Neutrosophic Sets and Systems

Volume 22 Article 6

1-1-2018

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Abstract. Neutrosophic sets and their application to decision support have become a very important topic. In real situations, there are different sources of indeterminacy. This paper suggests a new decision-making model based on Neutrosophic Cognitive Maps (NCMs) for making comprehensive decisions from a multi-objective approach (diagnosis, decisions, and prediction) during the execution of many projects simultaneously. A Soft Computing technique like Fuzzy Cognitive Maps (FCMs) has been widely used for decision-making process in project management, but this technique has the limitation of not considering the indeterminacy between concepts. This limitation is overcome by the proposed model since NCMs can represent the indeterminacy or neutrality. The new model includes neutrosophic sets in the map's connections. Finally, the suggested model has been compared with traditional FCM-based model considering efficiency and efficacy

Keywords: Neutrosophic cognitive maps, neutrosophic sets, project management, single valued neutrosophic numbers.

1 Introduction

Project management is characterized by being a complex and dynamic system with high degrees of uncertainty [1]. Consequently, there is a low percentage of success in projects as shown in the reports of the Standish Group International Incorporated. Standish Group is continuously studying the behavior of different companies since 2004; these studies address around 5000 projects annually. Reports of this group show that the numbers of satisfactorily delivered, closed or failed, and renegotiated projects have moved by around 35%, 18%, and 43% respectively [2].

To mitigate this situation, many international project management schools like Project Management Institute (PMI) with its PMBOK standard [3], ISO 21500 standard developed by the International Standards Organization (ISO) [4], and CMMI proposed by Software Engineering Institute [5] have developed guidelines and recommendations for project managers. However, these guides are very generic and frequently need to be personalized to be applied in different contexts. Besides, the techniques they propose do not define clearly how to deal with uncertainty, impression, and incomplete information [6]. In other words, these guidelines are not enough to solve the problems and limitations still presented in project management. Nevertheless, many of these problems are associated with the decision-making process in project management.

In this sense, different authors have referred to decision making as an essential process in project management [7], and others like Trumper et al. [8] defined the project management as the art of making right decisions. Cunha et al. [9] stated that project success depends on how software project managers deal with the problems and make decisions.

In project management, the main decision-making process occurs in project's cuts, see Figure 1. In this respect, decisions should be made out of a multi-objective approach, which includes a diagnosis to know the real state of the ongoing project, making corrective decisions in order to mitigate delays and deviations, and finally predict the project evolution according to the decisions made. It is also important in project management to consider an adequate balance between time, cost, and quality [10].

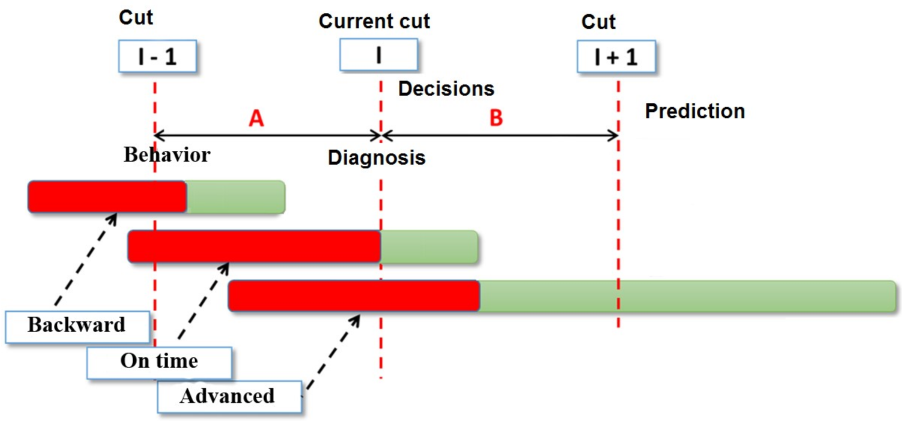

Figure 1. Decision making by cuts in projects.

Generally, the decision-making process in project management involves multiple stakeholders with different degrees of expertise; hence, a consensus process should be carried out in order to reach a generally accepted opinion. Besides, experts on many occasions need to express indeterminacy relationships existing between concepts.

From the previous analysis, it is perceived that there are opportunities to improve the guidelines and recommendations provided by international Standards and schools for project management through the use of Soft Computing techniques. Fuzzy Cognitive Maps (FCMs) is a suitable tool for the representation and simulation of dynamic and complex systems with the presence of uncertainty and incomplete information [11].

FCMs were introduced by Kosko in 1986 [12] as an extension of the Cognitive Maps Theory developed by Axelrod in 1976 [13]. In FCMs, there are three possible types of relations between concepts: positive relation, negative relation, or non-existence of relations, see Figure 2. The widespread use of Fuzzy Cognitive Maps is due to its features of simplicity, adaptability, and capability of dealing with uncertainty, vagueness and incomplete information, besides their capacity to represent feedback relationship [14]. For this reason, FCMs have been widely employed for modeling complex and dynamic systems such as project management [15].

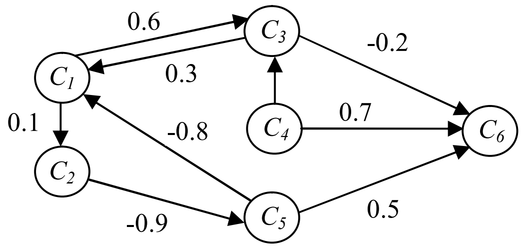

Figure 2. Representation of a basic Fuzzy Cognitive Map.

Some authors have focused on IT projects, such is the case of Rodriguez-Repiso, Setchi, and Salmeron who used FCMs in [16] to model critical success factors and the relationships between them. Following this line, Salmeron et al. [17] presented a model for predicting the impact of risks in ERP maintenance projects. Leyva et al. [18] presented a model to select IT projects using the business modeling and FCMs. Zare Ravasan et al. [19] proposed a dynamic model based on FCMs to identify the most important ERP projects failure factors.

In construction projects, Ahn et al. [20] used FCMs for the prediction of labor productivity. Bağdatlı, Akbıyıklı, and Papageorgiou developed in [21] a decision-making model based on FCMs for the cost-benefit analysis, taking into account the risk analysis. Khanzadi et al. [22] presented an FCM model for dynamic analysis of changes in construction projects.

Regarding risk analysis, Jamshidia et. al [23] had developed an FCM model for risk analysis in maintenance outsourcing projects, and in another work [24] he proposed the use of FCM to support decision making for the dynamic risk assessment in project management, taking into account the probability of occurrence and the impact of each risk factor. Other authors following different approaches developed models based on FCMs for stakeholders evaluation [25], and project schedule overrun prediction [26].

From the previous revision, it was perceived that the mentioned models based on traditional FCMs in project management do not consider, despite its importance, the indeterminacy between concepts. Indeterminacy is frequently presented in the decision-making process [27], mainly, when experts are not sure if one factor may or may not impact another.

However, traditional FCMs have the limitation of not considering the indeterminacy relations between concepts [28]. In this respect, Smarandache in 1995 introduced the Neutrosophic Theory, making possible the representation of indeterminacy [29]. Such characteristic is helpful for modeling decision-making problems [30] since it considers all aspects of decision such as agree, not sure, and disagree [31]. For this reason, Neutrosophic Logic has been widely used in decision-making environments [32], [33], [34].

An application of this theory in FCMs is the Neutrosophic Cognitive Maps (NCMs) developed by Vasantha & Smarandache in 2003 [35]. NCMs overcomes the drawback presented in traditional FCMs of not representing the indeterminacy relations between concepts.

However, NCMs have been little applied in project management. Bhutani et al. [36] used NCMs for the identification and evaluation of success factors in IT projects. Betancourt, Leyva, and Pérez proposed in [37] a new method for modeling risk interdependencies ing projects. In another context, Pramanik and Chackrabarti carried out in [38] a study to assess the impact of problems faced by construction workers in West Bengal, India, based on NCMs to find its solutions. Following this line, Monda and Pramanik modeled in [39] the problems of Hijras in West Bengal, India, using NCM.

It was noticed that in the previous papers, the linguistic evaluations are not represented by neutrosophic sets, but by a single number which represents the degree of causality between two concepts or by the letter *I* to indicate the indeterminacy, without sufficiently exploiting all the potentialities of neutrosophic sets.

In general, many of the aforementioned articles about decision making in project management, only make a diagnosis without making decisions or predictions. In some of them, the map is constructed with the help of multiple experts without proposing any method for the consensus process. On the other hand, in the majority of these papers, the concepts of time, cost, and quality were not properly considered.

This article aims at proposing a model based on neutrosophic cognitive maps for making comprehensive decisions out of a multi-objective approach (diagnosis, decision, and prediction) during projects execution, considering the indeterminacy relations between concepts. In the proposed model, experts' evaluations are expressed by neutrosophic sets, taking into account an adequate balance between cost, time, and quality.

The remaining of the paper is structured as follows: Section 2 describes preliminary concepts and notation of Neutrosophic theory. In section 3, the neutrosophic cognitive map for decision making in project management is introduced. In section 4, authors compare the results of project management decisions by using a traditional fuzzy cognitive map with the neutrosophic cognitive map. The paper ends with conclusions in Section 5.

2 Preliminary concepts and notation

The traditional fuzzy set introduced by Zadeh in 1965 [40] uses one real value $\mu A(x) \in [0,1]$ to represent the grade of membership of fuzzy set A defined on universe X.

Definition 1. A fuzzy set consists of two elements, a linguistic label, and a membership function μ. Function μ of X is a mapping from the set X to the unit interval $\mu : X \rightarrow [0, 1]$, where μ (x) is called a degree of membership.

An example of a fuzzy set is represented by the triangular functions as shown in Figure 3. Let A be a fuzzy set represented by the following function of membership:

$$\mu_A(x) = \begin{cases} 0, x < a \\ \dfrac{x-a}{b-a}, a \le x \le b \\ \dfrac{c-x}{c-b}, b \le x \le c \\ 0, x > c \end{cases}$$

High
$\mu_A(x)$

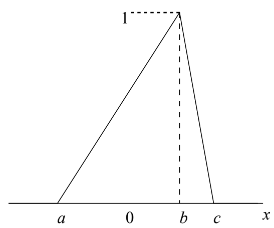

Figure 3. Fuzzy set "High" based on triangular membership $\mu_A(x)$ with values (a, b, c) and its graphical representation.

In this case, a triangular number (a, b, c) represents the membership function. However, fuzzy set only considers the membership degree of an element x of a fuzzy set *A* and fails to consider falsity-membership [41].

In 1986, Atanassov introduced the intuitionistic fuzzy sets (IFS) [42] which is a generalization of fuzzy sets. The intuitionistic fuzzy sets consider both truth-membership $\mu_A(x)$ and falsity-membership $f_A(x)$, with $\mu_A(x), f_A(x)$

$\in [0,1]$ and $0 \leq \mu_A(x)+f_A(x) \leq 1$. Intuitionistic fuzzy sets can only handle incomplete information but not the indeterminate and inconsistent information [43].

An alternative that extends the theory of fuzzy logic and helps to improve the treatment of uncertainty is the introduction of concepts of neutrality dealing with neutrosophic numbers. Neutrosophy logic was introduced by Smarandache in 1995 [44].

Definition 2. Let *M* be a neutrosophic set in universe *X* characterized by a quintuple $(Label, X, \mu_M(x), \tau_M(x), \sigma_M(x))$ where: *Label* is a linguistic term which represents the name of set, X represents the universe of discourse, $\mu_M(x) \in [0,1]$ represents a membership function, $\tau_M(x) \in [0,1]$ represents a indeterminacy-membership function, and $\sigma_M(x) \in [0,1]$ represents a falsity-membership function, where $0 \leq \mu_M(x) + \tau_M(x) + \sigma_M(x) \leq 3$.

This definition implies that each value of the domain $x \in X$ when evaluated in neutrosophic set *M*, such that *M(x)* returns the value $(\mu_M (x), \tau_M (x), \sigma_M (x))$ where the first component represents the membership degree of the value x to the set M, the second component represents the indetermination degree of the value x to the set *M*, and the third component means the non-membership degree of the value *x* to the set *M*.

Single Valued Neutrosophic Set (SVNS) is an instance of a neutrosophic set which can be used in real scientific and engineering applications, see definition 3.

Definition 3. Let *X* be a space of points (objects), with a generic element in *X* denoted by *x* represents a single valued neutrosophic number (SVN) and is characterized by a vector *(V, I, F)* where *V* indicates truth-value, *I* indeterminacy-value, and *F* falsity-value.

In order to extend fuzzy logic definitions with neutrosophic theory, authors include a definition 4 of neutrosophic linguistic variables.

Definition 4. A neutrosophic linguistic variable consists of quintuple *(Var, T(x), X, G, M)* in which *Var* is the name of the variable, *T(X)* is the set of linguistic terms associated with the variable, *X* is the universe of discourse, *M* is a semantic rule which associates to each linguistic value $z \in T(x)$ its meaning *M(z)*, where *M(z)* denotes a neutrosophic set in *X*, see definition 2, and *G* is the set of syntactic rules for the generation of compound terms, based on the atomic terms that make up the sentences that give place to each linguistic value.

$$\mu_A(x) = \begin{cases} (x-a)u_A/(b-a) & (a \leq x < b) \\ u_A & (x = b) \\ (c-x)u_A/(c-b) & (b < x \leq c) \\ 0 & otherwise \end{cases}$$

$$\tau_A(x) = \begin{cases} \big(b-x+v_A(x-a)\big)/(b-a) & (a \leq x < b) \\ r_A & (x = b) \\ \big(x-b+v_A(c-x)\big)/(c-b) & (b < x \leq c) \\ 1 & otherwise \end{cases}$$

$$\sigma_A(x) = \begin{cases} \big(b-x+f_A(x-a)\big)/(b-a) & (a \leq x < b) \\ f_A & (x = b) \\ \big(x-b+f_A(c-x)\big)/(c-b) & (b < x \leq c) \\ 1 & otherwise \end{cases}$$

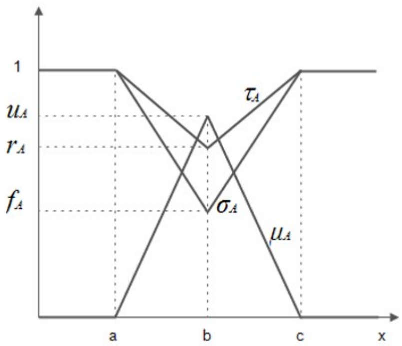

Figure 4. Neutrosophic set, $\mu_A(x)$ membership function, $\tau_A(x)$ indeterminacy-membership function and $\sigma_A(x)$ falsity-membership function.

Other important concept is a T-norm and S-Conorms functions. Let *T* be a T-norm function and *S* a co-norm function:

TNorma funtion $T: [0,1] \times [0,1] \rightarrow [0,1]$ for example (min), with following properties:

- $T(a, b) = T(b, a)$ *Commutativity*
- $T(T(a, b), c) = T(a, T(b, c))$ *Associativity*
- *Si* $a \geq b$ *y* $c \geq d$ *then* $T(a, c) \geq T(b, d)$ *Monotony*
- $T(a, 1) = a$ *Neutro element*

Conorma funtion $S: [0,1] \times [0,1] \rightarrow [0,1]$ for example (max), with following properties:

- $S(a, b) = S(b, a)$ *Commutativity*
- $S(S(a, b), c) = S(a, S(b, c))$ *Associativity*
- *Si* $a \geq b$ *y* $c \geq d$ *then* $S(a, c) \geq S(b, d)$ *Monotony*
- $S(a, 0) = a$ *Neutro element*

In order to operate with single valued triangular neutrosophic numbers, Şahin, Kargın, and Smarandache in [45] describe operations as follows:

Let A_1 be represented by number $((a_1, b_1, c_1); u_A, r_A, f_A)$ and B_2 is represented by number $((a_2, b_2, c_2); u_B, r_B, f_B)$ with T as T-norm and S_1, S_2 two co-norms then:

Sum: $A_1 (+) B_2= ((a_1+a_1 , b_1+b_2, c_1+c_2); T(u_A, u_B), S_1(r_A , r_B), S_2(f_A, f_B))$ (1)

Difference: A_1 (-) B_2= $((a_1\text{-}c_2,\ b_1\text{-}b_2,\ c_1\text{-}a_2);\ T(u_A, u_B),\ S_1(r_A, r_B),\ S_2(f_A, f_B))$ (2)

Product: A_1 (*) B_2= $((a_1a_2,\ b_1b_2,\ c_1c_2);\ T(u_A, u_B),\ S_1(r_A, r_B),\ S_2(f_A, f_B))$ if $c_1, c_2 > 0$ (3)

A_1 (*) B_2= $((a_1c_2,\ b_1b_2,\ c_1a_2);\ T(u_A, u_B),\ S_1(r_A, r_B),\ S_2(f_A, f_B))$ if $c_1 < 0$, $c_2 > 0$ (4)

A_1 (*) B_2= $((c_1c_2,\ b_1b_2,\ a_1a_2);\ T(u_A, u_B),\ S_1(r_A, r_B),\ S_2(f_A, f_B))$ if $c_1, c_2 < 0$ (5)

Division: A_1 (/) B_2= $((a_1/c_2,\ b_1/b_2,\ c_1/a_2);\ T(u_A, u_B),\ S_1(r_A, r_B),\ S_2(f_A, f_B))$ if $c_1, c_2 > 0$ (6)

A_1 (/) B_2= $((a_1/a_2,\ b_1/b_2,\ c_1/c_2);\ T(u_A, u_B),\ S_1(r_A, r_B),\ S_2(f_A, f_B))$ if $c_1 < 0$, $c_2 > 0$ (7)

A_1 (/) B_2= $((c_1/a_2,\ b_1/b_2,\ a_1/c_2);\ T(u_A, u_B),\ S_1(r_A, r_B),\ S_2(f_A, f_B))$ if $c_1, c_2 < 0$ (8)

Product by scalar: $kA_1 = ((ka_1,\ kb_1,\ kc_1);\ u_A,\ r_A,\ f_A)$ if $k > 0$ (9)

$kA_1 = ((kc_1,\ kb_1,\ ka_1);\ u_A,\ r_A,\ f_A)$ if $k < 0$ (10)

Inverse: $(A_1)^{-1} = ((1/c_1,\ 1/b_1,\ 1/a_1);\ u_A,\ r_A,\ f_A)$ with $A_1 \neq (0,0,0)$ (11)

3 A Neutrosophic Cognitive Map for decision making in Project Management

In this section, the model based on a NCMs for making comprehensive decisions out of a multi-objective approach (diagnosis, decision, and prediction) during projects execution, considering the indeterminacy relations between concepts is proposed. The main characteristics of the model are:

- It is based on expert triangulation methods to avoid high dependence of one expert and mitigate the experts slant.
- Introduces a new representation of neutrosophic cognitive maps by including neutrosophic sets into maps connections.
- Manages two types of indeterminacy, the first one is when the value of some indicators is unknown and the second one is when experts declare indeterminacy between two concepts, see Figure .
- Takes into account an adequate balance between cost, time, and quality.
- Provides solutions for diagnosis, decision, and prediction simultaneously.
- Uses computing with word techniques to aggregate the individual cognitive maps.

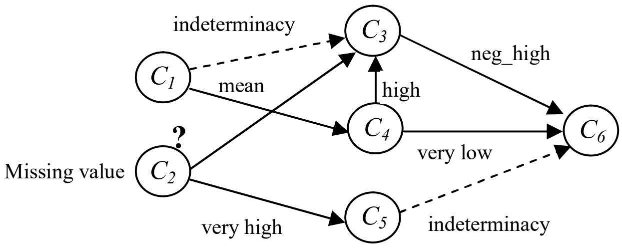

Figure 5. Neutrosophic cognitive map with indeterminacy relationships between concepts

The proposed model consists of two algorithms:

Algorithm PM_NCM 1: the construction of the neutrosophic cognitive map

1. *Defining the project management's problems, context, and particularities.*
2. *Selecting k experts in project management.*
3. *Evaluating the expertise degree for each expert, by using co-evaluation methods and computing with word techniques (t-tuples technique* [46]*).*

   for each Expert$_i$

   for each Expert$_j$: $i \neq j$

   Expert$_i$ = Aggregate(Expert$_i$, Evaluation (Expert$_{ji}$)) // Expert$_{ji}$ represents evaluation of expert j over expert i.

   end for

   end for
4. *Establishing indicator, diagnosis, decision, and prediction concepts associated with project management problems by using brain storming techniques (carrousel style).*
5. *Building the individual maps for each expert*

   For each Expert$_i$

   QueueMaps ← Expert$_i$ builds a map by considering identified concepts in the previous step. Each map edge is represented by a neutrosophic set represented in Table 1

End for

6. *Ncm = AggregateMaps(QueueMaps) //Finally getting a map, where each map's node represents one of the following elements: a cause of project delay, a decision, a prognosis.*

In the proposed model, five experts were selected, who identified the following concepts for the construction of the individual maps:

- Indicators: these reflect the current state of the project under evaluating, they can be expressed in different domains, numerical, linguistic or interval. the Indicators are calculated by project management systems and they are associated with each project management knowledge area such as performance, quality, and logistic. For the construction of the individual maps, experts have identified the following indicators concepts:
  - SPI: scheduling performance indicator.
  - CPI: cost performance indicator.
  - EFPI: efficacy performance indicator, represents the quality of the project.
  - LPI: logistic performance indicator.
  - DQPI: data quality performance indicator, representing the quality of data in project management information system.
  - HRCPI: human resource correlation performance indicator, which represents the correlation between the plan and real-time in human resource scheduling.
  - HREPI: human resource efficacy performance indicator, which represents the efficacy of human resources.
  - HREFI: human resource efficiency performance indicator.
- Diagnosis concepts reflect the causes of project difficulties. In order to improve the project performance, these elements should be identified carefully, since they have a crucial impact on projects decisions. The following factors were selected by experts as diagnosis concepts:
  - F1. Defects quality control.
  - F2. Defects tasks control.
  - F3. Defects HR efficiency: defects on human resource efficiency.
  - F4. Defects HR efficacy: defects on human resource efficacy.
  - F5. Defects on scheduling.
  - F6. Defects on logistic.
  - F7. Defects on cost management.
  - F8. Defects on cost scheduling.
- Decision concepts represent the possible decisions to be made in order to correct project deviation and they are mainly related to the causes of the problems. Decision concepts were identified as follows:
  - D1. Increase quality control.
  - D2. Leave the project manager.
  - D3. Increase control milestones.
  - D4. Rewards HR: rewards to human resources.
  - D5. Penalize HR: penalize to human resources.
  - D6. New HR contracts: contracts more human resources.
  - D7. Rescheduling.
  - D8. Extra hours scheduling.
  - D9. Improve logistics management.
  - D10. Decrease cost.
  - D11. Rescheduling scope.
- Prediction concepts are identified to know what will happen to the project if a certain decision is made. Experts defined the following prediction concepts:
  - P1. Improve quality.
  - P2. Recover delays.
  - P3. Improve cost balance.
  - P4. Increase perceived quality.
  - P5. Increase HR motivation: increase human resource motivation.
  - P6. Decrease quality.
  - P7. Increase delays.
  - P8. Increase costs defects.
  - P9. Increase scope defects.
  - P10. Decrease HR motivation: decrease human resource motivation.

In the algorithm 1, each expert builds his own map establishing his preferences by using the neutrosophic sets defined in Table 1. The relations are represented with positive influence, negative influence or without influence (indeterminacy). Experts describe their preferences by using the following linguistic terms *LBTL = {negative highest, negative very high, negative high, negative mean, negative low, negative very low, none, very low, low, mean, high, very high, highest, indeterminacy}*

Linguistic terms	**Neutrosophic sets based on triangular functions**
neg_highest	(-0.83, -1.0, -1.0, 0.95, 0.45, 0.15)
neg_very high	(0.67, -0.83, -1.0, 0.95, 0.45, 0.15)
neg_high	(-0.5, -0.67, -0.83, 0.95, 0.45, 0.15)
neg_mean	(-0.33, -0.5, -0.67, 0.95, 0.45, 0.15)
neg_low	(-0.17, -0.33, -0.5, 0.95, 0.45, 0.15)
neg_very low	(0, -0.17, -0.33, 0.95, 0.45, 0.15)
none	(0, 0.07, 0.17, 0.95, 0.45, 0.15)
very low	(0, 0.17, 0.33, 0.95, 0.45, 0.15)
low	(0.17, 0.33, 0.5, 0.95, 0.45, 0.15)
mean	(0.33, 0.5, 0.67, 0.95, 0.45, 0.15)
high	(0.5, 0.67, 0.83, 0.95, 0.45, 0.15)
very high	(0.67, 0.83, 1.0, 0.95, 0.45, 0.15)
highest	(0.83, 1.0, 1.0, 0.95, 0.45, 0.15)
indeterminacy	(0, 0, 0, 0.1, 0.9, 0.1)

Table 1. Neutrosophic sets to represent map relationships.

Algorithm PM_NCM 2: the simulation process of the neutrosophic cognitive map

Inputs
ncm: neutrosophic cognitive map
maxepoch: max number of epoch
indicators: means project indicators to evaluate project during cut

1. *Initialize(prediction_memory)*
2. *continue_criteriom = true*
3. *diagnosis = do_initial_diagnosis(indicator, ncm)*
4. *epoch = 1*
5. *while continue_criteriom && epoch <= maxepoch do*
6. *decisions = do_aggregate_svns(diagnostic, decisions, ncm)*
7. *prediction = do_aggregate_svns(decisions, prediction, , ncm)*
8. *continue_criteriom = do_compare_distance (prediction_memory, prediction, epsilon)*
9. *if continue_criteriom*
10. *prediction_memory = prediction*
11. *diagnosis = do_aggregate_svns(prediction, diagnosis, ncm)*
12. *end if*
13. *epoch += 1*
14. *end while*
15. *Sort diagnosis, decisions, prediction*
16. *Return diagnosis, decisions, prediction*

In the simulation process, users can exploit the map, using it to make comprehensive decisions. The process is started with the activation of some of the map's indicator nods during the execution of a project, triggering off the activation of the rest of the map's concepts (diagnosis, decisions, and predictions). The simulation process is carried out by using equations (12) and (13), where W_{ij} represents a neutrosophic set, not a single value, such is the case of traditional FCMs or other neutrosophic cognitive maps' approaches. In order to operate with neutrosophic sets between neutrosophic sets and numbers, the equations (2), (3), (4), (5), (6), (7), (8), (9), (10) and (11) were used.

$$A_i(epoch+1) = f\left(A_i(\text{epoch}) + \sum_{i=1}^{n} \text{W}_{\text{ji}} \cdot \text{A}_{\text{j}}(\text{epoch}) \right) \quad (12)$$

The hyperbolic tangent function is used in order to force the concept value to be monotonically mapped into the range [-1,1] [47].

$$S_i(W_{ij}) = \tanh(\lambda W_{ij}) = \frac{e^{\lambda W_{ji}} - e^{-\lambda W_{ji}}}{e^{\lambda W_{ji}} + e^{-\lambda W_{ji}}} \quad (13)$$

4 Analysis and discussion.

To validate the proposed model, the authors selected the database DPME5 from the Research Database Repository for Project Management provided by UCI [48]. This database contains 6115 records with 8 attributes. All attributes are represented by real values in [0, 1] interval. This database contains 3175 projects evaluated as "bad performance", 607 project evaluated as "regular performance", and 2333 projects evaluated as "correct performance".

Authors implemented two cognitive maps. The first map "PM_FCM" is based on a traditional fuzzy cognitive map FCM for decision making in project management. The Map was constructed by means of the concepts and relations illustrated in tables 2.3.4.6.

	Defects quality control F1	Defects tasks control F2	Defects HR efficiency F3	Defects HR efficacy F4	Defects on scheduling F5	Defects on logistic F6	Defects on cost management F7	Defects cost scheduling F8
SPI	very low	very high	very high	low	very high	mean	very low	mean
CPI	very low	very high	very high	none	mean	high	very high	very high
EFPI	highest	mean	none	very high	mean	none	none	none
LPI	low	low	very low	very low	low	very high	high	mean
DQPI	high	mean	very low	high	none	none	low	none
HRCPI	very low	very low	high	low	very high	very low	very low	very low
HREPI	very high	mean	very low	very high	none	none	none	none
HRFPI	very low	high	very high	very low	high	very low	low	very low

Table 2. Initial diagnosis: the relations between indicators and diagnosis concepts.

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
F1	highest	low	mean	very low	low	very low	low	low	very low	very low	mean
F2	mean	highest	highest	low	low	very low	mean	low	very low	very low	mean
F3	very low	very high	mean	very high	very high	high	mean	high	low	low	mean
F4	very high	high	mean	very high	very high	low	mean	mean	low	very low	high
F5	mean	high	highest	low	low	low	very high	low	mean	low	high
F6	low	very high	low	low	very low	very low	mean	very low	very high	low	mean
F7	low	low	highest	very low	very low	very low	mean	very low	high	very high	mean
F8	very low	highest	low	very low	very low	very low	very high	very low	mean	mean	very high

Table 3. Represents the decision process through relations between diagnosis and decisions concepts.

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
D1	very high	low	low	very high	very low	neg_very high	neg_mean	mean	neg_highest	low
D2	mean	mean	none	mean	mean	low	neg_high	very low	very low	low
D3	high	very high	high	mean	low	neg_very high	very low	none	low	low

D4	high	high	mean	high	very high	neg_high	neg_very high	very high	low	very low
D5	mean	mean	mean	mean	low	mean	high	neg_very high	mean	mean
D6	low	high	low	none	low	very high	mean	neg_highest	very high	low
D7	high	very high	high	low	mean	none	neg_mean	low	low	low
D8	mean	very high	high	mean	low	none	neg_very high	neg_low	very low	mean
D9	mean	high	very high	mean	low	very low	low	neg_very low	low	low
D10	none	low	very high	low	low	mean	very low	neg_highest	low	low
D11	high	very high	high	low	mean	low	neg_very high	low	mean	low

Table 4. Represents the prediction process through relations between decisions and prediction concepts, used by PM_FCM model.

	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**
D1	very high	neg_low	low	very high	very low	neg_very high	neg_mean	mean	neg_highest	low
D2	mean	mean	indeterminacy	mean	mean	low	neg_high	very low	very low	low
D3	high	very high	high	indeterminacy	low	neg_very high	very low	none	low	low
D4	high	high	indeterminacy	high	very high	neg_high	neg_very high	very high	low	very low
D5	mean	mean	mean	mean	low	mean	high	neg_very high	mean	mean
D6	low	high	low	indeterminacy	low	very high	mean	neg_highest	very high	low
D7	high	very high	high	low	mean	indeterminacy	neg_mean	low	low	low
D8	mean	very high	high	mean	low	indeterminacy	neg_very high	neg_low	very low	mean
D9	mean	high	very high	mean	low	very low	low	neg_very low	low	low
D10	indeterminacy	low	very high	low	low	mean	very low	neg_highest	low	low
D11	high	very high	high	low	mean	low	neg_very high	low	mean	low

Table 5. Represents the prediction process through relations between decisions and prediction concepts, used by PM_NCM model.

	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**
P1	very low	low	low	very low	low	low	very low	low
P2	none	very low	very low	low	very low	very low	very low	very low
P3	none	very low	very low	very low	very low	very low	very low	very low
P4	very low	mean	very low	low	very low	very low	very low	very low
P5	very low	very low	very low	low	low	low	low	low
P6	highest	highest	low	very high	mean	mean	low	low
P7	low	very high	very high	high	very high	high	high	high
P8	very low	high	high	low	mean	mean	very high	very high
P9	highest	very high	mean	highest	high	low	high	mean
P10	high	highest	very high	highest	high	mean	mean	mean

Table 6. Represents the prediction process through relations between prediction and diagnosis concepts.

The second map "PM_NCM" is based on a neutrosophic cognitive map NCM for decision making in project management. The Map was constructed by means of the concepts and relations illustrated in tables 2.3.5.6, and according to the algorithms (1) and (2) explained previously, see Figure 6.

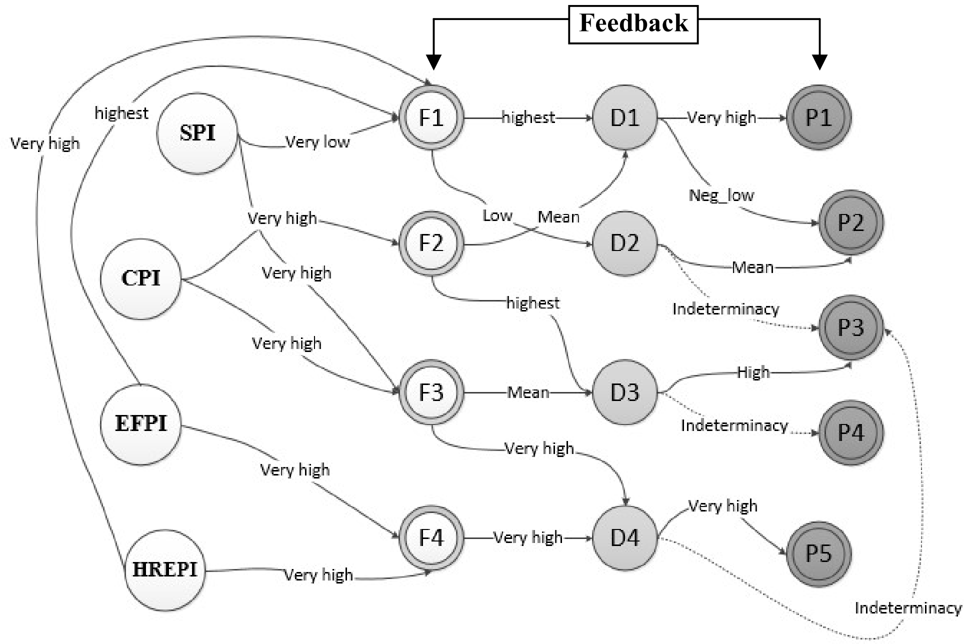

Figure 6. Partial representation of the aggregated neutrosophic cognitive map "PM_NCM".

The relationships between the maps' concepts are shown in the following tables: Table 2 represents the initial diagnosis process of both maps, which connects the indicator and diagnosis nods. Table 3 represents the decision process of both maps through the connection between diagnosis and decision nods. Tables 4 represents the prediction processes in PM_FCM through the connection between decision and prediction nods whereas table 5 represents the same process in PM_NCM, in which the indeterminacy relations were considered, see Figure 6. Table 6 represents the prediction process of both maps through the connection between prediction and diagnosis nods, in which the feedback relationships is expressed.

The two models were compared considering efficiency and efficacy. Concerning efficiency, PM_FCM obtained better results, PM_FCM was 6.9 times faster than PM_NCM. The model PM_FCM evaluated the 6115 records in 9.8 sec as an average, while PM_NCM evaluated the same records in 63.22 sec.

In regards to the indeterminacy relations between concepts, the simulation results showed that PM_NCM have the capability to represent efficiently the indeterminacy relations, in contrast with PM_FCM. Hence, PM_NCM is better than PM_FCM when it comes to dealing with uncertainty, missing values, and incomplete information.

In terms of efficacy, the authors of this paper introduced a metric success C to evaluate the two models as follows: Let ρ be a model, a metric success C is defined in (14) as a percentage of records classified as experts do, where n represents the number of records. This equation was applied in order to evaluate the result of diagnosis, decisions, and prediction of both PM_FCM and PM_NCM.

$$C(\rho) = 100 \frac{\sum_{i=1}^{n} S_i(\rho)}{n} \quad (14) \qquad S_i(\rho) = \begin{cases} 0 & \text{if not coincidence with experts} \\ 1 & \text{if coincidence with experts} \end{cases}$$

The authors of this paper consider model's efficacy metrics to be the capacity to detect true indeterminacy records. In this sense, this paper redefines precision P (15) and recalls R (16) metrics to evaluate the models capacity to detect the indeterminacy as follows:

$$P(\rho) = 100 \frac{|Z(\rho) \cap I|}{Z(\rho)} \quad (15) \qquad R(\rho) = 100 \frac{|Z(\rho) \cap I|}{I} \quad (16)$$

Let ρ be a model, $Z(\rho)$ is the set of records that a model ρ detects with high indeterminacy and I is the set of records with true high indeterminacy.

Algorithm	PM_FCM	PM_NCM
Successful diagnosis	85%	95,33
Successful decision	93%	100%
Successful prediction	84,1%	94,45%
Precision on indeterminacy detection (diagnosis)	-	60%
Precision on indeterminacy detection (decisions)	-	75%
Precision on indeterminacy detection (prediction)	-	72%
Recall on indeterminacy detection (diagnosis)	-	100%
Recall on indeterminacy detection (decisions)	-	100%
Recall on indeterminacy detection (prediction)	-	95%

Table 7. The comparison results between PM_FCM and PM_NCM.

Respecting successful evaluation in diagnosis, decision, and prediction, PM_NCM reported better results than PM_FCM. Regarding precision on indeterminacy detection (P) and recall of indeterminacy detection (R), PM_NCM reported good results. PM_FCM did not report any results since it does not consider the indeterminacy relations between concepts.

5. Conclusions

In this paper, we proposed a new decision-making model based on Neutrosophic Cognitive Maps (NCMs) for making comprehensive decisions from multi-objective approach (diagnosis, decisions, and prediction), considering an adequate balance between time, cost, and quality, during the execution of many projects simultaneously. The suggested model overcomes the drawback of not representing indeterminacy relations between concepts presented in traditional Fuzzy Cognitive Maps FCMs. Besides, the NCM model constitutes a more realistic and robust tool to decision support through considering all aspects of the decision-making process and dealing efficiently with uncertainty, missing values, and incomplete information. The suggested model was compared with a traditional FCM-based model, showing its superiority regarding successful evaluation in diagnosis, decision, and prediction; and when it comes to dealing with uncertainty, missing values, and incomplete information. The traditional FCM-based model provided better results in respect to efficiency. In the future, we will extend the application of the proposed model to other disciplines, mainly, in medical diagnosis.

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Received: September 18, 2018. Accepted: October 10, 2018