Diabetic Neuropathy Severity Assessment: A Neutrosophic approach

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Abstract

In this work a Neutrosophic approach has been implemented to assess the severity of diabetic neuropathy. Vibratory Perception Threshold (VPT) data was acquired from 600 participants. The acquired data was utilised to obtain the various criteria to assess the severity of diabetic neuropathy which is a fatal consequence of Diabetes mellitus. A single valued Neutrosophic set was employed to assess and evaluate the given medical condition. Multi Criteria Decision Making (MCDM) was used to address the severity. The hybrid score accuracy function and the collective correlation of the decision matrices were calculated and were used to estimate the weights which ultimately aided in the ranking process. The results corroborated that Grade II neuropathy is the most severe condition and needs more conscientious diagnosis.

Keywords: Diabetic Neuropathy; Neutrosophic Set; MCDM; Diabetes; Biothesiometry; Vibration Perception Threshold

1. Introduction

A graph is a convenient approach to depict relationships between objects, which are represented by vertices, and their relationships, which are represented by edges. In fuzzy graph model, uncertainty is measured interms of fuzzy member-ship values. A fuzzy graph is a symmetric binary fuzzy relation on a fuzzy subset [3]. The elements have a value ranging from 0-1 representing the degree of membership. The concept of fuzzy sets and fuzzy relations was introduced by L. A. Zadeh [4] and further studied the concept of generalized study of uncertainty [5]. The concept of fuzzy bridges, forest and trees, clusters and cut nodes and their properties has been studied by Rosenfeld [6]. Raymond T Yeh et. al. introduced the concept of connectedness in fuzzy graphs. Techniques of pattern classification and clustering analysis and various connectivity properties of a fuzzy graph has also been introduced [7].

Intuitionistic fuzzy relations and its graph representation were first introduced by Atanassov [8]. He also added a new element to the fuzzy set formulation that establishes the degree of non-membership. The fuzzy sets provide information about an element's degree of membership in a set, whereas intuitionistic fuzzy sets provide information about an element's degree of non-membership. The only

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restriction is that the sum of these two degrees do not exceed unity [8- 10]. However, fuzzy graphs and intuitionistic fuzzy graphs fail when the relationships between nodes or vertices are uncertain. To overcome this problem of uncertainty, a new concept was introduced which is called the Neutrosophic sets. Neutrosophic logic was first introduced by Florentin Smarandache in 1995 and defined Neutrosophic set (NS) as a set of three components - a degree of Truth ($\mathfrak{T}$), a degree of Indeterminacy ($\mathfrak{I}$) and a degree of Falsity ($\mathfrak{F}$) [11]. It characterizes each value statement in three dimensional Neutrosophic space, which includes space for truth, indeterminacy and falsity [$\mathfrak{T}$, $\mathfrak{I}$, $\mathfrak{F}$] which are real subsets of]-0, 1+[. The neutral values are represented by indeterminacy factor which does not dependent truth and falsity values. NSs are more generic than Intuitionistic fuzzy set and also NSs has no restriction on the degree member-ship value of $\mathfrak{T}$, $\mathfrak{I}$ and $\mathfrak{F}$ [12, 13, 14, 15]. The concept of single-valued neutrosophic sets (SVNs) was proposed by Wang et al. whose functions of truth, indeterminacy and falsity are independent and lie in the range [0,1] [17]. The extensions of SVNs can be found on [16, 18, 19].

The generalization of classical statistics is called the neutrosophic statistics (NS) which can be used to determine the uncertain and unclear test data observations. Muhammad Aslam et.al [32] presented the introduced a new kind of diagnosis tests, neutrosophic diagnosis tests (NDT). They have illustrated NDT with a real example from the medical field. Bazhdar N et. al. [33] have introduced a new intelligent system using neutrosophic and statistical fundus image features for screening diabetic retinopathy. Muhammad Aslam et. al. [34] have presented a t-test of a correlation coefficient using neutrosophic statistics which helps to analyze the significance of correlation uncertainties level of significance. They also have applied this new version of tests in the data collected from diabetic patients and proved it is an effective test. Abdolreza Rashno et. al. [35] have written a new algorithm for the segmentation process of retina images of diabetic patients. This algorithm consists of four stages which includes computation of the indeterminacy set, the truth set T in neutrosophic domain. In the continuation, the next steps involved shortest path technique and cost function for cluster –based to estimate the number of clusters. Finally, the algorithm gives flittered fluid regions.

In this work, SVN is combined with the score functions of SVN number and ranking method for SVN numbers to assess severity of Diabetic Neuropathy based on multi attribute decision making. To determine the best attributes, the score function was used to rank the total values of each possibility. Multi- criteria decision making (MCDM) is used to solve problems involving multiple criteria and produce quality decision making. Diabetic Neuropathy is a type of nerve damage that results from high blood sugar level [20]. The nerves in the legs and feet are most frequently damaged by diabetic neuropathy. To predict the severity of Diabetic Neuropathy, the Vibration Perception Threshold (VPT) of the right and left foot was acquired using a biothesiometer which basically quantifies loss of sensation, especially in case of severe neuropathy. An approach to combine the severity measures of Diabetic Neuropathy and MCDM has been proposed in this work. A brief history of the evolution of MCDM approaches is given in the book by Köksalan et al. It gives a quick overview of the advancement of MCDM from prehistoric to present times [24]. One of the challenge areas with the highest growth across various disciplines is MCDM. How to compare a set of options based on several criteria is the main issue. Making judgments while considering numerous criteria's is referred to as MCDM. This technique can be broadly divided into two groups: continuous MODM (Multi-Objective Decision Making) approaches and discrete MCDM, often known as discrete MADM (Multi-Attribute Decision Making) [25]. When multiple criteria have emerged, the MCDM approach aids in selecting the best options. The best option can be found by examining the scope and weights of multiple criteria. The major goal is to identify diverse applications and methodologies, and to recommend approaches that can be used to identify the best alternatives most robustly and effectively [26]. Ehrgott et al. did a job of compiling extensive studies, in which well-known researchers in the field released individual studies on several MCDM method classes [27].

2. Basic Definitions

We provide all the definitions in the contest of neutrosophic sets.

Definition 2.1 A neutrosophic set S is defined as $S = \{\langle x: \mathfrak{T}_s(x), \mathfrak{I}_s(x), \mathfrak{F}_s(x)\rangle, x \in X\}$ Here, the membership functions $\mathfrak{F}, \mathfrak{I}, \mathfrak{F}$ defines truth, indeterminacy and falsity member-ship values of the element $x \in X$ to the set S which satisfy the conditions: $\mathfrak{T}, \mathfrak{I}, \mathfrak{F}: X \rightarrow]0^-, 1^+[$, $-0 \leq \mathfrak{F}_s(x) + \mathfrak{I}_s(x) + \mathfrak{F}_s(x) \leq 3^+$ where $\mathfrak{F}_s(x), \mathfrak{I}_s(x), \mathfrak{F}_s(x)$ are in $]0^-, 1^+[$.

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Definition 2.2 A single valued neutrosophic set $= \{ \langle x: \mathfrak{T}_s(x), \mathfrak{I}_s(x), \mathfrak{F}_s(x) \rangle, x \in X\}$, the membership functions $\mathfrak{F}, \mathfrak{I}, \mathfrak{F}$ defines degree of truth, indeterminacy and falsity of the element $x \in X$ to the set S which satisfy the conditions: $\mathfrak{F}, \mathfrak{I}, \mathfrak{F}: X \rightarrow [0,1]$.

3. MCDM method using score functions of single valued Neutrosophic set

Assume $A = \{A_1, A_2, \ldots, A_m\}\ (m \geq 2)$ be the set of logistic centres and $B = \{B_1, B_2, \ldots, B_n\}\ (n \geq 2)$ are the set of criteria and $D = \{D_1, D_2, \ldots, D_d\}\ (d > 2)$ be the set of decision makers. The weights of the criteria and the decision makers are unknown. Therefore, we employ MCDM technique which uses the hybrid score accuracy function which comes under SVN that uses linguistic variables.

The algorithm is as follows:

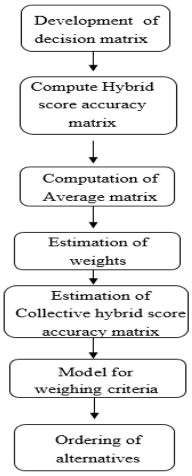

Figure 1: Algorithm of the proposed work

4. Methodology

Diabetes is a long-term illness. The majority of the calories we consume are converted to glucose and delivered into the bloodstream. The pancreas releases insulin when the blood sugar levels rise. A hormone called insulin, which is secreted by the pancreatic beta cells, facilitates the uptake of blood sugar by cells. Because the pancreas does not create enough insulin or because cells cease to respond to insulin, diabetes is characterized by elevated blood sugar levels. This eventually causes significant health problems like heart disease, vision loss, etc [21]. There are two types of diabetes: Type 1 and Type 2 Diabetes.

Diabetic Neuropathy (DN) is a complication of type 1 and type 2 diabetes that causes damage to the nerves due to high sugar level in the blood. It brings about the greatest suffering and mortality. DN is a group of clinical disorders that, individually or together, affect various parts of the nervous system. It may be silent and carry out its ravages unnoticed, or it may exhibit clinical symptoms and signs that may be general and sneaky with gradual advancement, nevertheless resemble those of many other diseases [22]. One of the most crucial indicators for recognizing diabetic neuropathy patient is the loss of sensation. The Vibration Perception Threshold (VPT) has been routinely used to assess the degree of neuropathy in diabetic patients, with an elevated VPT value to be one of the important and earliest clinical indicators of a disease of the peripheral nerves. It provides a quick, affordable, and accurate screening tool for evaluating high-risk patients.

4.1 Vibration perception using biothesiometer

The presence of neuropathy is a crucial factor in evaluating if a foot is particularly prone to painless damage, which can progress to a persistent and spreading ulcer. This has major ramifications and might result in massive amputations below or above the ankle and knee. Neuropathy can be qualitatively assessed by means of using a tuning fork, hot and cold sensation and pricks. But quantitative assessments of the protective sensation in the foot should be done in order to report any incremental risks and damage. Many procedures, such as nerve conduction investigations, are

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available but unfeasible due to their high cost [28]. Hence, simple techniques like using vibration perception proves very useful and effective. The device that produces vibration at specific voltage levels is known as a Vibrometer/Biothesiometer. The vibrometer model that was used in the study is the Vibrometer VPT by Diabetik Foot Care India Pvt Ltd. The technical specifications of the device are shown in Table 1[29].

Table 1: Technical Specifications of Vibrometer

Features	Specification
Power supply	230 V
Frequency	50 Hz
Fuse rating	100 mA
Operating temperature	15-45^{o} C
Humidity	15-90% non-condensing
Operating pressure	523 mm Hg
Vibration Frequency	120 Hz
Vibration output range	0-50 V
Computer Interface	RS232C
Display	LED

4.2 Data generation

In this study, a health camp was organized in a hospital and the data was collected from 696 volunteers using the aforementioned model of vibrometer. Out of the 696 volunteers 78 were normal subjects where the maximum VPT value for both the foot was found to be less than 15. The minimum age of the participant involved in the study was 35 and the majority consisted of participants above the age of 50. All the volunteers were informed about the procedure and an informed consent was obtained from the all the subjects involved in the study. The subjects were then asked to sit in a relaxed position. The vibrometer probe was initially placed on the hands in order to provide a sense and impression of vibration. Then the probe was applied at six points on the foot as illustrated in Fig.2 and the voltage level was simultaneously increased. The points shown in the figure represent the parts of foot namely the (i) big foot, (ii)1st metatarsal, (iii) 3rd metatarsal, (iv) 5th metatarsal, (v) In step and (vi) heel respectively. The level of severity was classified and assessed by using the voltage perception range as shown in Table 3 which led to categorizing the subjects into Right mild loss, left mild loss, right moderate loss, left moderate loss, right severe loss and left severe loss as shown in Table 2. The procedure was stopped immediately if the volunteer felt any slight discomfort. Several trials were conducted, and the data generated was transmitted via the RS23C serial interface to the PC.

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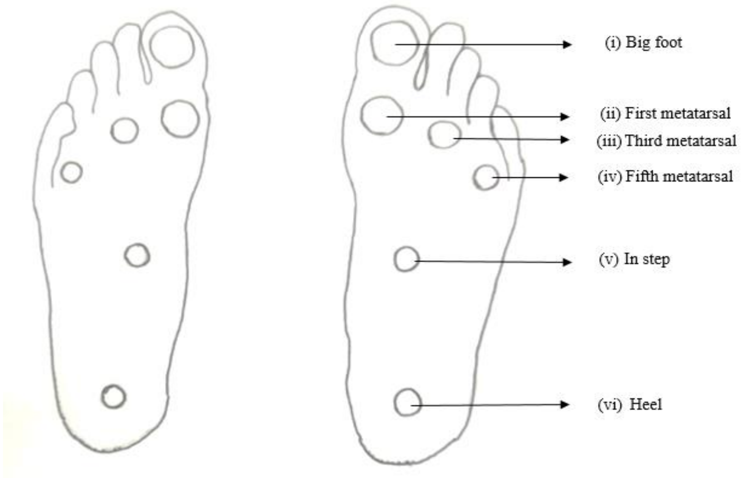

Figure 2: Foot diagram illustrating the placement of biothesiometer probe [30]

Table 2: Allocation for biothesiometer values [30-31]

Voltage perception range (V)	Frequency of vibration (Hz)	Level of severity
<15	4-225	Normal Study or level 1
16-20	256-625	Mild Loss of Vibratory Perception or level 2
21-25	256-625	Moderate Loss of Vibratory Perception or level 3
>25	>625	Severe Loss of Vibratory Perception or level 4

Table 3: Category of subjects according to severity

Category based on Severity	Number of subjects
Right mild loss	180
Left mild loss	176
Right moderate loss	112
Left moderate loss	112
Right severe loss	150
Left severe loss	150

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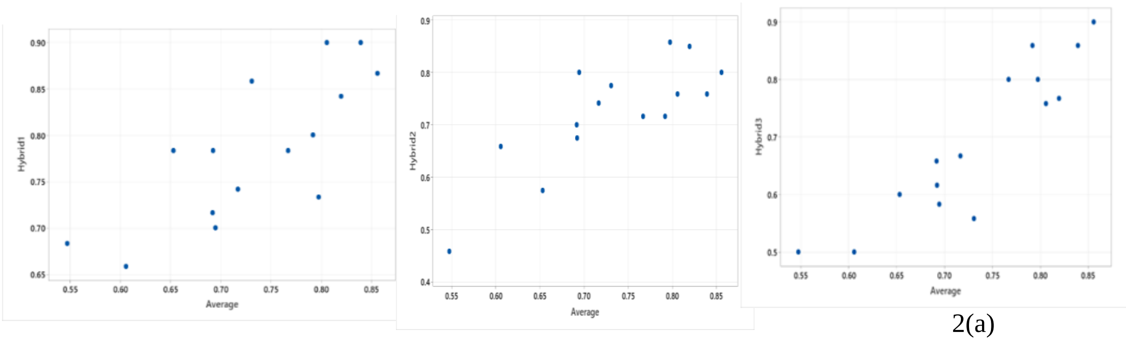
Multi- criteria decision making (MCDM) was implemented where the five criteria's were considered for each patient as shown in Table 1. Neutrosophic sets have been developed by a group of three doctors (decision makers) - D_1, D_2, D_3 to evaluate the severity of diabetes based on three types: normal (N_1), Grade 1 diabetes (N_2), and Grade 2 diabetes (N_3).



2(a)

2(b) 2(c)

Figure 3: Plot illustrating correlation between (a) Hybrid matrix 1 and average matrix (b) Hybrid matrix 2 and average matrix (c) Hybrid matrix 3 and average matrix

Thus, the three decision-makers create the following decision matrices by rating the alternatives in relation to the criterion using linguistic factors.

Step 1: Formation of decision matrix

$$D_1: \begin{pmatrix} & F_1 & F_2 & F_3 & F_4 & F_5 \\ K_1 & (0.6,0.3,0.2) & (0.5,0.4,0.1) & (0.7,0.3,0.1) & (0.8,0.1,0.1) & (0.6,0.3,0.3) \\ K_2 & (0.7,0.3,0.2) & (0.7,0.3,0.1) & (0.8,0.2,0.2) & (0.9,0.1,0.1) & (0.7,0.2,0.3) \\ K_3 & (0.8,0.2,0.1) & (0.8,0.3,0.2) & (0.9,0.3,0.1) & (0.9,0.1,0.1) & (0.8,0.1,0.4) \end{pmatrix}$$

$$D_2: \begin{pmatrix} & F_1 & F_2 & F_3 & F_4 & F_5 \\ K_1 & (0.7,0.2,0.1) & (0.3,0.5,0.4) & (0.6,0.2,0.2) & (0.6,0.1,0.1) & (0.6,0.3,0.3) \\ K_2 & (0.8,0.3,0.3) & (0.4,0.3,0.3) & (0.6,0.2,0.2) & (0.7,0.2,0.2) & (0.7,0.3,0.3) \\ K_3 & (0.9,0.4,0.1) & (0.5,0.2,0.2) & (0.7,0.2,0.1) & (0.8,0.2,0.3) & (0.8,0.1,0.1) \end{pmatrix}$$

$$D_3: \begin{pmatrix} & F_1 & F_2 & F_3 & F_4 & F_5 \\ K_1 & (0.7,0.5,0.5) & (0.5,0.5,0.5) & (0.7,0.2,0.1) & (0.5,0.4,0.4) & (0.5,0.5,0.5) \\ K_2 & (0.7,0.5,0.3) & (0.6,0.4,0.4) & (0.8,0.1,0.1) & (0.7,0.2,0.2) & (0.6,0.3,0.3) \\ K_3 & (0.8,0.4,0.2) & (0.5,0.3,0.3) & (0.9,0.1,0.1) & (0.8,0.1,0.1) & (0.7,0.2,0.1) \end{pmatrix}$$

Step 2: Computation of hybrid score accuracy matrix

Using the aforementioned method for single values Neutrosophic group decision making to determine the highest severity of diabetes based on its types. Take $\delta = 0.5$

The following equation is used to compute score matrix from above decision matrix:

$$hyb_{ij}^{q} = \frac{1}{2} * \delta * (1 + T_{ij}^{q} - F_{ij}^{q}) + \frac{1}{3} * (1 - \delta) * (2 + T_{ij}^{q} - I_{ij}^{q} - F_{ij}^{q})$$

Hybrid score accuracy matrix:

$$hyb_1: \begin{pmatrix} & F_1 & F_2 & F_3 & F_4 & F_5 \\ K_1 & .7000 & .6833 & .7833 & .8583 & .6583 \\ K_2 & .7417 & .7833 & .8000 & .9000 & .7166 \\ K_3 & .8416 & .7833 & .8666 & .9000 & .7333 \end{pmatrix}$$

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$$hyb_2: \begin{pmatrix} & F_1 & F_2 & F_3 & F_4 & F_5 \\ K_1 & .8000 & .4583 & .7166 & .7750 & .6583 \\ K_2 & .7416 & .5750 & .7166 & .7583 & .7000 \\ K_3 & .8500 & .6750 & .8000 & .7583 & .8583 \end{pmatrix}$$

$$hyb_3: \begin{pmatrix} & F_1 & F_2 & F_3 & F_4 & F_5 \\ K_1 & .5833 & .5000 & .8000 & .5583 & .5000 \\ K_2 & .6666 & .6000 & .8583 & .7583 & .6583 \\ K_3 & .7666 & .6166 & .9000 & .8583 & .8000 \end{pmatrix}$$

Step 3: Computation of average matrix using equation

$$havg_{ij}^{*} = \frac{1}{n}\sum_{q=1}^{n}(hyb_{ij}^{q})$$

Average matrix ($havg_{ij}^{*}$) is formed

$$havg_{ij}^{*} \quad \begin{pmatrix} & F_1 & F_2 & F_3 & F_4 & F_5 \\ K_1 & .6944 & .5472 & .7666 & .7305 & .6055 \\ K_2 & .7166 & .6528 & .7916 & .8055 & .6917 \\ K_3 & .8194 & .692 & .8555 & .839 & .7970 \end{pmatrix}$$

The correlation co-efficient between Hyb^q and $Havg^*$ is given

$$\varsigma_q = \sum_{i=1}^{m}\frac{\sum_{j=1}^{p} hyb_{ij}^{s}\, hyb_{ij}^{*}}{\sqrt{\sum_{j=1}^{p}(hyb_{ij}^{q})^2}} \text{ x } \frac{1}{\sqrt{\sum_{j=1}^{p}(hyb_{ij}^{*})^2}} \text{ where } q = \{1,2,3\}$$

The correlation plots for the respective matrices is given in Fig 2(a),2(b) and 2(c) respectively.

To find Ω_1:

$hyb_1 \times havg^*$	$\sum_{j=i}^{\rho} hyb_{ij}^{1} hyb_{ij}^{*}$	$\sqrt{\sum_{j=1}^{\rho}(hyb_{ij}^{1})^2}$	$\sqrt{\sum_{j=1}^{\rho}(hyb_{ij}^{*})^2}$
$\begin{pmatrix} .4861 & .3740 & .6000 & .627 & .3 \\ .3381 & .5113 & .633 & .725 & .49 \\ .6077 & .5420 & .741 & .755 & .58 \end{pmatrix}$	2.4866 2.7031 3.2995	1.6550 1.2442 1.4571	1.5065 1.641 1.795

$$\varsigma_1 = \frac{2.4866}{1.65502 \text{ X } 1.5065} + \frac{2.7031}{1.24425 \text{ X } 1.641} + \frac{3.2995}{1.4572 \text{ X } 1.795} = 3.582$$

To find Ω_2:

$hyb_2 \times havg^*$	$\sum_{j=i}^{\rho} hyb_{ij}^{2} hyb_{ij}^{*}$	$\sqrt{\sum_{j=1}^{\rho}(hyb_{ij}^{2})^2}$	$\sqrt{\sum_{j=1}^{\rho}(hyb_{ij}^{*})^2}$
$\begin{pmatrix} .5555 & .2511 & .5494 & .5662 & .3 \\ .5315 & .3754 & .5673 & .6109 & .4 \\ .6965 & .4671 & .6844 & .6363 & .6 \end{pmatrix}$	2.3211 2.5693 3.1684	1.074 1.1631 1.4298	1.5065 1.641 1.795

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$$\varsigma_2 = \frac{2.3211}{1.074 \text{ X } 1.5065} + \frac{2.5693}{1.16314 \text{ X } 1.641} + \frac{3.1684}{1.423 \text{ X } 1.795} = 4.025$$

To find $\Omega_{3:}$

$hyb_2 \times havg^*$	$\sum_{j=i}^{\rho} hyb_{ij}^2 hyb_{ij}^*$	$\sqrt{\sum_{j=1}^{\rho}(hyb_{ij}^2)^2}$	$\sqrt{\sum_{j=1}^{\rho}(hyb_{ij}^*)^2}$
$\begin{pmatrix} .4051 & .274 & .6133 & .4262 & .30 \\ .4778 & .392 & .67953 & .6101 & .45 \\ .6282 & .427 & .7999 & .7201 & .63 \end{pmatrix}$	20216 2.615 3.2129	0.943 1.193 1.4636	1.5065 1.641 1.795

$$\varsigma_3 = \frac{2.0216}{0.943 \text{ X } 1.5065} + \frac{2.615}{1.193 \text{ X } 1.641} + \frac{3.2129}{1.464 \text{ X } 1.795} = 3.982$$

Step 4: Estimation of weights

$$\Sigma_q = \frac{\varsigma_q}{\sum_{q=1}^{n}\varsigma_q}, 0 \leq \Sigma_q \leq 1 \text{ for q=1, 2, 3, . . ., n}$$

The weight of three decision makers is determined from the equation given below:

$$\varsigma_1 + \varsigma_2 + \varsigma_3 = 10.777$$

$$\square_1 = \frac{\varsigma_1}{\varsigma_1 + \varsigma_2 + \varsigma_3} = 0.3323$$

$$\square_2 = 0.3735$$

$$\square_3 = 0.3695$$

Step 5: Estimation of collective hybrid score – accuracy matrix

As a result, the following equation is used to combine the hybrid score-accuracy values of the various decision makers' choices $\mathfrak{N} = (hyb_{ij})n \text{ x } p = \sum_{q=1}^{m} \square_q \, hyb_{ij}^s$ and the collective hybrid score – accuracy matrix is formulated as given below:

$$\square_1 \text{ x hyb}_1 = \begin{pmatrix} 0.2810 & 0.1820 & 0.2530 & 0.2430 & 0.2012 \\ 0.2382 & 0.2160 & 0.2630 & 0.2680 & 0.2300 \\ 0.2720 & 0.2300 & 0.2800 & 0.2790 & 0.2650 \end{pmatrix}$$

$$\square_2 \text{ x hyb}_2 = \begin{pmatrix} 0.2594 & 0.2044 & 0.2864 & 0.2730 & 0.2262 \\ 0.2677 & 0.2440 & 0.2960 & 0.3009 & 0.2580 \\ 0.3060 & 0.2585 & 0.3195 & 0.3134 & 0.2980 \end{pmatrix}$$

$$\square_3 \text{ x hyb}_3 = \begin{pmatrix} 0.2566 & 0.2022 & 0.2800 & 0.2700 & 0.2240 \\ 0.2650 & 0.2142 & 0.2925 & 0.2980 & 0.2655 \\ 0.3030 & 0.2557 & 0.3160 & 0.3100 & 0.2945 \end{pmatrix}$$

Adding all three matrices

$$\mathfrak{N} = \begin{pmatrix} 0.7470 & 0.5886 & 0.8194 & 0.786 & 0.6514 \\ 0.7709 & 0.6742 & 0.8515 & 0.8664 & 0.7535 \\ 0.8810 & 0.7442 & 0.9155 & 0.9024 & 0.8575 \end{pmatrix}$$

Step 6: Model for weighing criteria

Using the linear programming model $Max\, \eta = \frac{1}{n}\sum_{j=1}^{p}\eta_i hyb_{ij}$, the weight vector of the criteria is obtained as in η = [0.1, 0.1,0.25,0.2,0.15].

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Step 7: Ordering of alternatives

Using the equation $\omega(P_i) = \sum_{j=1}^{p} \eta^i hyb^{ij}$ overall hybrid score- accuracy values can be computed

$$\omega(Ni)\ (i = 1,2,3):$$

$$\omega(N1) = 0.59332$$

$$\omega(N2) = 0.64379$$

$$\omega(N3) = 0.7005$$

The ranking order of severity of diabetic neuropathy is as follows:

$$K_3 > K_2 > K_1$$

Therefore, Grade 2 Diabetic Neuropathy has the highest severity.

5. Conclusion

The severity of diabetic neuropathy disease is evaluated in this work using a single valued neutrosophic set concept and a scoring function. The approach of multi criteria decision making is used to address the issue of uncertainty. A group of three decision-makers established a neutrosophic set model after taking into account five criteria for each patient with diabetic neuropathy to determine which type of the condition is the most severe. The result revealed that diabetic neuropathy in Grade 2 is the most severe. This approach of decision-making is therefore applicable in a variety of situations where there are uncertainties.

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