A NEW NEUTROSOPHIC CLINICAL DECISION SUPPORT MODEL FOR THE TREATMENT OF PREGNANT WOMEN WITH HEART DISEASES

Salah Hasan Al-subhi[*1], Pedro Antonio Román Rubio[**], Pedro Piñero Pérez[*], Elpiniki I. Papageorgiou[***], Roberto García Vacacela[****], Gaafar Sadeq S. Mahdi [*]
[*] Universidad de Ciencias Informáticas, La Habana, Cuba
[**] Servicio Nacional de Cardiopatía y Embarazo, Hospital Docente Ginecobstétrico "Ramón González Coro" - Instituto de Cardiología y Cirugía Cardiovascular, La Habana, Cuba
[***] Faculty of Technology, University of Thessaly, Geopolis Campus Ring Road of Larisa-Trikala, GR41500 Larisa, Greece. Institute for Bio-Economy and Agri-Technology (iBO), Center for Research and Technology–Hellas (CERTH), 6th km Charilaou-Thermi Rd, GR 57001 Thermi, Thessaloniki, Greece
[****] Universidad Católica Santiago de Guayaquil, Guayaquil, Ecuador

ABSTRACT
One of the risks during pregnancy, with high negative impact on both pregnant and fetus is cardiovascular disease suffering. Early diagnosis and appropriate treatment of this pathology significantly reduce the risk for pregnant. The treatment of pregnant women with heart diseases is characterized by the insufficient availability of experts with knowledge of medical specialties involved, and by the presence of situations of indeterminacy, uncertainty, vagueness, and incomplete data. Hence the need to create novel computational techniques for supporting clinical decision making during the treatment of these diseases. In this paper, we suggest a new model based on Neutrosophic Cognitive Map that integrates diagnosis, treatment, and prognosis processes for supporting clinical decision making during the treatment of pregnant women with cardiovascular diseases. The model introduces a new approach to represent the map's connections, by using Triangular Neutrosophic Numbers, making it possible to quantify the truth, indeterminacy, and falsity degrees of experts' preferences. The new model aims to improve the accuracy of diagnosis and treatment of heart diseases during pregnancy; and to mitigate the lack of expertise in this area. In validation process, a data base with 1019 cases provided by Cardiovascular and Pregnancy National Service / Gynecology and Obstetrics Hospital Ramón Gonzales Coros is used, and model's results are evaluated by experts to demonstrate the efficiency of the proposed model for treating these diseases during pregnancy.

KEYWORDS: Clinical Decision Support Model, Neutrosophic Cognitive Maps, Triangular Neutrosophic Numbers, Heart Diseases in Pregnancy.

MSC: 94D05, 92C50

RESUMEN
Uno de los riesgos durante el embarazo, con mayor impacto negativo tanto para la gestante como para el feto, es el padecimiento de las enfermedades cardiovasculares. El diagnóstico temprano y el adecuado tratamiento de esta patología disminuye significativamente el riesgo para las pacientes. El tratamiento de las embarazadas cardiópatas se caracteriza por la insuficiente disponibilidad de expertos que dominen las especialidades médicas involucradas, y la presencia de situaciones de indeterminación, incertidumbre, vaguedad e información incompleta. De ahí la necesidad de introducir novedosas técnicas computacionales para apoyar la toma de decisión clínica durante el tratamiento de las enfermedades cardiovasculares durante el embarazo. En este trabajo, proponemos un nuevo modelo basado en Mapas Cognitivos Neutrosóficos que integra los procesos de diagnóstico, tratamiento y pronóstico para apoyar la toma de decisión clínica durante el tratamiento de gestantes cardiópatas. El modelo introduce un nuevo enfoque para representar las conexiones del mapa mediante Números Neutrosóficos Triangulares, permitiendo cuantificar los grados de certeza, indeterminación y falsedad de las preferencias de los expertos. El nuevo modelo pretende mejorar la precisión del diagnóstico y tratamiento de las enfermedades cardiovasculares durante el embarazo, así como mitigar la falta de experticia en este campo. En el proceso de validación, se emplea una base de datos de 1019 casos provista por el Servicio Nacional de Cardiopatía y Embarazo, Instituto de Cardiología y Cirugía Cardiovascular / Hospital de Ginecología y Obstetricia Ramón Gonzales Coros, y los resultados del modelo son evaluados por expertos para demostrar la eficiencia del modelo propuesto en el tratamiento de estas enfermedades durante el embarazo.

PALABRAS CLAVES: Modelo de apoyo a la decisión clínica, mapas cognitivos neutrosóficos, números neutrosóficos triangulares, enfermedades cardiovasculares durante el embarazo.

[1] salahcuba@yahoo.com

1. INTRODUCTION

The treatment of cardiovascular diseases during pregnancy is a very complex task. In developed countries, these diseases constitute the main maternal cause of death, no related to pregnancy [43]. Some institutions point out that between 0.2% and 4% of pregnant suffer complications because of these diseases. Some cardiovascular diseases during pregnancy are congenital heart diseases [40], rheumatic valvulopathy mainly pregnant women with valve prostheses [33], cardiac arrhythmias [32], peripartum cardiomyopathy that frequently appears in the peripartum period [42], and coronary artery [41].

In particular, an increase in the incidence of these diseases is identified by two fundamental factors:

- The incidence of hereditary factors [21].
- The increase of risk factors such as hypertension, diabetes, and obesity in women who develop their first pregnancy at an advanced age [13].

The diagnosis and treatment of cardiovascular pathologies during pregnancy constitute a complex decision-making problem characterized by the following elements:

- At the time of the consultation, the medical team must make a diagnosis, prescribe a treatment and estimate a prognosis of disease evolution. In this scenario, three sequential decision-making problems hardly interconnected are identified. The first problem is associated with diagnosis process, in which the disease and its level of severity are identified from the analysis of a large number of factors, such as symptoms, signs, personal and family history, and complementary examinations, among others. Once the disease is diagnosed, decisions associated to determine the appropriate treatment are made in order to eliminate or control maternal-fetal effects. When prescribing a treatment, doctors forecast the possible patient evolution, which is the third decision-making problem.
- There are situations of uncertainty and vagueness. For example, some symptoms of these diseases tend to be confused with the pregnancy symptoms itself [9]. Besides, there is a presence of indeterminacy relationships among concepts of diagnostic, treatment, and prognosis processes. An example of that is, sometimes, the effect of a treatment on patient evolution is not known exactly. Another sources of uncertainty can be due to the variation of physicians' opinions and experiences [10].
- There is insufficiency of experts in the treatment of cardiovascular diseases during pregnancy. The treatment of these diseases requires the knowledge of several specialists such as: cardiologists with knowledge of pregnancy, obstetricians experienced in cardiovascular diseases, and neonatologists with experience in obstetrics and cardiology. In Latin America region, there are centers specialized in the treatment of cardiovascular diseases during pregnancy only in Cuba, Argentina, Colombia, and Brazil [30].
- Because prospective or randomized studies about cardiovascular diseases during pregnancy are scarce, the principal guidelines' recommendations for the management of these diseases mainly correspond to the lowest evidence level C [31]. This situation provokes low accuracy in decisions emitted by physicians with regard to diagnosis and treatment of these diseases during pregnancy.

From the aforementioned analysis, it is evident the need to develop a clinical decision support tool for diagnosis, treatment, and prognosis of cardiovascular diseases during pregnancy. In this sense, soft computing techniques are robust for modeling complex and dynamic systems with presence of uncertainty, inaccuracy, and vagueness [8]. For the selection of the technique to model the problem in question, the following elements have been taken into account:

- The ability to manage numerous interrelated concepts with different degrees of causality.
- The ability to represent indeterminacy and feedback relationships presented among concepts.
- The possibility to aggregate experts' knowledge with different degrees of expertise involved in the decision-making process.
- Considering not only the accuracy and predictability of the results, but also the transparency and interpretability of these results and the decision-making process.
- The capacity to deal with uncertainty, vagueness and imprecision embedded in data provided from different sources such as: medical history, physical examination, doctor's evaluation, laboratory tests, and imaging tests.

Based on the previous elements which show the complexity of the decision making problem, in this research study, particularly, we propose the use of Fuzzy Cognitive Maps (FCMs) [18] considering the advantages of this technique in comparison with other soft computing techniques, in terms of interpretability, scalability, aggregation of knowledge, dynamism and feedback representation capacity [27].

1.1. Previous works on FCMs and its extensions for clinical decision support.

FCMs have been used for clinical decision support systems. Bourgani et al. [5] examines and compares different FCM structures proposed for developing medical decision support systems. Apostolopoulos [4] employed FCM for the prediction of coronary artery disease. Papageorgiou et al. [28] developed a decision support system for the prediction of pulmonary infections. Stylios et al. [38] introduced a medical decision support system based on distributed m-FCM to model the way by which the obstetrician makes a decision for a normal delivery or a caesarean section. Subramanian et al. [39] developed an integrated decision support approach for the estimation of breast cancer risk grade. Continuing with this line, Büyükavcu et al. [7] employed a Rule-Based FCM to evaluate risk factors of breast cancer, and Li et al. [19] proposed an Interval-valued FCM for breast cancer risk prediction. Papageorgiou employed a new FCM approach for the treatment planning decision in radiotherapy [25], [26]. The same author applied FCM to determine the success of radiation therapy process [29]. Iakovidis and Papageorgiou [15] developed a new FCM approach based on Intuitionistic FCM for pneumonia severity classification. For celiac disease classification, Najafi et al. [24] developed a medical decision support system based on FCMs and computing with words (CWW), and Amirkhani et al. [3] introduced an automatic computer-aided diagnosis system based on iFCM. Jayashree et al. [16] employed FCM for geospatial dengue outbreak risk prediction of tropical regions of Southern India. Mago et al. [22] used FCM to assess the severity level of periodontal disease in dental patients. Georgopoulos and Stylios [12] applied their augmented FCMs with Case-based Reasoning technique in the speech pathology area to diagnose language impairments. Habib and Akram [14] used FCM to determine the risk for cardiovascular diseases (CVDs), and nutrition level in infants aged 0–6 months.
In order to handle indeterminacy relationships that could exist among decisions concepts, i.e. considering a situation where it is difficult to decide whether a relation between two concepts exists or not, different authors has employed Neutrosophic Cognitive Maps (NCMs) introduced by Vasantha & Smarandache in 2003 [17]. NCMs are the integration of Fuzzy Cognitive Maps (FCMs) proposed by Kosko in 1986 [18] and the Neutrosophic Sets (NCs) developed by Smarandache in 1995 [36]. NCMs overcome the limitation of traditional FCMs of not representing indeterminacy relationships. Shanmugam and Preethi [34] developed a new model based on NCM with Genetic Algorithm (GA) for the classification of arthritis disease. Gaurav et al. [11] employed NCM and GA for modeling of medical disease diagnosis, the model was applied in the speech pathology area for the diagnosis of language impairments. William et al. [44] employed NCMs to analyze the impact of risk factors of breast cancer and its solution.

1.2. Motivation and aims of this work.

From the previous analysis, it is noticed that:

- There is a need to improve the accuracy of clinical decisions during the diagnosis and treatment of pregnant women with cardiovascular diseases, and to mitigate the lack of expertise in this area.
- The applications of FCMs and its extensions tackle the decision-making problem in isolation, since they are directed to either diagnosis, treatment, or prognosis. No work has been reported in which the tree processes are integrated into a clinical decision support tool.
- There are no applications of FCMs or its extensions for the treatment of cardiovascular diseases during pregnancy.
- There is a need to improve the indeterminacy representation. The NCMs-based models identified the consulted literature represent indeterminacy relationships by the symbol *I*, and the rest of the map's relationships are represented as in traditional FCMs. The symbol *I* is swept during the simulation process making it possible only to indicate the outputs nodes with indeterminacy situation.

This paper is directed toward the creation of a new model based on Neutrosophic Cognitive Map (NCM) for supporting clinical decision making during the treatment of cardiovascular diseases during pregnancy. The proposed model aims to improve the accuracy of diagnosis and treatment of heart diseases during pregnancy, and thereby contribute to reduce risks during pregnancy and raise the quality of life of pregnant women.
The innovation aspects of this research work are the following:

- The integration of the diagnosis, treatment, and prognosis processes in a clinical decision support tool.
- The application of NCMs for the treatment of cardiovascular diseases during pregnancy.
- The introduction of a new approach for indeterminacy representation. In contrast of current NCM-based models which represent the indeterminacy relationships by the symbol *I*, the proposed model represents the map's relationships through Triangular Neutrosophic Numbers (TNNs). Hence, experts can now be able to not only to describe the relationship among concepts, but also to express the truth, indeterminacy and falsity degrees of their preferences.

The work is organized as follows. Section 2 describes preliminary concepts of the Triangular Neutrosophic Numbers. Section 3 presents the new neutrosophic clinical decision support model for the treatment of pregnant women with cardiovascular diseases. Section 4 is dedicated to the analysis of the research's results, and finally the conclusions of the work are presented in section 5.

2. TRIANGULAR NEUTROSOPHIC NUMBERS

In this section, main definitions of Triangular Neutrosophic Numbers. The concept of Fuzzy Sets (FSs) was introduced for the first time by L. Zadeh in 1965 [45], where it is assumed that there is a membership function indicating the degree of belongingness and the degree of non-belongingness is gust the complete to 1. Later on, Atanassov [2] proposed the IFSs as an extension of fuzzy sets which can handle the lack of knowledge by using a non-membership degree. However, in the intuitionistic fuzzy logic, membership, non-membership, and hesitancy are all completely dependent in each other. Thus, in many complex decision-making problems, TIFNs present some limitation. In order to overcome this limitation, IFSs were extended by Smarandache in 1995 [36], by introducing a new component called indeterminacy-membership function. Neutrosophic sets theory considers that truth membership function, falsity membership function, and indeterminacy membership function are independent of each other.

Definition 1 [36]**.** A neutrosophic set $A = \{(x, T_A(x), I_A(x), F_A(x)) \mid x \in U\}$ is defined by a truth-membership function $T_A(x) \rightarrow [0, 1]$, an indeterminacy-membership function $I_A(x) \rightarrow [0, 1]$, and a falsity-membership function $F_A(x) \rightarrow [0, 1]$. Therefore $0 \leq \sup T_A(x) + \sup I_A(x) + \sup F_A(x) \leq 3$.

For NSs be implemented in practical problem, Wang et al. [20] defined the single valued neutrosophic set (SVNS), as a special case of NSs.

Definition 2 [20]**.** Let *X* be a universe of discourse. A single valued neutrosophic set (SVNS) *A* over *X* is an object having the form $A = \{\langle x,\ T_A(x), I_A(x), F_A(x)\rangle : x \in X\}$, $T_A(x) : X \rightarrow [0, 1]$, $I_A(x) : X \rightarrow [0, 1]$ and $F_A(x) : X \rightarrow [0, 1]$ with $0 \leq T_A(x) + I_A(x) + F_A(x) \leq 3$ for all $x \in X$. $T_A(x), I_A(x), F_A(x)$ denote the degrees of membership, indeterminacy, and non-membership, respectively, of x to *A*.

Later on, the concept of triangular neutrosophic numbers (TNNs) was introduced as a special form of single valued neutrosophic sets.

Definition 3 [1]**.** A single valued triangular neutrosophic set $\tilde{A}$ is a vector $\tilde{A} = \langle (a_1, a_2, a_3); \propto_{\tilde{A}}, \theta_{\tilde{A}}, \beta_{\tilde{A}} \rangle$ such that (a_1, a_2, a_3) represents the boundary of a triangular function where $a_1 \leq a_2 \leq a_3$, and $\propto_{\tilde{A}}, \theta_{\tilde{A}}, \beta_{\tilde{A}} \in [0,1]$ denote the maximum truth-membership degree, minimum indeterminacy-membership degree and minimum falsity-membership degree, respectively , see Figure 1. $\propto_{\tilde{A}}, \theta_{\tilde{A}}, \beta_{\tilde{A}}$ are used to calculate $T_{\tilde{A}}(x)$, $I_{\tilde{A}}(x)$ and $F_{\tilde{A}}(x)$ from $\mu_{\tilde{A}}$ for all $x \in U$, as follows

$$T_{\tilde{A}}(x) = \begin{cases} \propto_{\tilde{A}} \left(\frac{x-a_1}{a_2-a_1}\right) & (a_1 \leq x \leq a_2) \\ \propto_{\tilde{A}} & (x = a_2) \\ \propto_{\tilde{A}} \left(\frac{a_3-x}{a_3-a_2}\right) & (a_2 < x \leq a_3) \\ 0 & \text{otherwise} \end{cases} \quad (2.1)$$

$$I_{\tilde{A}}(x) = \begin{cases} \frac{(a_2-x+\theta_{\tilde{A}}(x-a_1))}{(a_2-a_1)} & (a_1 \leq x \leq a_2) \\ \theta_{\tilde{A}} & (x = a_2) \\ \frac{(x-a_2+\theta_{\tilde{A}}(a_3-x))}{(a_3-a_2)} & (a_2 < x \leq a_3) \\ 1 & \text{otherwise} \end{cases} \quad (2.2)$$

$$F_{\tilde{A}}(x)=\begin{cases}\dfrac{\left(a_2-x+\beta_{\tilde{A}}(x-a_1)\right)}{(a_2-a_1)} & (a_1\le x\le a_2)\\ \beta_{\tilde{A}} & (x=a_2)\\ \dfrac{\left(x-a_2+\beta_{\tilde{A}}(a_3-x)\right)}{(a_3-a_2)} & (a_2< x\le a_3)\\ 1 & \text{otherwise}\end{cases} \quad (2.3)$$

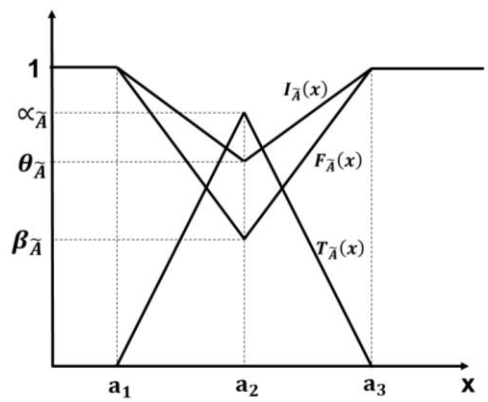

Figure 1. Graphical representation of a triangular neutrosophic set $\tilde{A}$

Definition 1 [1]. Let $\tilde{a}=\langle (a_1, a_2, a_3); \propto_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}\rangle$ and $\tilde{b}=\langle (b_1, b_2, b_3); \propto_{\tilde{b}}, \theta_{\tilde{b}}, \beta_{\tilde{b}}\rangle$ be two triangular neutrosophic numbers and $\gamma \neq 0$ be any real number. Then:

- Addition of two triangular neutrosophic numbers

$$\tilde{a}\oplus\tilde{b}=\langle (a_1+b_1, a_2+b_2, a_3+b_3); \propto_{\tilde{a}}\wedge\propto_{\tilde{b}}, \theta_{\tilde{a}}\vee\theta_{\tilde{b}}, \beta_{\tilde{a}}\vee\beta_{\tilde{b}}\rangle \quad (2.4)$$

- Subtraction of two triangular neutrosophic numbers

$$\tilde{a}\ominus\tilde{b}=\langle (a_1-b_3, a_2-b_2, a_3-b_1); \propto_{\tilde{a}}\wedge\propto_{\tilde{b}}, \theta_{\tilde{a}}\vee\theta_{\tilde{b}}, \beta_{\tilde{a}}\vee\beta_{\tilde{b}}\rangle \quad (2.5)$$

- Multiplication of two triangular neutrosophic numbers

$$\tilde{a}\otimes\tilde{b}=\begin{cases}\langle (a_1b_1, a_2b_2, a_3b_3);\ \propto_{\tilde{a}}\wedge\propto_{\tilde{b}}, \theta_{\tilde{a}}\vee\theta_{\tilde{b}}, \beta_{\tilde{a}}\vee\beta_{\tilde{b}}\rangle & \text{if } (a_3>0, b_3>0)\\ \langle (a_1b_3, a_2b_2, a_3b_1);\ \propto_{\tilde{a}}\wedge\propto_{\tilde{b}}, \theta_{\tilde{a}}\vee\theta_{\tilde{b}}, \beta_{\tilde{a}}\vee\beta_{\tilde{b}}\rangle & \text{if } (a_3<0, b_3>0)\\ \langle (a_3b_3, a_2b_2, a_1b_1);\ \propto_{\tilde{a}}\wedge\propto_{\tilde{b}}, \theta_{\tilde{a}}\vee\theta_{\tilde{b}}, \beta_{\tilde{a}}\vee\beta_{\tilde{b}}\rangle & \text{if } (a_3<0, b_3<0)\end{cases} \quad (2.6)$$

- Division of two triangular neutrosophic numbers

$$\tilde{a}\oslash\tilde{b}=\begin{cases}\langle \left(\frac{a_1}{b_3},\frac{a_2}{b_2},\frac{a_3}{b_1}\right);\ \propto_{\tilde{a}}\wedge\propto_{\tilde{b}}, \theta_{\tilde{a}}\vee\theta_{\tilde{b}}, \beta_{\tilde{a}}\vee\beta_{\tilde{b}}\rangle & \text{if } (a_3>0, b_3>0)\\ \langle \left(\frac{a_3}{b_3},\frac{a_2}{b_2},\frac{a_1}{b_1}\right);\ \propto_{\tilde{a}}\wedge\propto_{\tilde{b}}, \theta_{\tilde{a}}\vee\theta_{\tilde{b}}, \beta_{\tilde{a}}\vee\beta_{\tilde{b}}\rangle & \text{if } (a_3<0, b_3>0)\\ \langle \left(\frac{a_3}{b_1},\frac{a_2}{b_2},\frac{a_1}{b_3}\right);\ \propto_{\tilde{a}}\wedge\propto_{\tilde{b}}, \theta_{\tilde{a}}\vee\theta_{\tilde{b}}, \beta_{\tilde{a}}\vee\beta_{\tilde{b}}\rangle & \text{if } (a_3<0, b_3<0)\end{cases} \quad (2.7)$$

- Multiplication of a triangular neutrosophic number by a constant value

$$\gamma\otimes\tilde{a}=\begin{cases}\langle (\gamma a_1, \gamma a_2, \gamma a_3);\ \propto_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}\rangle & \text{if } (\gamma>0)\\ \langle (\gamma a_3, \gamma a_2, \gamma a_1);\ \propto_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}\rangle & \text{if } (\gamma<0)\end{cases} \quad (2.8)$$

- Division of a triangular neutrosophic number by a constant value

$$\tilde{a}\oslash\gamma=\begin{cases}\langle \left(\frac{a_1}{\gamma},\frac{a_2}{\gamma},\frac{a_3}{\gamma}\right);\ \propto_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}\rangle & \text{if } (\gamma>0)\\ \langle \left(\frac{a_3}{\gamma},\frac{a_2}{\gamma},\frac{a_1}{\gamma}\right);\ \propto_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}\rangle & \text{if } (\gamma<0)\end{cases} \quad (2.9)$$

- Inverse of a triangular neutrosophic number

$$\tilde{a}^{-1} = \langle \left(\frac{1}{a_3}, \frac{1}{a_2}, \frac{1}{a_1}\right); \propto_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \rangle \quad \text{where } (\tilde{a} \neq 0) \tag{2.10}$$

3. THE NEW NEUTROSOPHIC CLINICAL DECISION SUPPORT MODEL FOR THE TREATMENT OF PREGNANT WOMEN WITH CARDIOVASCULAR DISEASES

This section proposes the new neutrosophic clinical decision support model for the treatment of pregnant women with cardiovascular diseases. The suggested model is based on triangular neutrosophic numbers and integrates the diagnostic, treatment and prognostic processes for supporting medical decision making during the treatment of cardiovascular diseases during pregnancy. Unlike other models identified in the consulted literature, the proposed model represents all the map's relationships including indeterminacy by triangular neutrosophic numbers, see definition 3. This has the advantage of quantifying the truth, indeterminacy, and falsity degrees.
The phases of the proposed model are detailed in the following algorithm:

Algorithm_1. the pseudo-code algorithm for the construction and exploitation of the NCM

Select K medical experts (K> 2) with similar expertise levels.
Identify the concepts to be related by each of the stages of the decision-making process (C_1, C_2 ... C_n, D_1, D_2 ... D_r, R_1, R_2 ... R_s). Such as the concepts C_q correspond to diagnostic nodes, the concepts of D_j correspond to decision nodes associated with the treatment, and the concepts R_i are those associated with the prognosis process.
Assign the linguistic variable L to represent the causal relationships among concepts.
Each expert e_i constructs a map M_{e_i} by expressing their preferences about the direction and intensity of relations among concepts, such that w_{ij} represents the weight of the connection between C_i and C_j.
Aggregate the maps M_{e_i} constructed by experts to obtain the aggregated map M_c.
C_0 is the initial vector that represents symptoms and signs, t = 1
stability = false
Make diagnosis
    While not *stability* && t <= max_iteration do
        $C_i^{t+1} = f\left(\left(C_i^{\,t} \oplus \sum_{i=1}^{n} w_{ji} \otimes C_j^{\,t}\right)\right.$
        stability = $\forall\ C^t,\ |C^{t+1} \ominus C^t| < \varepsilon$
        t = t + 1
    End While
$D_0 = C^t$, $t = 1$
Stability = false
Perform treatment
    While not *stability* && t <= max_iteration do
        $D_i^{t+1} = f\left(\left(D_i^{\,t} \oplus \sum_{i=1}^{n} w_{ji} \otimes D_j^{\,t}\right)\right.$
        stability = $\forall\ D^t,\ |D^{t+1} \ominus D^t| < \varepsilon$
        t = t + 1
    End While
$R_0 = D^t$, t = 1
Stability = false
Perform prognosis
    While not *stability* && t <= max_iteration do
        $R_i^{t+1} = f\left(\left(R_i^{\,t} \oplus \sum_{i=1}^{n} w_{ji} \otimes R_j^{\,t}\right)\right.$
        stability = $\forall\ R^t,\ |R^{t+1} \ominus R^t| < \varepsilon$
        t = t + 1
    End While
Return(C^t,D^t,R^t)

In order to build the proposed map, the algorithm_1 was applied. Three experts, in this case, physicians from National Service of Cardiopathy and Pregnancy and Hospital "Ramón González Coro" for Gynecology and Obstetrics of Cuba, with approximately 20 years of experience in the treatment of pregnant with heart disease was selected. The participation of multiple experts for the map construction reduces the bias that can be

caused by considering the preferences of only one expert.
First, experts identified the relevant nodes of the map, as shown in Table 1.

Table 1. Maps' nodes

Type	Nodes
Input data (symptoms and signs)	Age (A) Obesity (OB) Smoking (TAB) Family pathological history (FPH) Personal pathological history (PPH) Electrocardiogram (ECG) Ultrasound (ECO) Functional class (FC)
Diagnosis	Obstruction at exit (OEX) Obstruction at entry (OEN) Rhythm disorders (RD) Conduction disorders (CDS) Congenital diseases (CD) Genetic diseases (GD)
Treatment	Pregnancy interruption (PI) Diuretic treatment (DT) Anti-arrhythmic treatment (AAT) Treatment with beta blockers (TBB) Anticoagulants treatment (ACT)
Prognosis	Eutectic delivery (ED) Dystocic delivery (PD) Child with complications (CHC) Child without complications (NOCHC) Mother with complications (MC) Mother without complications (NOMC)

After that, experts describe the cause-effect relationships among nodes by using the linguistic terms represented by triangular neutrosophic numbers, as shown in Table 2.

Table 2. Triangular neutrosophic numbers to represent maps' relationships

Linguistic terms	Triangular neutrosophic numbers
Negatively_Extremely_High (NEXH)	(-1.0, -1.0, -0.83, 0.99, 0.02, 0.01)
Negatively_Very_High (NVH)	(-1, -0.83, -0.67, 0.99, 0.02, 0.01)
Negatively_ High (NH)	(-0.83, -0.67, -0.5, 0.99, 0.03, 0.02)
Negatively_Medium (NM)	(-0.67, -0.5, -0.33, 0.99, 0.03, 0.02)
Negatively_Low (NL)	(-0.5, -0.33, -0.17, 0.99, 0.04, 0.03)
Negatively_Very_Low (NVL)	(-0.33, -0.17,0, 0.99, 0.04, 0.03)
Nothing (N)	(0, 0, 0, 0, 0, 0)
Very_Low (VL)	(0, 0.17, 0.33, 0.99, 0.04, 0.03)
Low (L)	(0.17, 0.33, 0.5, 0.99, 0.04, 0.03)
Medium (M)	(0.33, 0.5, 0.67, 0.99, 0.03, 0.02)
High (H)	(0.5, 0.67, 0.83, 0.99, 0.03, 0.02)
Very_High (VH)	(0.67, 0.83, 1.0, 0.99, 0.02, 0.01)
Extremely High (EXH)	(0.83, 1.0, 1.0, 0.99, 0.02, 0.01)
Indeterminacy (IND)	(-0.17, 0, 0.17, 0.5, 0.99, 0.5)

Next step is the aggregation of individual maps built by each expert as follow:
Let $\tilde{a}_1, \tilde{a}_2 \ldots \tilde{a}_n$ be the preferences of n experts, being $\tilde{a}_1 = (a_{11}, a_{12}, a_{13}, \propto_{\tilde{a}_1}, \theta_{\tilde{a}_1}, \beta_{\tilde{a}_1})$, then, the preferences aggregation is performed by using the operator *Agg* in the equation 4.1:

$$Agg\ (\tilde{a}1, \tilde{a}2, \ldots\ \tilde{a}\text{n}) = \left(\frac{\sum_{i=1}^{n} a_{i1}}{n}, \frac{\sum_{i=1}^{n} a_{i2}}{n}, \frac{\sum_{i=1}^{n} a_{i3}}{n}, T(\propto_{\tilde{a}_i}), S_1(\theta_{\tilde{a}_i}), S_2(\beta_{\tilde{a}_i}) \right) \tag{3.1}$$

Being T a t-norm function, $T: [0,1] \times [0,1] \rightarrow [0,1]$, for example (Min), and $S1$, $S2$: a s-norm function, $S: [0,1] \times [0,1] \rightarrow [0,1]$, for example (Max) [37].
Finally, the aggregated map is obtained, as shown in Figure 2.

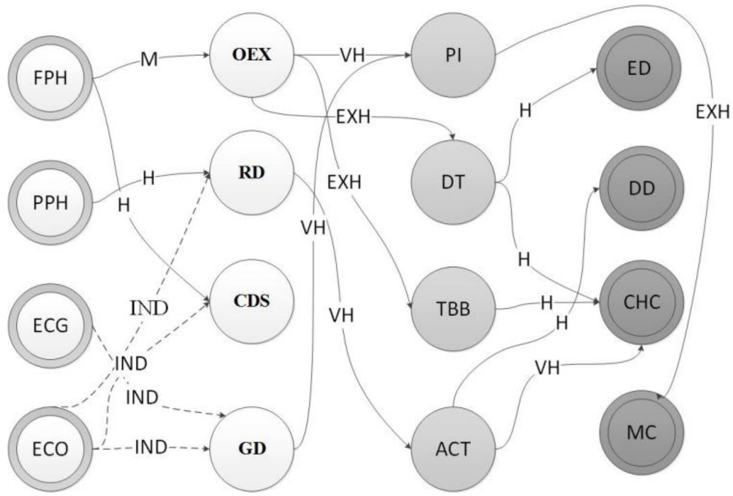

Figure 2. Partial view of the Neutrosophic Cognitive Map for the treatment of heart diseases during pregnancy

The simulation process consists of calculating the activation levels, in successive iterations, of the nodes. This simulation additionally requires the definition of an initial vector. The initial vector, in this particular case, comprises the symptoms and signs presented by a pregnant woman. The possible diagnosis nodes are generated from these input data. The nodes derived from the diagnosis process are used as the initial vector for the next process associated with decisions that represent the possible treatments. Finally, the outputs generated by the decision process are used as input data in the prognosis process. Map's nodes in the three processes are calculated at each step of the simulation as follows:

$$A_i^{t+1} = f\left(A_i^{\,t} \oplus \sum_{i=1}^{n} W_{ji} \otimes A_j^{\,t}\right) \tag{3.2}$$

where A_i^{t+1} is the value of the concept C_i in step $t + 1$ of the simulation, $A_j^{(t)}$ is the value of the concept C_j in step t of simulation, w_{ji} is the weight of the connection between the concepts C_j and C_i, $f(.)$ is the activation function [6]. According to the initial vector, the map will converge to one of the following states: fixed point, limit cycle or chaotic attractor. The design of the proposed model allows the execution of the diagnosis, treatment and prognosis processes sequentially.

4. EXPERIMENTAL ANALYSIS

For model validation, a data base with 1019 cases of pregnant women with different cardiovascular pathologies provided by the National Cardiopathy and Pregnancy Service and "Ramón González Coro" Hospital of Cuba was used. The model was implemented in Ruby and introduced as a module into GESPRO platform designed for multiple purposes [35]. The results of the application of the proposal map with the aforementioned database's data were evaluated by 3 experts, in this case, medical specialists in the treatment of cardiovascular diseases during pregnancy. The evaluation criteria were:

- Successful evaluation in diagnosis.
- Successful evaluation in treatment.
- Successful evaluation in prognosis.
- Answer speed.

Each expert provides his or her preferences about each criterion by using one of the following linguistic terms LBTL = {*nothing, very low, low, mean, high, very high, perfect*},
Experts evaluation were aggregated using 2-tuple linguistic model [23], and the following results were obtained, see Table 3.

Table 3. Experts' preferences

	Criteria	e1	e2	e3	Aggregated experts' preferences
1	Successful evaluation in diagnosis	high	mean	very high	(high, 0.0)
2	Successful evaluation in treatment	low	high	mean	(mean, 0.0)
3	Successful evaluation in prognosis	very high	high	very high	(very high, -0.4)
4	Answer time	perfect	high	very high	(very high, 0.0)
Aggregated experts' preferences					(high, 0.1)

The best evaluations were given for "Answer speed" and "Successful evaluation in prognosis" criteria. The criterion with worst result was "Successful evaluation in treatment". In general, the overall experts' evaluation about the model's results associated to diagnosis, decision, and prediction processes was high. Besides, experts expressed their satisfaction with results interpretability and highlighted the high performance of the neutrosophic medical decision support tool regarding to the answer time. On the other hand, medical staff expressed special interest with the model capacity of interrelating different concepts associated with diagnosis, treatment, and prognosis.

The model can also be used for learning and educational purposes using a scenario-based learning approach. Through "what-if" questions, medical professionals can develop their knowledge and skills for problems solution in a safety context. This learning approach is suitable for training inexperienced medical personal, since it gives them the opportunity to observe and predict the effect of their decisions associated to diagnosis and treatment on the evolution of pregnant women with heart diseases.

5. CONCLUSIONS

In this article, a new clinical decision support model based on Neutrosophic Cognitive Map (NCM) for the treatment of cardiovascular diseases during pregnancy was presented. The proposed model integrates the diagnosis, treatment, and prognosis processes into one framework. Unlike other models based on NCMs, the new model represents the map's connections by triangular neutrosophic numbers, making it possible to consider the truth, indeterminacy, and falsity degrees of experts' preferences. Among the model advantages found by physicians, it is highlighted its ability to interrelate different concepts associated with the treatment of heart diseases during pregnancy and the results interpretability. The use of the proposed model contributed to improve the professional level of inexperienced medical personal in the treatment of pregnant women with heart diseases. Besides, the proposal improves the precision of decisions and facilitates the early detection of diseases in scenarios where there are no specialized medical personnel in the treatment of this kind of diseases. As future work, it is proposed to extend the use of this model for the diagnosis, treatment and prognosis of other diseases, as well as the construction of the map by using machine learning techniques.

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