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Application of Fuzzy Algebraic Model to Statistical Analysis of Neuro-Psychopathology Data

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Abstract

The purpose of this paper is to describe and present applications of fuzzy logic in analysis of certain neuro-psychopathological symptoms. These symptoms have been linked to conditions relating to occupational hazards. Our method of data analysis which is based on Hamacher operation on picture fuzzy sets is then applied to analyse such occupational hazards. Our result proves to be effective and applicable in medical decision processes especially in situations where such neuro-psychopathological symptoms are detectable by first-aid diagnostic machines.

Keywords: Fuzzy logic, Hamacher sum, Hamacher product, Psychopathology.

1 | Introduction

Psychopathology is a subject that deals with problems related to mental health: how to understand them, how to classify them, and how to fix them. Thus, the topic of psychopathology extends from research to treatment and covers every step in between [4]. Proper understanding of causes of mental disorders therefore allows for effective treatments. The major problem aspect of work is psychopathology (emotional or behaviour disorders) which results from inhuman work conditions such as profit maximization and exploitation, poor leadership particularly task-oriented leadership, poor followership, selfishness and laziness. Occupation, when not managed very well, affects, ab initio, individual's personal, family, physical, social, and psychological health. In fact, work can cause permanent injury to man's physical and psychological health and can also reduce one's life span [3].

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Occupational stress occurs when some elements of work generate negative impacts on an employee's physical and mental well-being. World Health Organisation [9] estimates that about 154 million people suffer from depression, 25 million people suffer from schizophrenia, 91 million people are affected by alcohol use disorder and 15 million people suffer from drug use disorder. Hence, psychopathology is a global problem.

The precipitating and maintenance factors of some psychopathological symptoms are: hypertension, diabetics, drug related symptoms, depressions, schizophrenia, anxiety and other neurotic symptoms, sexual and reproductive dysfunctions, poor intra and interpersonal relationships, marital stress and family crises have been linked to conditions relating to occupational hazards and demands including occupational stress and betrayal of trust by the employer or employee ([1] and [2]). Due to the nature of the problem stated above, this paper proposes a model that can be used to address such problems in any organization to prevent poison to the workers.

Psychiatry is the most multifarious domain in medical sciences. Psychiatry diseases are not directly measured due to unclear symptomatic presentations. Results of investigation and treatment are physically correlated with the course of morbidity and such correlations can head to biased decision making. It is often noticed that different diseases present with analogous types of symptoms and vice versa. Also behind deposit of symptoms, there is possibility of multiple diseases evident in case of psychopathology with mania.

Researchers attempted to use hard computing techniques, such as heuristic and probabilistic algorithm in diagnosing psychiatry diseases. But they found that such algorithm are rigid to actually evaluate morbidity [6]. On the other hand, the merit of fuzzy logics lies on competence to handle non-discrete quantitative inputs and analyze like human beings.

General causes of occupational psychopathology can be divided into two major groups namely work related factors and individual factors. The work-related factors are: work overload, time pressures, bad relations with supervisor, change of work, role ambiguity, frustration, conflict at work and, job design and harassment. The individual factors can be enumerated as follows; financial worries, marital problems, pregnancy, problems with children clash of spouse, personal traits and excessive consumptions of alcohol.

The data for this work is obtained from two different hospitals, using different case files that span over five years. Medical results, together with the associated symptoms of patients whose cases are of interest to this study were collected for analysis.

2. Methodological Approach

This study applies fuzzy algebraic model to analyze the data. We assume that all a levels are the same, that is, the two major criteria are of the same significant level. A fuzzy set is a pair (X,μ) where $X \neq \phi$ and μ a membership function. The reference set X is called universe of discourse, and for each $x \in X$ the value μ_x is called the grade of membership of $x \in (X,\mu)$. The function $\mu = \mu_A$ is called the membership function of the fuzzy set $A = (X,\mu)$. The fuzzy set is said to be convex if and only if $\mu_A(\lambda x_1 + (1-\lambda)x_2) \geq min\{\mu_{\bar{A}}(x_1), \mu_{\bar{A}}(x_2)\}$, $x_1, x_2 \in X, \lambda \in [0,1]$, where μ_A and $\mu_{\bar{A}}$ are membership functions of A and its complement $\bar{A}$ respectively. The typical pairs of non-parameterized t-norms(τN) and t-conorms$(\tau(N)$ are given respectively by the Hamacher product

$$t(\mu_{\tilde{A}}(x), \mu_{\tilde{B}}(x)) = \frac{\mu_{\tilde{A}}(x) \cdot \mu_{\tilde{B}}(x)}{\mu_{\tilde{A}}(x) + \mu_{\tilde{B}}(x) - \mu_{\tilde{A}}(x) . \mu_{\tilde{B}}(x)}. \quad (1)$$

The Hamacher sum is given by

$$s(\mu_{\tilde{A}}(x),\mu_{\tilde{B}}(x))=\frac{\mu_{\tilde{A}}(x)+\mu_{\tilde{B}}(x)-2\mu_{\tilde{A}}(x).\mu_{\tilde{B}}(x)}{1-\mu_{\tilde{A}}(x).\mu_{\tilde{B}}(x)}. \quad (2)$$

We recall some basic definitions and algebra of Intuitionistic Fuzzy Sets (IFS) and Picture Fuzzy Sets (PFS):

– Intuitionistic fuzzy sets

Let $X \neq \emptyset$ be the universe of discourse. The Intuitionistic IFS over X is defined by:

$$A = \{[\hat{\mu}_A(x), \hat{\mu}_B(x)] | x \in X\}, \quad (3)$$

where $\hat{\mu}_A: X \rightarrow [0,1]$ *and* $\hat{\mu}_B: X \rightarrow [0,1]$ are respectively membership and non-membership function of IFS A. Here $0 \leq \hat{\mu}_A + \hat{\mu}_B \leq 1$ *for all* $x \in X$ and $\pi := 1 - (\hat{\mu}_A(x) + \hat{\mu}_B(x))$ is called the degree of indeterminacy of $x \in X$ in IFS A. The pair $(\hat{\mu}_A, \hat{\mu}_B)$ is called Intuitionistic Fuzzy Value or Intuitionistic Fuzzy Number (IFN) by Xu [10].

– Picture fuzzy sets

Let *X* be a universe of discourse objects. A picture fuzzy set over *X*, denoted by $\hat{P}$ is defined as follows:

$$\hat{P} = \{[\hat{\mu}_{A\hat{P}}(x), \hat{\theta}_{\hat{P}}(x), \ \hat{\mu}_{B\hat{P}}(x)] | x \in X\}, \quad (4)$$

where $\hat{\mu}_{A\hat{P}}: X \rightarrow [0,1]$, $\hat{\theta}_{\hat{P}}: X \rightarrow [0,1]$ *and* $\hat{\mu}_B: X \rightarrow [0,1]$ are called positive neutral and negative degree of membership of picture fuzzy set $\hat{P}$, respectively. Here, $0 \leq \hat{\mu}_{A\hat{P}}(x) + \hat{\theta}_{\hat{P}}(x) + \hat{\mu}_{B\hat{P}}(x) \leq 1$ *for all* $x \in X$. Besides, $\theta_{\hat{P}}(x)$ denotes degree of refusal of $x \in X$ and is defined by $\pi := 1 - \left(\hat{\mu}_{A\hat{P}}(x) + \hat{\theta}_{\hat{P}}(x) + \hat{\mu}_{B\hat{P}}(x)\right)$. The pair $(\hat{\mu}_{A\hat{P}}, \hat{\theta}_{\hat{P}}, \hat{\mu}_{B\hat{P}})$ is called Picture Fuzzy Value (PFV) or Picture Fuzzy Element (PFE).

2.1. Hamacher Operation on Picture Fuzzy Set

2.1.1. Hamacher operations

The TN and TCN are useful notions in fuzzy set theory, which are used to define general union and intersection of fuzzy set. The definition and conditions of TN and TCN are proposed by Roychowdhury and Wang [11]. The generalized union and generalized intersection of intuitionistic fuzzy sets based on TN and TCN were provided by Deschrijver and Kerre [5]. In 1978, Hamatcher introduced HOs known as Hamacher sum $(\oplus)$ and Hamacher product $(\otimes)$, which are examples of TN and TCN respectively and are given by

$$T_H(u_A, u_B) = u_A \oplus u_B = \frac{u_A + u_B - u_A u_B - (1-\varphi)u_A u_B}{1 - (1-\varphi)u_A u_B}. \quad (5)$$

$$T_H^* = (u_A, u_B) = u_A \otimes u_B) = \frac{u_A u_B}{\varphi + (1-\varphi)(u_A + u_B - u_A u_B}. \quad (6)$$

For $\varphi=1$, the Hamacher TN and TCN reduce to the forms:

$$T_H = (u_A, u_B) = u_A \oplus u_B = u_A + u_B - u_A u_B. \quad (7)$$

$$T_H^* = (u_A, u_B) = u_A \otimes u_B = u_A u_B. \quad (8)$$

T_H and T_H^* represent algebraic TN and TCN respectively. When $\xi = 2$, the Hamacher TN and TCN will conclude to the form

$$T_H = (u_A, u_B) = u_A \oplus u_B = \frac{u_A + u_B}{1 + u_A u_B}. \quad (9)$$

$$T_H^* = (u_A, u_B) = u_A \otimes u_B = \frac{u_A u_B}{1 + (1 - u_A)(1 - u_B)}. \quad (10)$$

We make use of the Hamacher operations on PFNs provided by Wei [7] and Wu & Wei [8]. Let *X* and *Y* be two PFSs, then Hamacher Sums and Products of the two PFSs *X* and *Y* are denoted by $(\hat{p}_1 \oplus \hat{p}_2)$ and $(\hat{p}_1 \otimes \hat{p}_2)$, respectively, and defined by

$$\hat{p}_1 \oplus \hat{p}_2 = \left(\frac{\hat{\mu}_{A1} + \hat{\mu}_{A2} - \hat{\mu}_{A1}\hat{\mu}_{A2} - (1-\varphi)\hat{\mu}_{A1}\hat{\mu}_{A2}}{1 - (1-\varphi)\hat{\mu}_{A1}\hat{\mu}_{A2}}, \frac{\hat{\theta}_1\hat{\theta}_2}{\varphi + (1-\varphi)(\hat{\theta}_1 + \hat{\theta}_2 - \hat{\theta}_1\hat{\theta}_2)}, \frac{\hat{\mu}_{B1}\hat{\mu}_{B2}}{\varphi + (1-\varphi)(\hat{\mu}_{B1} + \hat{\mu}_{B2} - \hat{\mu}_{B1}\hat{\mu}_{B2}} \right) \quad (11)$$

And

$$\hat{p}_1 \otimes \hat{p}_2 = \left(\frac{\hat{\mu}_{A1}\hat{\mu}_{A2}}{\varphi + (1-\varphi)(\hat{\mu}_{A1} + \hat{\mu}_{A2} - \hat{\mu}_{A1}\hat{\mu}_{A2}}, \frac{\hat{\theta}_1 + \hat{\theta}_2 - \hat{\theta}_1\hat{\theta}_2 - (1-\varphi)\hat{\theta}_1\hat{\theta}_2}{1 - (1-\varphi)\hat{\theta}_1\hat{\theta}_2}, \frac{\hat{\mu}_{B1} + \hat{\mu}_{B2} - \hat{\mu}_{B1}\hat{\mu}_{B2} - (1-\varphi)\hat{\mu}_{B1}\hat{\mu}_{B2}}{1 - (1-\varphi)\hat{\mu}_{B1}\hat{\mu}_{B2}} \right) \quad (12)$$

2.2. Model for Multiple Component Analysis (MCA)

In this section, Multiple Component Analysis (MCA) method using picture fuzzy information model is proposed based on the operators where weights are real numbers and values of attributes are PFNs. To illustrate effectiveness of the proposed MCA method, an application of neuro-psychopathology under picture fuzzy information is given. Let $Y = (y_1, y_2, \dots, y_r)$ be the discrete set of alternatives and $X = (x_1, x_2, \dots, x_s)$ be the set of attributes.

Let $\Phi = (\phi_1, \phi_2, \dots, \phi_s)$be the weight vector of the attribute such that $\phi_b > 0, (b = 1,2, \dots, s)$ and $\sum_{b=1}^{s} \phi_b = 1$, and let

$R = (\hat{\mu}_{ab}, \hat{\varphi}_{ab}, \hat{v}_{ab})$, be an r by s picture fuzzy decision matrix. Here, $\hat{\mu}_{ab}$ is the degree of the positive membership for which alternative Y_a satisfies the attribute X_b given by decision. $\hat{\varphi}_{ab}$ denotes the degree of neutral membership such that alternative Y_a does not satisfy the attribute X_b. $\hat{v}_{ab}$ provides the degree that the alternative Y_a does not satisfy the attribute X_b given by the decision.

Let $\hat{P} = (\hat{\mu}_{ab}, \hat{\varphi}_{ab}, \hat{v}_{ab})$ be a PFI. Then the score function is given by $\hat{S}_p$ is defined as

$$\hat{S}_p = \hat{\mu}_{ab} - \hat{v}_{ab}, \text{ where } \hat{S}_p \in [-1, 1]. \quad (13)$$

2.2.1. Steps in using MCA

Step 1. Construction of matrix R by decision under PF-Information

$$\begin{pmatrix} \hat{\alpha}_{11} & \hat{\alpha}_{12} \cdots & \hat{\alpha}_{1r} \\ \hat{\alpha}_{21} & \hat{\alpha}_{22} \cdots & \hat{\alpha}_{2r} \\ \vdots & \vdots \ \ddots & \vdots \\ & \hat{\alpha}_{a1}\hat{\alpha}_{a2}\hat{\alpha}_{ar} & \end{pmatrix}. \quad (14)$$

Step 2. Finding the values of $\hat{\alpha}_a$ $(a = 1,2, \dots, r)$ based on decision matrix R. These values are found by using PFH.

= PFH $(\hat{\alpha}_{a1}, \hat{\alpha}_{a2}, \dots, \hat{\alpha}_{ab}) = \bigoplus_{b=1}^{s} (\phi_b \hat{\alpha}_{ab}) =$

$$\left(\frac{\prod_{b=1}^{s}(1+(\xi-1)\hat{\mu}_b)^{\phi_b} - \prod_{b=1}^{s}(1-\hat{\mu}_b)^{\phi_b}}{\prod_{b=1}^{s}(1+(\xi-1)\hat{\mu}_b)^{\phi_b} + (\xi-1)\prod_{b=1}^{s}(1-\hat{\mu}_b)^{\phi_b}}, \frac{\xi\prod_{b=1}^{s}(\hat{\varphi}_b)^{\phi_b}}{\prod_{b=1}^{s}(1+(\xi-1)\hat{\varphi}_b)^{\phi_b} + \prod_{b=1}^{s}(\hat{\varphi}_b)^{\phi_b}}, \frac{\xi\prod_{b=1}^{s}(\hat{\upsilon}_b)^{\phi_b}}{\prod_{b=1}^{s}(1+(\xi-1)\hat{\upsilon}_b)^{\phi_b} + \prod_{b=1}^{s}(\hat{\upsilon}_b)^{\phi_b}} \right)\hat{\alpha}_a$$

Step 3. Calculate the score $\hat{S}(\hat{\alpha}_a), (1,2, \dots, r)$.

Step 4. Rank them $\phi_a > 0, (a = 1,2, \dots, r)$

Step 5. Arrange them in ascending order.

Step 6. Stop.

2.3. Numerical Example and Data Collection

Seven major causes of occupational psychopathology have been considered in this study according to DSM-IV-TR guidelines. These symptoms denote independent factor. Data of total number of 400 adult cases have been collected from two different hospitals. A control group (none) has been considered to validate the model. The grades of these cases are unknown. Appropriate ethical measures have been taken to preserve data privacies. Our study excludes Patients whose ages are below the working-class age (35 -60).

Table 1. Occupational Psychopathology (OCP) and the corresponding abbreviations.

Serial No	Symptoms	Abbreviation
1	Tension and anxiety	TAT
2.	Anger	ANG
3.	Aggression	AGG
4.	High blood pressure	HBP
5.	Inability to relax	ITR
6.	Excessive alcohol/tobacco use	EAL
7.	Forgetfulness & increased absenteeism	FIA

Step 1. Decision matrix R is constructed by a professional or expert under PF information as follows.

Step 2. Let $\xi = 4$. By using the PFH operator of the overall performances values $\hat{\alpha}_a$ of probable occupational stress, φ_a $(a = 1,2,3,4,5,6,7)$ are obtained as follows:

$\hat{\mu}_{ab}$=(0.45,0.9,0.2,0.35), $\hat{\varphi}_{ab}$ =(0.24,0.03,0.25,0.64) and $\hat{\upsilon}_{ab}$ = (0.10,0.04,0.29,0.05) with assign weight

ϕ_b =(0.15,0.20,0.25,0.18)

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$$\hat{\alpha}_1=\left(\begin{array}{c} \dfrac{[(1+3\times0.45)^{0.15}(1+3\times0.9)^{0.2}(1+3\times0.2)^{0.25}(1+3\times0.35)^{0.18}]-[(1-0.45)^{0.15}(1-0.9)^{0.2}(1-0.2)^{0.25}(1-0.35)^{0.18}]}{[(1+3\times0.45)^{0.15}(1+3\times0.9)^{0.2}(1+3\times0.2)^{0.25}(1+3\times0.35)^{0.18}]+2[(1-0.45)^{0.15}(1-0.9)^{0.2}(1-0.2)^{0.25}(1-0.35)^{0.18}]}, \\ \dfrac{4[(0.24)^{0.15}(0.03)^{0.2}(0.25)^{0.25}(0.64)^{0.18}]}{\left[(1+3\times(1-0.24))^{0.15}(1+3\times(1-0.03))^{0.2}(1+3\times(1-0.25))^{0.25}(1+3\times(1-0.64))^{0.18}\right]-2[(0.24)^{0.15}(0.03)^{0.2}(0.25)^{0.25}(0.64)^{0.18}]}, \\ \dfrac{3\times[(0.25)^{0.15}\times(0.07)^{0.2}\times(0.49)^{0.25}\times(0.01)^{0.18}]}{\left[(1+3\times(1-0.25))^{0.15}(1+3\times(1-0.07))^{0.2}(1+3\times(1-0.49))^{0.25}(1+3\times(1-0.01))^{0.18}\right]-2[(0.25)^{0.15}(0.07)^{0.2}(0.49)^{0.25}(0.01)^{0.18}]} \end{array}\right)$$

=(0.5153,0.1583,0.1679). By similar way $\hat{\alpha}_2, \hat{\alpha}_3\ \hat{\alpha}_4\ , \hat{\alpha}_5\ , \hat{\alpha}_6$ *and* $\hat{\alpha}_7$ are obtained as follows: $\hat{\alpha}_2$= (0.4108, 0.5328, 0.0247), $\hat{\alpha}_3$ = (0.5922, , 0.1175, 0.2894), $\hat{\alpha}_4$ = (0.3511, 0.2458, 0.1681), $\hat{\alpha}_5$= (0.4882,0.1249,0.2344), $\hat{\alpha}_6$ =(0.3542, 0.2349, 0.1067) and $\hat{\alpha}_7$ = (0.2486, 0.1354, 0.0158).

Step 3. By using the equation above 13, the score values $\hat{S}(\hat{\alpha}_a), (a = 1,2,3,4,5,7)$ of the overall PFIs $\hat{\alpha}_a$, $(a = 1,2,3,4,5,7)$ are obtained as follows

$\hat{S}(\hat{\alpha}_1)$ = 0.5153 – 0.1679 = 0.3474. Similarly, $\hat{S}(\hat{\alpha}_2)$ = 0.3861, $\hat{S}(\hat{\alpha}_3)$ = 0.3028, $\hat{S}(\hat{\alpha}_4)$ = 0.1830, $\hat{S}(\hat{\alpha}_5)$ = 0.2538, $\hat{S}(\hat{\alpha}_6)$ = 0.2457 *and* $\hat{S}(\hat{\alpha}_7)$ = 0.2300.

Step 4. The ranking order of φ_a $(a = 1,2,3,4,5,6,7)$ in accordance with the value of the score functions $\hat{S}(\hat{\alpha}_a), (a = 1,2,3,4,5,7)$ of the overall PFIs is as follows: $\varphi_2 > \varphi_1 > \varphi_3 > \varphi_5 > \varphi_6 > \varphi_7 > \varphi_4$.

Step 5. the first diagnosis will be focused on φ_2.

Step 6. Stop.

In comparisons with other existing methods (manual methods), the ranking order of alternatives is slightly different but the optimum alternative is more desirable and focuses on this method. Thus, the proposed method is stable and can be applied by any professional that has the machine that gives first aid diagnosis.

3. Conclusion

Our system has better advantages over the traditional approach of analyzing psychopathological conditions. The result is efficient in detecting the areas where the diagnosis should be focused. It thus proves to be a better tool that will aid physicians in medical decision process.

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