Fuzzy NoVaRM Approach to Medical Diagnosis via Analyzing the Risk Factors of Tuberculosis

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Abstract

Tuberculosis (TB) is a communicable disease that is caused by organisms known as Mycobacterium Tuberculosis. TB, typically affects the lungs. People with lung TB cough, sneeze or spit, which causes TB to spread via the air. Just a few bacteria must be inhaled for someone to become ill. Ten million people contract tuberculosis each year. Despite being a preventable and treatable condition, TB kills 1.5 million people annually, making it the leading infectious killer in the world. The key to reducing infection transmission and ultimately eliminating TB is early detection of the disease and successful treatment. In this context, this study proposes a technique called Fuzzy Normalized Value- based Ranking Method(F-NoVaRM) to provide a decision support platform for physicians in the effective diagnosis of TB.

Keywords: Fuzzy multi-criteria Decision making, F-NoVaRM, Risk factors, Tuberculosis, Mathematics Subject Classification (2020): 03B52, 03E72.

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1. Introduction

Decision-making models are the supporting systems that give decision-makers the necessary knowledge about the options and their features. Additionally, fuzzy-based Muti-Criteria Decision Making (MCDM) techniques give decision-makers the ability to assess the alternatives even in the absence of access to numerical data, making them more useful in a variety of circumstances. The two most crucial processes in a MCDM process are the calculation of the weight values of criteria and the value of the preferred alternatives to existing criteria. Decisions occasionally don't go as expected since subjectivity continues to be important. Additionally, a deeper study of the functions performed by each method is required in order to create one that is more precise. Therefore, selecting proper processes at least will result in the desired outcome. On the other hand, many scientists are still delving further into the study of decision-making procedures in an effort to develop a process that reduces the subjectivity of decision-makers.

The World Health Organization (WHO) Global Tuberculosis Report 2022 offers a thorough and current analysis of the TB epidemic as well as developments in the disease's prevention, diagnosis, and treatment at the international, regional, and national levels. This is carried out in line with international TB commitments, policies, and objectives. As is customary, the 2022 version of the report is mostly based on information collected by WHO from national ministries of health during annual data collection rounds. 202 nations and territories that account for more than 99% of global population and TB cases reported data in 2022. One of the top ten killers in the world is tuberculosis [4].

The COVID-19 pandemic continues to have a damaging impact on access to TB diagnosis and treatment and the burden of TB disease. Progress made in the years up to 2019 has slowed, stalled or reversed, and global TB targets are off track. The most obvious and immediate impact was a large global drop in the reported number of people newly diagnosed with TB. From a peak of 7.1 million in 2019, this fell to 5.8 million in 2020 (–18%), back to the level last seen in 2012. In 2021, there was a partial recovery, to 6.4 million (the level of 2016–2017). The three countries that accounted for most of the reduction in 2020 were India, Indonesia and the Philippines (67% of the global total). They made partial recoveries in 2021, but still accounted for 60% of the global reduction compared with 2019 [4].

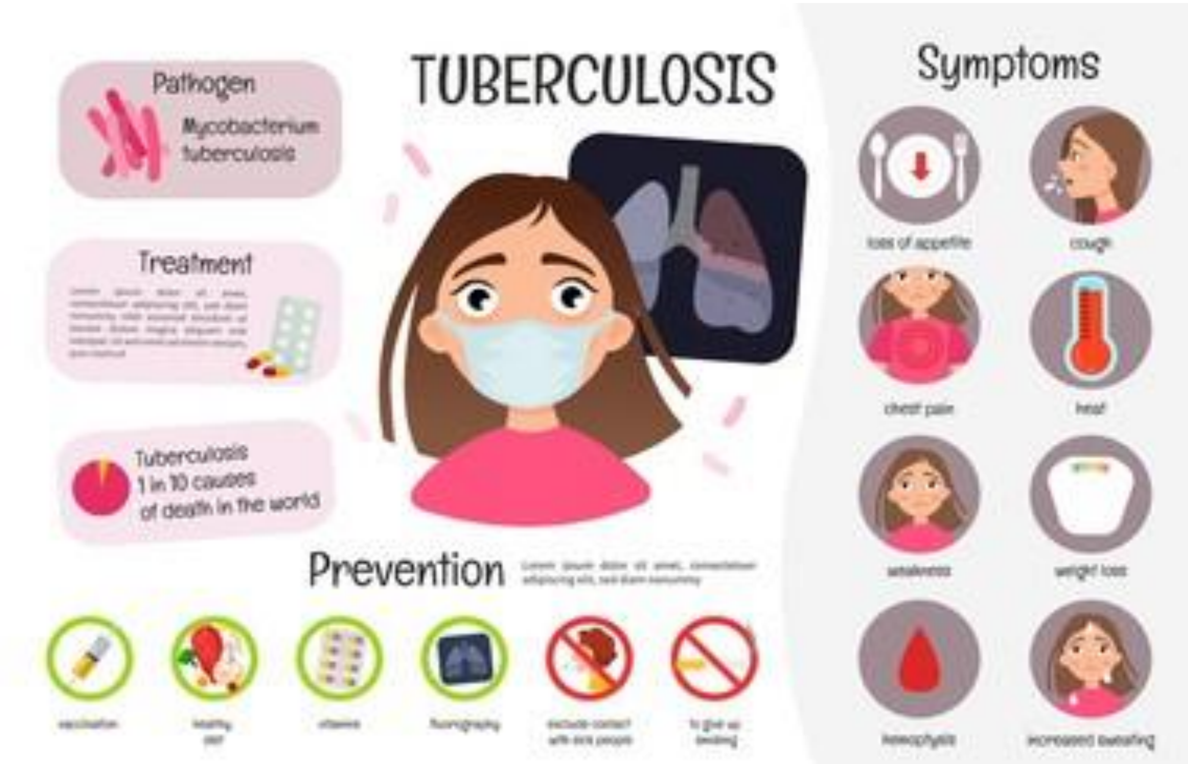


Fig1.Picture depicting symptoms, treatment and prevention of TB [Source: shutterstock.com]

There have been many studies carried out in the diagnosis of Tuberculosis under fuzzy environment. In 2016, Ekata, Praveen Kumar et al analysed pulmonary tuberculosis using the neuro-fuzzy inference system [1]. In 2018, Deny predicted TB disease using C4.5 algorithm. The result of this study is an application that can help people to make the diagnosis of TB disease from an early age. To recognize the types of tuberculosis, Imianvan in 2011 used the fuzzy expert system [6]. Web GIS-based valuation using SAW methods was designed to identify high risk [5]. Deep learning techniques were used to identify tuberculosis disease [14]. A fuzzy expert system was designed for the diagnosis of tuberculosis [9]. Classification and counting of MT from sputum microscopic images were done using fuzzy logic [12]. Fuzzy logic based medical expert system was framed for the diagnosis of chronic kidney disease [8].

Sebhatu S et al. analysed soft computing techniques were used for Pulmonary tuberculosis diagnosis [16]. Tuberculosis Association of India published all the most relevant topics related TB [17]. A Neuro-fuzzy inference system was designed for diagnosing tuberculosis [7]. In 2020 Erika Mutiara in a study the optimization of the Naive Bayes method was carried out with the Particle Swarm Optimization method as attribute selection to improve predictions accuracy applied to patient data that was declared positive tuberculosis and negative tuberculosis [2]. Mellado Pena et al. studied to identify the tuberculosis treatment for children especially focused on drug-resistant cases from the Spanish Society [10]. The Genetic-Neuro Fuzzy Inferential method was proposed for the diagnosis of TB [11]. An Artificial immune recognition system was framed to the diagnosis of tuberculosis disease [15]. In 2021, Ezhilarasan and Felix combined the salient features of ELECTRE and TOPSIS methods under a fuzzy environment to analyse the risk factors of TB. Moreover, the comparative analysis is demonstrated to find the most influencing risk factors of TB [3].

Here in this paper, adapting the data from [3], we are trying to present a comparatively easier Fuzzy decision-making method known as F-NoVaRM to find the utmost influencing risk factors of TB.

2. Preliminaries

In this section, we kindle memories of some introductory notions on the theory of fuzzy sets.

Definition 2.1. (Klir and Yuan, 2001)
Let X be the universal set. A fuzzy set in X is a set of ordered pairs,
A = {(x, μ_A(x)); x $\in$X}, where μ_A: X$\to$[0,1] is called the membership function of A in X and [0,1] is called the membership set.

Definition 2.2. [Gani and Mohamed, 2012]

A triangular fuzzy number (TFN) is defined as (a_1, a_2, a_3) where the membership function is given by

$$\mu_a(x) = \begin{cases} 0 & if \quad x \le a_1 \\ \frac{x-a_1}{a_2-a_1} = \mu_1(x) & if \quad a_1 \le x \le a_2 \\ \frac{a_3-x}{a_3-a_2} = \mu_2(x) & if \quad a_2 \le x \le a_3 \\ 0 & if \quad x \ge a_3 \end{cases} \tag{1}$$

Definition 2.3. Fuzzy Conversion Scale: Conversion scales that are used to convert linguistic concepts into fuzzy numbers.

3. Risk Factors and Stages of TB

3.1 Risk Factors of TB

The major risk factors related to TB infection and disease were identified as following:

Diabetes has been shown to increase the risk of active TB disease. It is estimated that currently 70% of people with diabetes live in low- and middle-income countries, and the rates are steadily increasing in areas where TB is endemic, including India and sub-Saharan Africa [13]. *Immunity problem* is one of the main important the risk factors of TB. *Malnutrition* research clarifies that both microbial and macro deficiency (malnutrition) increase the risk of tuberculosis due to the weakening of the immune system [3]. *Alcohol* has been recognized as a strong risk factor for TB disease, and a recent meta-analysis of molecular epidemiological studies has established alcohol as risk factor for clustering (or recent transmission of TB) in both high- (OR = 2.6, CI = 2.13–3.3) and low-incidence countries (OR = 1.4, CI = 1.1–1.9) [13]. Active smoking a meta-analysis of 24 studies on the effects of smoking found that smokers had a higher risk of developing tuberculosis compared to non-smokers, as evidenced by the deaths of active TB patients (RR = 2.3–2.7). Crowded places have been known as the main risk factor for TB disease and in the most crowded places TB was found to spread easily in the air by sneezing, coughing, spitting [3]. *HIV* coinfection exacerbates the severity of TB disease while additionally TB coinfection accelerates HIV replication in affected organs including lungs and pleura [13]. *Air pollution* is a risk factor for tuberculosis on an individual level. This is because based on studies conducted on ambient air pollution, it is reasonable to assume that it is related to the incidence of tuberculosis. *Health care workers* in 2019, the proportion of TB patients among health care workers will be more than double the TB report rate. In addition, 22,134 cases of tuberculosis were reported among health workers in 76 countries; 47% of these cases are in India and 18% in China [3].

3.2 Stages of TB [3]

Early Infection the immune system fights infection. Infected people may also have a fever, parathyroid lymphadenopathy, or dyspnoea. It continues without signs and symptoms. *Early Primary Progressive (active)* the immune system does no longer manages preliminary infection. Patients regularly have nonspecific symptoms or signs (e.g., fatigue, weight loss, fever). Non-efficient cough develops. Diagnosis may be difficult. *Late Primary Progressive (active)* the Cough will become efficient, with extra symptoms and signs because the ailment progresses. Patients enjoy modern weight loss, rales and anemia. *Latent* mycobacteria persist within the body. There occurs no symptoms or signs and even the sufferers do no longer sense sick, but it is identified by diagnosing them.

4. Fuzzy Normalized Value based Ranking Method -Algorithm [F-NoVaRM]

In this paper, we explore a new model to find the most influencing risk factors of TB. The proposed model is as follows:

Step 1: Decide the ratings of alternatives.

Among the various criteria in decision-making, some might be a benefit criterion (a criterion that provides a high potential in the study) and some others might be a cost criterion (a criterion providing a low potential in the study).

Step 2: Construct an initial fuzzy decision matrix as follows:

$$\widetilde{D}= \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{matrix} C_1 & C_2 \dots & C_n \end{matrix} \\ \begin{pmatrix} x_{11} & x_{12} \cdots & x_{1n} \\ x_{21} & x_{22} \cdots & x_{2n} \\ x_{31} & x_{32} \cdots & x_{3n} \end{pmatrix} \end{array} \quad (2)$$

Step 3: Compute the criteria weights by any available weighing methods.

Step 4: Normalize the initial fuzzy decision matrix as follows: - [Neelima B. Kore, 2017]

For Benefit criteria, $C_j^* = \max_i \; c_{ij}$ (3)

$$\text{Now, } \tilde{r}_{ij} = \left({a_{ij}}/{C_j^*}, {b_{ij}}/{C_j^*}, {c_{ij}}/{C_j^*} \right) \quad (4)$$

$$\text{For Cost criteria, } \bar{a}_j = \min_i \; a_{ij} \quad (5)$$

$$\text{Now, } \tilde{r}_{ij} = \left({\bar{a}_j}/{c_{ij}}, {\bar{a}_j}/{b_{ij}}, {\bar{a}_j}/{a_{ij}} \right) \quad (6)$$

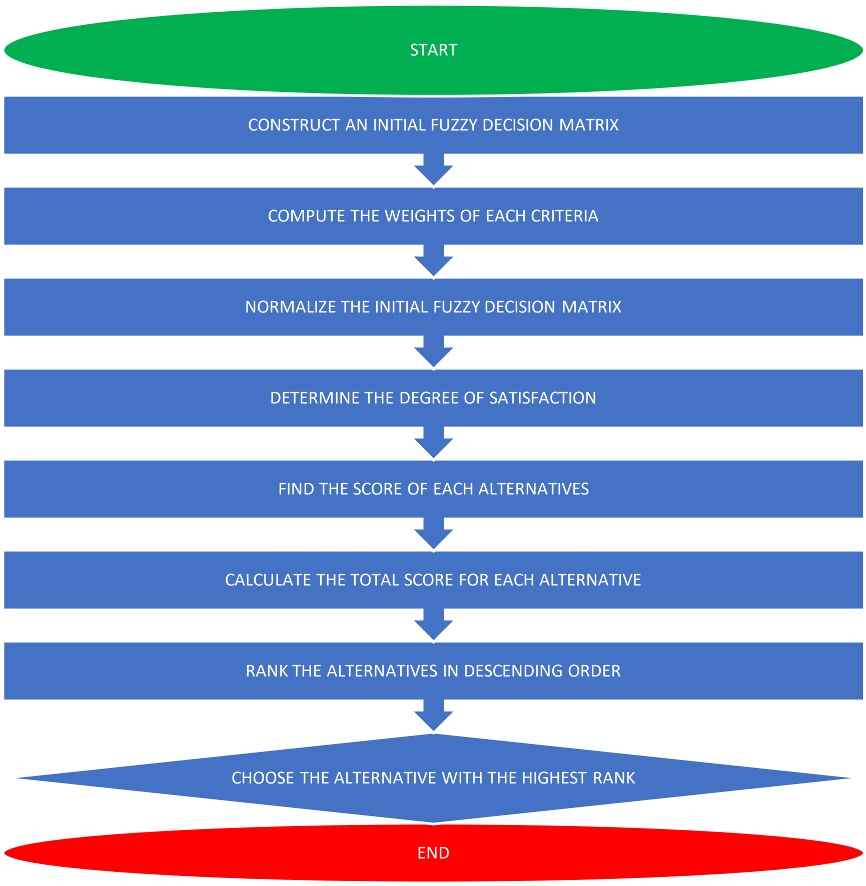
Step 5: Determine the degree of satisfaction by using the following equation:

$$d_{ij} = Val\,(a_{ij}, b_{ij}, c_{ij}) \quad (7)$$

Step 6: Calculate the score of each alternative by multiplying the degree by the corresponding weights of the criteria.

Step 7: Compute the total score for each alternative.

Step 8: Rank the alternatives in descending order.



ONSTRUCT AN I NITIAL
FUZZY DECISION MATRIX

Fig 2. Framework of methodology

5. F-NoVaRM on analyzing the risk factors of TB

This study's primary goal is to identify the biggest risk factor for tuberculosis based on its signs and symptoms. As a result, the risk variables for tuberculosis are ranked using decision-making algorithms. The risk factors are examined in light of the perspectives of the three decision-makers [3]. 10 risk variables, and 4 criteria were used for the analysis.

Step 1: Decide the ratings of alternatives.

Initially, possible alternatives and criteria are framed and evaluated with three decision-makers. Here we consider all the criteria as beneficiary criteria [3].

Table 1. List of Alternatives (Risk factors of Tuberculosis)

Risk factors	Notations
Diabetes	A_1
Immunity problem	A_2
Malnutrition	A_3
Alcohol	A_4
Active smoking	A_5
Crowded places	A_6
HIV infection	A_7
Air pollution	A_8
Kidney diseases and Cancer	A_9
Health care workers (In TB affected regions)	A_{10}

Table 2. List of Criteria (Stages of tuberculosis)

Criteria	Notations
Early infection	C_1
Early primary progressive	C_2
Late primary progressive	C_3
Latent	C_4

Table 3. Fuzzy Conversion Scale [3]

Linguistic Variables	Triangular Fuzzy numbers
Very Low Risk (VLR)	(0,0,0.25)
Low Risk (LR)	(0,0.25,0.5)
Medium Risk (MR)	(0.25,0.50,0.75)
High Risk (HR)	(0.50,0.75,1.00)
Very High Risk (VHR)	(0.75,1.00,1.00)

Step 2: The initial fuzzy decision matrix is as follows:

Table 4. Fuzzy Initial Decision Matrix

Alternatives/Criteria	C_1	C_2	C_3	C_4
A_1	**(0,.0.42,0.75)**	**(0.25,0.5,0.75)**	**(0.25,0.58,1)**	**(0.5,0.92,1)**
A_2	**(0.5,0.83,1)**	**(0.75,0.92,1)**	**(0.5,0.92,1)**	**(0.75,1,1)**
A_3	**(0.25,0.67,1)**	**(0.25,0.67,1)**	**(0.5,0.75,1)**	**(0.5,0.83,1)**
A_4	**(0,0,0.25)**	**(0,0,0.25)**	**(0,0.08,0.5)**	**(0,0.08,0.5)**
A_5	**(0,0.33,0.75)**	**(0,0.42,0.75)**	**(0.25,0.58,1)**	**(0.25,0.67,1)**
A_6	**(0,0.25,0.75)**	**(0,0.33,0.75)**	**(0,0.5,1)**	**(0,0.42,0.75)**
A_7	**(0.75,1,1)**	**(0.75,1,1)**	**(0.75,1,1)**	**(0.75,1,1)**
A_8	**(0,0.08,0.5)**	**(0,0.17,0.5)**	**(0,0.33,1)**	**(0,0.33,0.75)**
A_9	**(0,0.25,0.5)**	**(0,0.42,0.75)**	**(0,0.42,0.75)**	**(0.25,0.67,1)**
A_{10}	**(0.5,0.75,1)**	**(0.5,0.75,1)**	**(0,0.58,1)**	**(0.75,1,1)**

Step 3: The criteria weights calculated by entropy method [3] are as follows:

$$w(C_1) = 0.409, w(C_2) = 0.5, w(C_3) = 0.585, w(C_4) = 0.849.$$

Step 4: Using equations 3 and 4 we obtained the following matrix.

Table 5. Normalised Fuzzy Initial Decision Matrix

Alternatives/Criteria	C_1	C_2	C_3	C_4
A_1	**(0,.0.42,0.75)**	**(0.25,0.5,0.75)**	**(0.25,0.58,1)**	**(0.5,0.92,1)**
A_2	**(0.5,0.83,1)**	**(0.75,0.92,1)**	**(0.5,0.92,1)**	**(0.75,1,1)**
A_3	**(0.25,0.67,1)**	**(0.25,0.67,1)**	**(0.5,0.75,1)**	**(0.5,0.83,1)**
A_4	**(0,0,0.25)**	**(0,0,0.25)**	**(0,0.08,0.5)**	**(0,0.08,0.5)**
A_5	**(0,0.33,0.75)**	**(0,0.42,0.75)**	**(0.25,0.58,1)**	**(0.25,0.67,1)**
A_6	**(0,0.25,0.75)**	**(0,0.33,0.75)**	**(0,0.5,1)**	**(0,0.42,0.75)**
A_7	**(0.75,1,1)**	**(0.75,1,1)**	**(0.75,1,1)**	**(0.75,1,1)**
A_8	**(0,0.08,0.5)**	**(0,0.17,0.5)**	**(0,0.33,1)**	**(0,0.33,0.75)**
A_9	**(0,0.25,0.5)**	**(0,0.42,0.75)**	**(0,0.42,0.75)**	**(0.25,0.67,1)**
A_{10}	**(0.5,0.75,1)**	**(0.5,0.75,1)**	**(0,0.58,1)**	**(0.75,1,1)**

Step 5: Computing the degree of satisfaction by equation 7 gives:

Table 6. Satisfaction Matrix

Alternatives/Criteria	C_1	C_2	C_3	C_4
A_1	**0.41**	**0.5**	**0.6**	**0.86**
A_2	**0.80**	**0.91**	**0.6**	**0.96**
A_3	**0.66**	**0.66**	**0.86**	**0.80**
A_4	**0.04**	**0.04**	**0.14**	**0.14**
A_5	**0.35**	**0.41**	**0.595**	**0.66**
A_6	**0.29**	**0.35**	**0.5**	**0.41**
A_7	**0.96**	**0.96**	**0.96**	**0.96**
A_8	**0.14**	**0.197**	**0.39**	**0.35**
A_9	**0.25**	**0.41**	**0.41**	**0.66**
A_{10}	**0.75**	**0.75**	**0.55**	**0.96**

Step 6: Score matrix is as follows:

Table 7. Score Matrix

Alternatives/Criteria	C_1	C_2	C_3	C_4
A_1	**0.17**	**0.25**	**0.35**	**0.73**
A_2	**0.33**	**0.46**	**0.35**	**0.82**
A_3	**0.27**	**0.33**	**0.50**	**0.68**
A_4	**0.02**	**0.02**	**0.08**	**0.12**
A_5	**0.14**	**0.21**	**0.35**	**0.56**
A_6	**0.12**	**0.18**	**0.29**	**0.35**
A_7	**0.39**	**0.48**	**0.56**	**0.82**
A_8	**0.06**	**0.098**	**0.23**	**0.297**
A_9	**0.10**	**0.21**	**0.24**	**0.56**
A_{10}	**0.31**	**0.38**	**0.32**	**0.82**

Step 7: Total scores of the alternatives are given below:

Table 8. Total Scores of alternatives

Score (A_1)	**1.5**
Score (A_2)	**1.96**
Score (A_3)	**1.78**
Score (A_4)	**0.24**
Score (A_5)	**1.26**
Score (A_6)	**0.94**
Score (A_7)	**2.25**
Score (A_8)	**0.685**
Score (A_9)	**1.11**
Score (A_{10})	**1.83**

Step 8: On ranking the alternatives in descending order,

Table 9. Ranking of Alternatives

Scores	**Total score**	**Rank**
Score (A_1)	**1.5**	**5**
Score (A_2)	**1.96**	**2**
Score (A_3)	**1.78**	**4**
Score (A_4)	**0.24**	**10**
Score (A_5)	**1.26**	**6**
Score (A_6)	**0.94**	**8**
Score (A_7)	**2.25**	**1**
Score (A_8)	**0.685**	**9**
Score (A_9)	**1.11**	**7**
Score (A_{10})	**1.83**	**3**

$$A_7 > A_2 > A_{10} > A_3 > A_1 > A_5 > A_9 > A_6 > A_8 > A_4.$$

According to the newly developed F-NoVaRM approach the most influencing risk factor of tuberculosis is HIV infection.

6. Conclusion

The purpose of this article is to provide a new fuzzy MCDM technique F-NoVaRM to find the highest risk factor that causes tuberculosis. Here we conclude that the most influencing factor of TB is HIV infection. While conducting the same study using the most popular fuzzy MCDM techniques such as ELECTRE 1 and TOPSIS we observe that the optimal solution remains the same which shows the consistency and reliability of the proposed method. The advantage of the developed method is that it requires less computational effort compared to the existing methods. For future studies, one may extend this technique to various other areas of medical fields such as medical diagnosis, medical device selection and so on.

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