean fuzzy set operations and their applications in cognitive modelling may be necessary in order to implement PCM. All of the aforementioned issues will be resolved by the Pythagorean neutrosophic cognitive map, which is also good at managing a variety of uncertainties.

We obtained the following findings by applying the suggested method to data from [8] that contains intuitionistic fuzzy numbers and a score function from [26].

Result 3: We obtained the maximization of goal 1 (Equitable distribution) = 1.05 by taking Goal 1 into consideration and all other relations as constraints.

Results 4: We obtained the maximization of goal 2 (Timely response) = 1.02 by taking Goal 2 into consideration and all other relations as constraints.

Taking data from [11] which has Pythagorean fuzzy numbers and applying the proposed method we got the following results.

Result 5: We obtained the maximization of the goal 1 (Equitable distribution) = 1.07 by taking Goal 1 into consideration and all other relations as constraints.

Results 6: We obtained the maximization of goal 2 (Timely response) = 1.06 by taking Goal 2 into consideration and all other relations as constraints. Comparing the results, the Pythagorean neutrosophic environment's cognitive map produced significantly higher optimization values.

The main key feature of this paper is that this is the first work to integrate a fuzzy cognitive map with the Pythagorean neutrosophic set.

5 Conclusion

The method for handling the integration of fuzzy cognitive maps with goal programming in the Pythagorean neutrosophic fuzzy environment was provided by this work. The factors affecting the supply of oxygen are used as an example to demonstrate the productivity of the method. Eventually, the suggested approach can be used to address problems in a practical manner in many sciences and the field of medicine.

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