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Evaluation of factors that affect cognitive deterioration in older adults under a neutrosophic cognitive maps approach

Lorenzo Jovanny Cevallos Torres [1], Maikel Yeladi Leyva Vázquez [2], and Florenitn Smarandache[3]

[1] Universidad de Guayaquil, Facultad de Ciencias Matemáticas y Físicas, Guayaqui, Ecuador, Email: lorenzo.cevallost@ug.edu.ec
[2] Universidad de Guayaquil, Facultad de Ciencias Matemáticas y Físicas, Guayaqui, Ecuador, Email: maikel.leyvav@ug.edu.ec
[3] Prof. Florentin Smarandache, PhD, Postdoc, Mathematics Department, University of New Mexico, Gallup, NM 87301, USA, Email: smarand@unm.edu

Abstract. Due to the high rate of senescence and conditions associated with this intrinsic process, it has been necessary to carry out this research in order to determine the factors that affect the cognitive deterioration of older adults, discovering an environment of uncertainty and imprecision that supports the existence of the aforementioned cognitive decline. The research opens doors to the knowledge of new concepts and thus helps to explain this phenomenon using a non-classical logic such as neutrosophic logic with neutrosophic sets verifying the degrees of membership, non-membership and indeterminacy, the same one that helps us for making decisions through the association of reliable criteria. The neutrosophic logic was chosen for reasons of considering it a useful tool that models the way in which a decision is reached, the reliability that it provides at the time of producing results. We implement its extension in the neutrosophic cognitive maps modeling the factors with the purpose of a differential diagnosis.

Keywords: Cognitive Impairment, Uncertainty, Imprecision, Decision Making, Neutrosophic Logic, Neutrosophic Sets, Neutrosophic Cognitive Maps.

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1 Introduction

Currently, there is a high rate of older adults and it is estimated that for later years it will increase worldwide, this entails a series of conditions, illnesses or alterations in health status that will spread as age advances in people, among them is memory problems considered as a condition called cognitive impairment. Medical care usually obtains a diagnosis of cognitive impairment if they find different criteria such as: defective memory complaint, normal activities of daily living, general cognitive function normal, abnormal memory function for age, and absence of dementia ([1]).

It has been verified that causal risk factors before and after 65 years old would be associated with a high risk index of cognitive deterioration. Apart from the main factor of age, there is evidence of a relationship between other risk factors such as cardiovascular and genetic factors that could be related to cognitive decline after 65 years old ([2]). This review focuses on the identification of frequent cognitive deterioration in the age group between 65 and older with very important effects, thus perceiving the importance of a more in-depth study and analysis that deals with the associated factors in cognitive deterioration in older adults, [3,4].

The factors were determined by classification as: Age, in which it was classified as Older Adult (65-74 years) - Mature Older Adult (75-84 years) -Old Man (85+), Social Factor that includes (Social Interaction-Educational Level- Occupation-Social Isolation) ([5]), Psychological Factor that includes (Social Illnesses-Depression-Cultural Level-Physical Activity-Drug Use) ([6]) and finally the Biological Factor in which the sub-factors (Genetic Polymorphism-Cardiovascular Disease-Diabetes-Nutrition) ([7]) were analyzed, thus containing each sub-factor.

Based on this, it is complex to determine at what level of cognitive impairment the older adult is, which is why the use of artificial intelligence tools can deal with the uncertainty of a problem, for this there is neutrosophic logic that is very helpful within of the medical field allowing to demonstrate favorable results ([8,9]), through uncertainty with imprecision of data. In this research, a Neutrosophic approach will be used with neutrosophic sets, for the assessment of each factor that intervenes and discriminating causalities by presenting each case under rules of uncertainty, and finally defining and using Neutrosophic Cognitive Maps that serve to model a feedback system representing causal reasoning ([9]). In the process of analyzing cognitive impairment, neutrosophic sets were used,

assessing the input variables in which it was defined as the factors whose result allows us to identify the level of cognitive impairment ([3]).

This paper is divided into the following sections; Preliminary section contains the main concepts of Neutrosophic Sets and Neutrosophic Cognitive Maps (NCM) ([10-15]). The Results section is dedicated to presenting the results of applying NCM techniques to the problem of cognitive impairment in older adults. The article ends with the conclusions.

2 Preliminaries

This section is dedicated to expose the main concepts of Neutrosophic sets and Neutrosophic Cognitive Maps.

Definition 1: ([9]) Let X be a universe of discourse. A *Neutrosophic Set* (NS) is characterized by three membership functions, $u_A(x), r_A(x), v_A(x) : X \rightarrow \,]^-0, 1^+[$, which satisfy the condition $^-0 \leq \inf u_A(x) + \inf r_A(x) + \inf v_A(x) \leq \sup u_A(x) + \sup r_A(x) + \sup v_A(x) \leq 3^+$ for all $x \in X$. $u_A(x), r_A(x)$ and $v_A(x)$ denote the membership functions of truthfulness, indetermination and falseness of x in A, respectively, and their images are standard or non-standard subsets of $]^-0, 1^+[$.

NS are useful only as a philosophical approach, so *Single-Valued Neutrosophic Set* is defined for guarantying the applicability of neutrosophy, see Definition 2.

Definition 2: ([9]) Let X be a universe of discourse. A *Single-Valued Neutrosophic Set* (SVNS) A on X is an object of the form:

$$A = \{\langle x, u_A(x), r_A(x), v_A(x)\rangle : x \in X\} \quad (1)$$

Where $u_A, r_A, v_A : X \rightarrow [0,1]$, which satisfy the condition $0 \leq u_A(x) + r_A(x) + v_A(x) \leq 3$ for all $x \in X$. $u_A(x), r_A(x)$ and $v_A(x)$ denote the membership functions of truthfulness, indetermination and falseness of x in A, respectively. For convenience a *Single-Valued Neutrosophic Number* (SVNN) will be expressed as $A = (a, b, c)$, where $a, b, c \in [0,1]$ and satisfies $0 \leq a + b + c \leq 3$.

Neutrosophic Logic (NL) extends fuzzy logic. A proposition P is characterized by three components; see [16]:

$$NL(P) = (T,I,F) \quad (2)$$

Where component T is the degree of truthfulness, F is the degree of falsity and I is the degree of indetermination. T, I, and F belong to the interval [0, 1], and they are independent each other.

A *neutrosophic number* is formed by the algebraic structure a+bI, where I = indetermination. In the following we formally describe some important concepts.

Definition 3: ([17]) Let R be a ring. The *neutrosophic ring* $\langle R \cup I\rangle$ is also a ring, generated by R and I under the operation of R, where I is a neutrosophic element that satisfies the property $I^2 = I$. Given an integer n, then, n+I and nI are neutrosophic elements of $\langle R \cup I\rangle$ and in addition $0 \cdot I = 0$. Also, I^{-1}, the inverse of I is not defined.

E.g., a neutrosophic ring is $\langle \mathbb{Q} \cup I\rangle$ generated by $\mathbb{Q}$, which is the set of rationals.

Some operation using I is $I + I + \ldots + I = nI$.

Definition 4: ([8]) A *neutrosophic number* N is also defined as a number as follows:

$$N = d + I \quad (3)$$

Where d is the *determined part* and I is the *indeterminated part* of N.

Let $N_1 = a_1 + b_1 I$ and $N_2 = a_2 + b_2 I$ be two neutrosophic numbers, then some operations between them are:

1. $N_1 + N_2 = a_1 + a_1 + (b_1 + b_2)I$ (Addition),
2. $N_1 - N_2 = a_1 - a_1 + (b_1 - b_2)I$ (Difference),
3. $N_1 \times N_2 = a_1 a_2 + (a_1 b_2 + b_1 a_2 + b_1 b_2)I$ (Product),
4. $\frac{N_1}{N_2} = \frac{a_1 + b_1 I}{a_2 + b_2 I} = \frac{a_1}{a_2} + \frac{a_2 b_1 - a_1 b_2}{a_2(a_2 + b_2)} I$ (Division).

A *neutrosophic matrix* is a matrix whose components are elements of $\langle R \cup I\rangle$.

Thus, it is possible to generalize the operations between vectors and matrices on R to the ring $\langle R \cup I\rangle$.

A *neutrosophic graph* is a graph with at least one neutrosophic edge linking two nodes, that is to say, there is an edge with an indetermination on its two nodes connection, [9], see Figure 1.

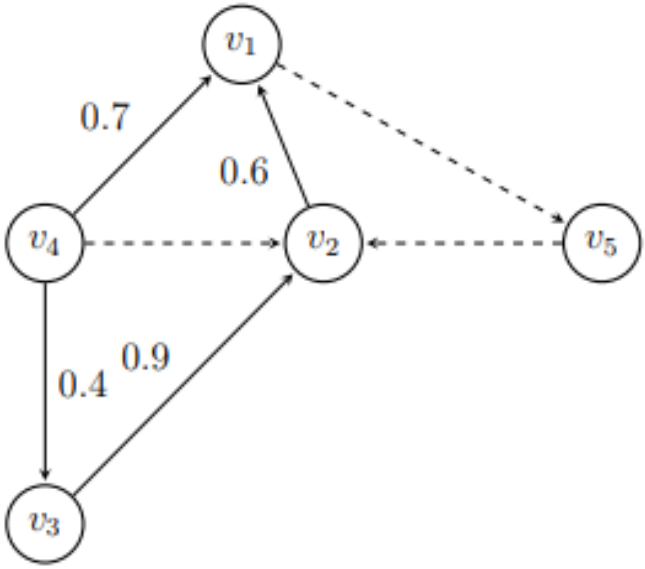

Figure 1: Example of neutrosophic graph. Source [9].

The de-neutrosophication process was introduced by Salmeron and Smarandache in [8], which converts a neutrosophic number in one numeric value. This process provides a range of numbers for centrality using as a base the maximum and minimum values of $I = [a_1, a_2] \subseteq [0, 1]$, based on Equation 4:

$$\lambda([a_1, a_2]) = \frac{a_1 + a_2}{2} \tag{4}$$

Each node constitutes a causal concept; this characteristic makes the representation flexible to visualize human knowledge. The adjacency matrix is obtained from the values assigned to the arcs.

The values obtained by the group of experts involved in the process are aggregated, conforming to the general knowledge to the relationships between the criteria. Activity results in the NCM. From the assessment of the causal relationships, the static analysis is performed. The knowledge stored in the adjacency matrix is taken as a reference. For the development of the present method, we work with the indegree of output as shown in Equation 5.

$$id_i = \sum_{i=1}^{n} \left| I_{ji} \right| \tag{5}$$

The outdegree (*od*) is calculated by Equation 6, and total degree (*td*) by Equation 7:

$$od_i = \sum_{i=1}^{n} \left| I_{ij} \right| \tag{6}$$

$$td_i = id_i + od_i \tag{7}$$

3 Results

In the present study, a sample of 134 persons was selected, a representative portion of the population, which corresponds to a group of people from whom the necessary information was obtained for the chosen problem, a segment that corresponded to older adults we were worked with. They are individuals from 65 to 89 years of age from the Municipal Gerontological Center "Dr. Arsenio de la Torre Marcillo" from the city of Guayaquil, which is made up of 400 older adults. Through the test of factors that was carried out on the group of older adults, it was possible to determine the incidence of the highest percentage, as shown in Table 1.

Incidence factors Test	**Gender**		**Age**			**Percentage of older adults with Incidence Factor**
	Male	Female	Older Adult	Mature Older Adult	Old Man	
Social interaction	5	2	4	2	1	5.22
Educational Level	7	4	7	3	1	8.21
Occupation	2	5	4	3	0	5.22
Social isolation	2	1	1	1	1	2.24
Social Illnesses	3	1	3	1	0	2.99
Depression	4	8	5	5	2	8.96
Cultural level	4	6	5	3	2	7.46
Physical Activity	7	11	13	3	2	13.43
Feeding Habits	6	3	7	2	0	6.71
Drug Use	3	2	5	0	0	3.73
Genetic polymorphism	15	10	16	6	3	18.66
Cardiovascular disease	4	5	5	4	0	6.72
Diabetes	5	3	7	0	1	5.97
Nutrition	4	2	5	0	1	4.48
TOTAL	71	63	87	33	14	100
	134		134			

Table 1. Incident factors: relationship between gender and age.

In a first approximation, a classic cognitive map was obtained as shown in Figure 2.

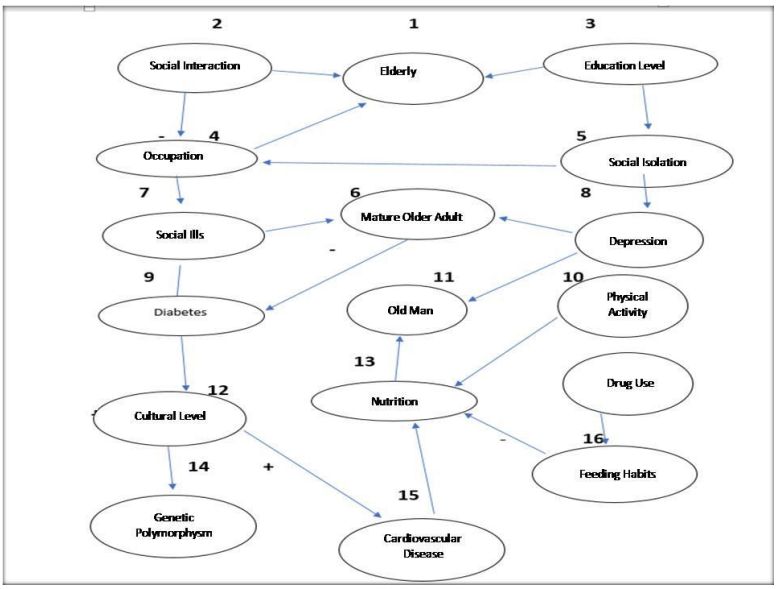

Figure 2. Representation of factors modeling their causalities in Cognitive Maps.

To determine the level of cognitive impairment, the sub-variables were divided for the neutrosophic logic, the input variables and the output variable. We performed the neutrosophic inference to obtain the level of cognitive impairment.

Figure 3 shows the input variables Age Factor (VFE), Social Factor (VFS), Psychological Factor (VFP) and Biological Factor (VFB) that was used in the process of calculating the level of cognitive impairment divided into three labels Mild Cognitive Decline (DCL), Moderate Cognitive Decline (DCM), Severe Cognitive Decline (DCS).

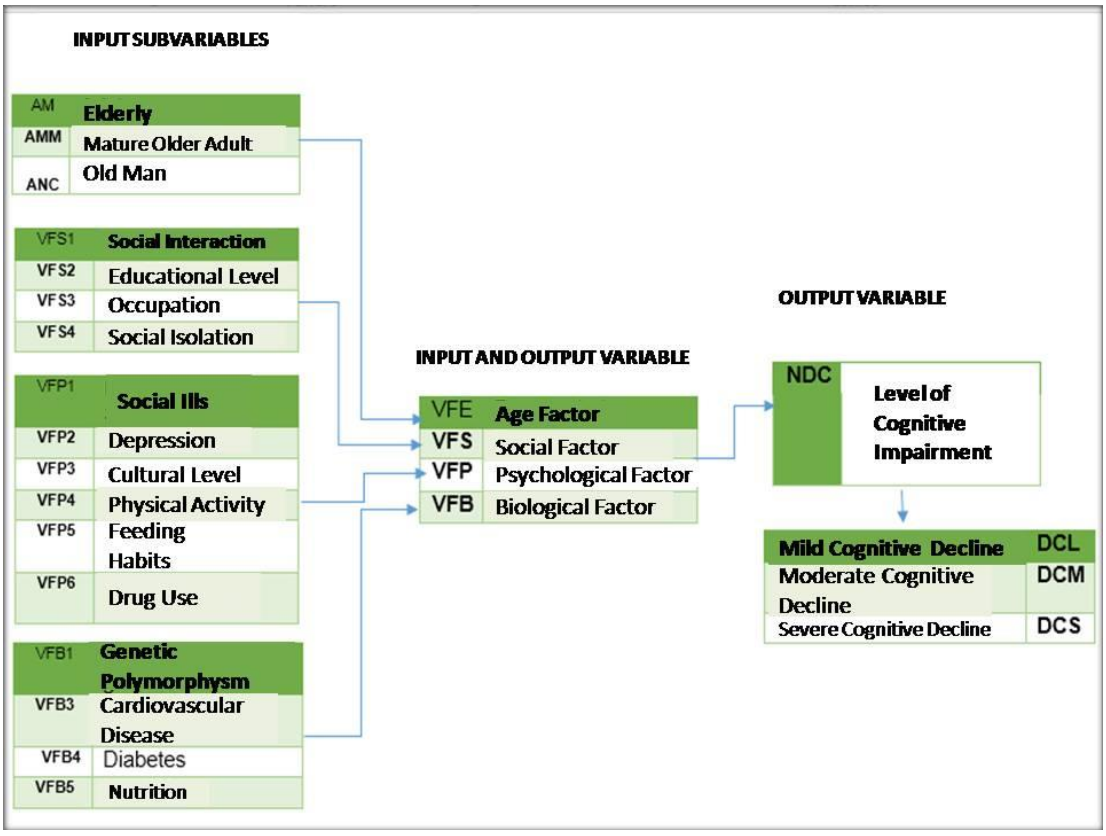

Figure 3. Inference of the level of cognitive impairment, variables of the Social, Psychological, and Biological factors with their respective weights.

Each of the possible combinations will be established to determine the level of cognitive impairment in an older adult with respect to the Age factor, classifying the social, psychological and biological factor as; low, medium and high; the Age factor, on the other hand, is classified as: older adult, mature older adult and old man, as shown in Tables 2, 3 and 4.

Social Factor	**Age Factor**		
	Older Adult	Mature Older Adult	Old Man
Low	DCL	DCL	DCM
Medium	DCL	DCM	DCS
High	DCM	DCS	DCS

Table 2. Rules with age factor and social factor.

Psychological Factor	**Age Factor**		
	Older Adult	Older Adult Mature	Old Man
Low	DCL	DCM	DCM
Medium	DCM	DCS	DCS
High	DCS	DCS	DCS

Table 3. Rules with age factor and psychological factor.

Biological Factor	Age Factor		
	Older Adult	Older Adult Mature	Old Man
Low	DCM	DCM	DCS
Medium	DCS	DCS	DCS
High	DCM	DCM	DCS

Table 4. Rules with age factor and biological factor.

A description of the selected factors is shown in Table 5.

Node	Factor	Description
VFE1	Older Adult	Definition of age between 65 -74 years old.
VFE2	Mature Older Adult	Definition of age between 75 -84 years old.
VFE3	Old man	Definition of age between 85 -89 years old.
VFS1	Social Interaction	Causality understood as interaction relationships with family, friends and people close to the older adult.
VFS2	Educational Level	Causality understood as the level of study that the older adult has had, as well as illiteracy and lack of education.
VFS3	Occupation	Causality understood as the occupations that the older adult has presented in his free time, since his young adult stage.
VFS4	Social isolation	Causality understood as the loneliness that the person presents due to underlying causes such as traumatic or emotional incidents, among others.
VFP1	Social diseases	Causality understood as conditions caused by a condition that the older adult has presented since the young adult stage, such as alcoholism, drug addiction, etc.
VFS2	Depression	Causality understood as the presence of depression in the older adult.
VFP3	Cultural Level	Causality understood as cultural activities carried out by the older adult from the older adult stage such as music, theater, among others.
VFP4	Physical Activity	Causality understood as physical activities carried out by the older adult from the older adult stage such as physical training, sports, mental activity games.
VFP5	Eating Habits	Causality understood as the food diet that the older adult has had since his youth.
VFP6	Drug Use	Causality understood as the recurrence of drugs that the older adult has consumed, or also self-medication.
VFB1	Genetic polymorphism	Causality understood as diseases inherited by genes in the elderly such as Alzheimer's etc.
VFB2	Cardiovascular disease	Causality understood as heart condition manifested by diseased blood vessels, structural problems, and blood clots.
VFB3	Diabetes	Causality understood as a group of diseases that results in excess sugar in the blood (high blood glucose).
VFB4	Nutrition	Causality understood as food intake in relation to the dietary needs of the body that the older adult has had.

Table 5. Intervening factors of the system to be modeled in the neutrosophic cognitive maps.

In the final calculation of the evaluation of the level of cognitive impairment, the results obtained are verified with the rules established in Table 6, which shows the general average incidence between factors.

Factor	Older Adult	Older Adult Mature	Old Man
VFS1	0.52	0.28	0.15
VFS2	0.36	0.33	0.18
VFS3	0.58	0.14	0.45
VFS4	0.85	0.53	0.36
VFP1	0.24	0.45	0.24
VFP2	0.52	0.36	0.15
VFP3	0.74	0.36	0.35
VFP4	0.38	0.35	0.12
VFP5	0.45	0.75	0.25
VFP6	0.25	0.28	0.13
VFB1	0.36	0.47	0.22
VFB2	0.86	0.25	0.79
VFB3	0.72	0.46	0.14
VFB4	0.58	0.62	0.38

Table 6. Incidence Result by Factor Subvariable.

The final result of the assessment of the level of cognitive impairment and the most influential factors of it are shown in Table 7 below:

Factor-Age	Impairment Factor	Graduation	Intervener Factor
Older Adult	Severe Cognitive Impairment (DCS)	0.86	Biological
Mature Older Adult	Moderate Cognitive Impairment (DCM)	0.75	Psychological
Old Man	Severe Cognitive Impairment (DCS)	0.79	Biological

Table 7. Average result of the level of cognitive impairment in age classification.

The results obtained through the mapping are defined based on centrality (C) or based on the factor with the greatest relationship with the causal nodes of the neutrosophic cognitive maps (Cb).

Node	C	Cb
VFE1	**0.45565**	**0.4456**
VFE2	**0.26265**	**0.8564**
VFE3	**0.25656**	**0.5656**
VFS1	**0.26565**	**0.6596**
VFS2	**0.65912**	**0.5656**
VFS3	**0.736643**	**0.3133**
VFS4	**0.126454**	**0.5646**
VFP1	**0.84638**	**0.2666**
VFP2	**0.26561**	**0.1646**
VFP3	**0.263335**	**0.3564**
VFP4	**0.13654**	**0.54545**
VFP5	**0.64645**	**0.6256**
VFP6	**0.26497**	**0.13124**
VFB1	**0.236465**	**0.2325**
VFB2	**0.498797**	**0.7313**
VFB3	**0.26464**	**0.4464**
VFB4	**0.645645**	**0.6464**

Table 8. Centrality of the factors studied.

We must emphasize that although we do not express it explicitly, the results in Table 8 are the consequence of applying neutrosophic measures that can make the results more accurate, although more imprecise, for example, the relationship between "Cardiovascular Disease" and "Feeding Habits" was not considered in the map of Figure 1, however, in the map designed by us the measure "I" is given as indeterminate, since common sense indicates that there is a relationship between these variables, although this relationship is unknown by us. Finally, by using Equation 4 the intervals are converted to crisp values.

The order of the factors is as follows:

VFS2≻VFS1≻VFS3≻VFS4≻VFP1≻VFP2≻VFP3≻VFP4≻VFP5≻VFP6≻VFB1≻VFB2≻VFB3≻VFB4. This result shows a predominance of factors associated with social factors (**VFS2**, **VFS1**, **VFS3**) over those related to psychological factors (**VFP1**, **VFP2**). Therefore, we can demonstrate that each factor can be thoroughly analyzed by means of neutrosophic techniques and draw a differential diagnosis of which is the intervening factor with the higher incidence, this is a big step for the field of medicine with the help of computational artificial intelligence since solutions with effective data and efficiency will be used.

Conclusion

This paper consisted in the study of factors incident in the cognitive deterioration of older adults. This is a problem of current interest since modern societies have considerably increased the aging of their population; therefore this has a social, familiar and personal interest. For this study, the Neutrosophic Cognitive Maps were used, which allow us studying the relationships between 17 variables related to cognitive deterioration in 134 older people in the city of Guayaquil. The Neutrosophic Cognitive Maps were selected to obtain more accurate results than with Fuzzy Cognitive Maps ([18]), although more imprecise, because the CNM allow imprecise relationships between variables to be included in the calculations. The most influential variables were "Educational Level", "Social Interaction" and "Occupation". This implies that must be social the most effective solution to this problem.

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