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A fuzzy NoVaRM vaccine selection decision-making model for Covid-19 : A case study in India

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Abstract

The SARS-CoV-2 virus causes coronavirus disease (Covid-19), an infectious disease that has recently become a major problem for nations all over the world. Vaccines are effective interventions for fighting a pandemic. The selection of vaccines is a pressing problem for public health authorities. Multi-Criteria Decision-Making (MCDM) is the best technique to offer a suitable solution. Here, in this research paper, we propose a new Fuzzy decision-making technique called the Fuzzy Normalized Value-based Ranking Method (F-NoVaRM) that could lead to the acceptance or rejection of a vaccine from several vaccine alternatives based on certain criteria such as feasibility, efficacy, age, price, and the interval between the doses.

Subject Classification (2010): *03B52, 03E72, 08 A72, 15B15, 68Q25, 62L86.*

Keywords: *Fuzzy multi-criteria decision-making methods, F-NoVaRM, Covid-19, Corona vaccination.*

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1. Introduction

"A novel coronavirus strain known as SARS-CoV-2 was discovered in Wuhan, China, on the eve of 2020. The number of confirmed cases of the infection, known as Covid-19, exceeded 80,000 by the end of February. A worldwide health emergency was proclaimed after the illness spread to 30 other nations. Nearly 3,000 people had died from Covid-19 in just two months, and many more were in danger." [Salzburg Global Seminar].

"A vast family of viruses known as coronaviruses (CoV) (Fig. 1) can cause illnesses ranging from the common cold to more serious conditions like Severe Acute Respiratory Syndrome (SARS-CoV) and Middle East Respiratory Syndrome (MERS-CoV). A novel coronavirus (nCoV) is a strain of the virus that has never been found in humans before." [WHO]

The majority of virus-infected individuals will recover without the need for special care after experiencing mild to moderate respiratory symptoms. Some people, nevertheless, will get quite sick and need medical help. "Serious illnesses are more common in older adults and those with underlying medical disorders such as diabetes, cancer, chronic respiratory diseases, or cardiovascular disease. At any age, anyone can contract Covid-19 and either become gravely ill or pass away. Knowing the sickness and how the virus spreads is the greatest strategy to stop or slow down transmission" [WHO].

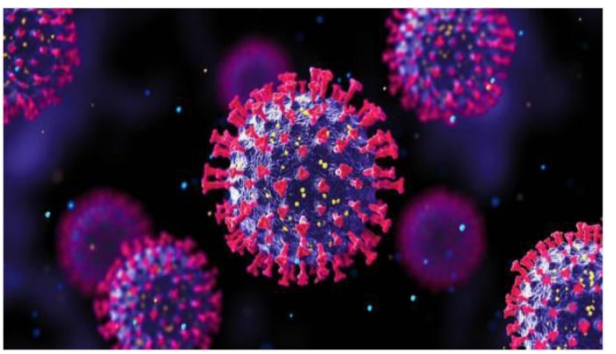
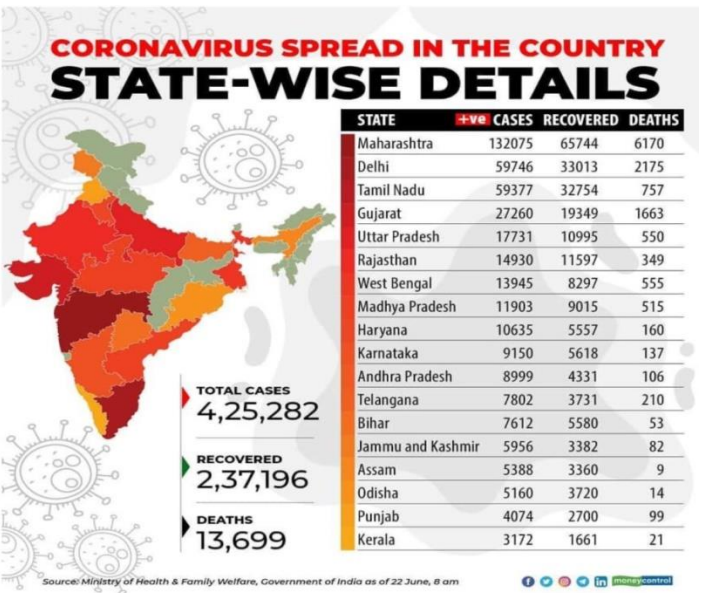


Figure 1
Corona Virus
[Source: https://www.istockphoto.com/photos/coronavirus]

Vaccines are efficient treatments that can lower the high rate of sickness worldwide. In order to recover from the recent Covid-19 epidemic, there is an urgent need for universal immunisation coverage. There are already a number of vaccines that can be implemented worldwide [2]. However, due to a lack of relevant information regarding the immunisation, many are worried about its safety and effectiveness [6], which contributes to vaccine reluctance. It should be noted, therefore, that the increasing apprehensions regarding the safety and effectiveness of the vaccine may cause this vaccination procedure to be delayed [6].

"More than 30 vaccine candidates were being developed in India as of early May 2020, with many of them already undergoing pre-clinical testing. The largest vaccine manufacturer in the world is Serum Institute of India (SII), situated in Pune. India can play a significant role in the COVAX program, which distributes vaccines to underdeveloped nations, thanks to its current capability." [Source-Wikipedia]. Figure 2 shows the state wise details of Corona virus spread in the country.

"Made by Bharat Biotech, a Hyderabad-based biotechnology company, Covaxin is the first Indian vaccine against the Covid-19-causing coronavirus. It is made from an inactivated virus [11, 12]. When introduced to a healthy human body, the inactivated virus triggers an immune response, developing antibodies to fight it [3]. These antibodies prove useful in preventing a severe case of Covid-19 when the person is exposed to live coronavirus. Covishield has been developed by Oxford-AstraZeneca and is being manufactured by the SII. It is an inactivated viral vaccine [13]. Covaxin and Covidshield remain the most popular and readily available options in India. Russian researchers at the Gamaleya Research Institute of Epidemiology and Microbiology created the adenovirus viral vector vaccination known as Sputnik to prevent Covid-19. The Russian Ministry of Health registered it on August 11, 2020, making it the first combination vector vaccination for Covid-19 prevention in history." [Source-Wikipedia].



STATE	+ve CASES	RECOVERED	DEATHS
Maharashtra	132075	65744	6170
Delhi	59746	33013	2175
Tamil Nadu	59377	32754	757
Gujarat	27260	19349	1663
Uttar Pradesh	17731	10995	550
Rajasthan	14930	11597	349
West Bengal	13945	8297	555
Madhya Pradesh	11903	9015	515
Haryana	10635	5557	160
Karnataka	9150	5618	137
Andhra Pradesh	8999	4331	106
Telangana	7802	3731	210
Bihar	7612	5580	53
Jammu and Kashmir	5956	3382	82
Assam	5388	3360	9
Odisha	5160	3720	14
Punjab	4074	2700	99
Kerala	3172	1661	21

Figure 2
CORONA-19 Spread- State wise Details
[Source: Ministry of Health &Family Welfare, June22, 2022]

Recently many studies have been conducted on predicting the probability of CORONA virus outbreak [1]. “As the prediction of real time transmission of Covid-19 is crucial, in 2020 Vijander singh and Ramesh Chandra Poonia produced a real time forecast using the SVM model. This model helped to plan resources, determine government policy, and provide survivors with immunity passports, and use the same plasma for care” [17]. Later, Bhatnagar and Poonia in a study conducted a descriptive analysis of Covid-19 in special reference of India based on different attributes such as age, gender, travel history, communication type and current status. They concluded that age is not a significant factor that affect a person to be captured by this disease and found a significant relationship between gender (male and female) and Transmission Type (imported from other country or communicated from local) of the patients [18, 19].

The selection of vaccination is an MCDM problem. There are different techniques to solve MCDM problems [5]. Here in the current study, we are proposing a new fuzzy value-based ranking method known as F-NoVaRM for selecting the most suitable Covid-19 vaccine (Fig. 3). This study mainly focuses on three types of vaccines such as Covishield, Sputnik, and Covaxin which we assumed as the alternatives A_1, A_2, and A_3. In order to select the best type of vaccine we need to rank the alternatives based on some criteria. Let the criteria under consideration be feasibility (C_1), efficacy (C_2), age (C_3), price (C_4), and the interval between the doses (C_5) [14, 15, 16].

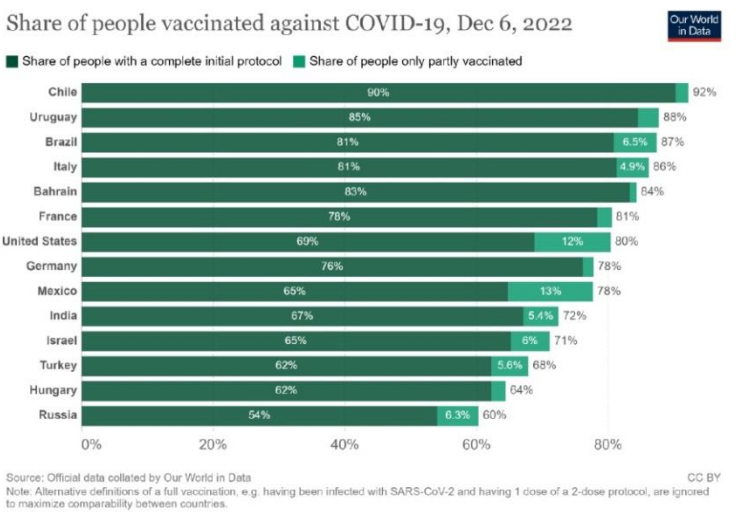


Figure 3
Chart Depicting the Vaccination Rate over worldwide
[Source: Our World in Data]

2. Preliminaries

This section presents some of the basic notions needed for the following sections.

Definition 1: (Fuzzy Set) [4]. Let X be the universal set. A fuzzy set in X is a set of ordered pairs, A ={(x, $\mu_A(x)$): x ∈ X} where μ_A: X → [0, 1] is called the membership function of A in X and [0, 1] is called the membership set.

Definition 2: (Triangular Fuzzy Number) [4]

"A triangular fuzzy number A is defined as (a_1, a_2, a_3) where the membership function is given by", (Fig. 4)

$$\mu_A(x) = \begin{cases} 0, & \text{if } x \le a_1 \\ \frac{x-a_1}{a_2-a_1} = p_1(x), & \text{if } a_1 \le x \le a_2 \\ \frac{a_3-x}{a_3-a_2} = p_2(x), & \text{if } a_2 \le x \le a_3 \\ 0, & \text{if } x \ge a_3 \end{cases} \quad (1)$$

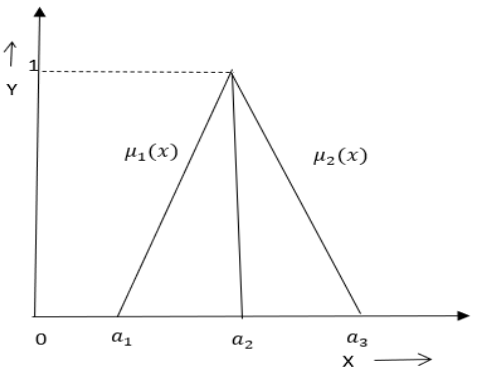


Figure 4
Triangular Fuzzy Membership Function

Definition 3: (Value of a Triangular Fuzzy number) [7]. The value of a triangular fuzzy number A = (a_1, a_2, a_3) is Val

$$(A) = \frac{a_1}{6} + \frac{2a_2}{3} + \frac{a_3}{6} \quad (2)$$

Definition 4: (Fuzzy Conversion Scale). "Conversion scales are used to convert linguistic concepts into fuzzy numbers. Normally, the criteria and options are rated on a scale of 1 to 9. Here we make use of triangular fuzzy numbers to represent the five linguistic ratings that have a consistent representation from 1 to 9" [8].

Definition 5: (Linguistic Variable) [Zadeh, 1973]. "Variables whose values are words or sentences in a natural or artificial language."

Table 1
Fuzzy Ratings for Linguistic Variables

Linguistic Variables	Triangular Fuzzy Number
Extremely Insignificant	(1, 1, 3)
Insignificant	(1, 3, 5)
Significant	(3, 5, 7)
Moderately Significant	(5, 7, 9)
Extremely Significant	(7, 9, 9)

3. The pairwise comparison method [9]

"Several populations are analysed in pairs using this method to see whether there are any notable differences between them. It may also be described as a process by which the decision-maker assesses the degree of preference for each pair of criteria by contrasting them with one another. To assist in comparing the preference value of one criterion to the other, an ordinal scale (1–9) is used. It is possible to calculate the number of comparisons using Cp=(n(n-1))/2. where n is the number of criteria and Cp is the number of comparisons. There are two primary processes in determining the criteria weights using the pairwise comparison approach. The first step is to compare the criteria and create a matrix. The matrix is filled with intensity values, such as 1, 3, 5, 7, and 9, which stand for equal importance, moderate importance of one over the other, strong importance, very strong importance, and extreme importance respectively. The lower left numbers in the matrix are inverse values, while the diagonal is always 1. Activity j has the reciprocal value when compared to activity i if activity i has one of the aforementioned values allocated to it. The reciprocal values of the upper diagonal are used to fill the lower triangular matrix. As a result, the comparison matrix is finished. The criteria weight, sometimes referred to as the principal eigenvector or the priority value, must be determined in the second phase. The values in each column are added up in this phase, and the sum of the normalised scores for each row is divided by the number of criteria. Each element is then divided by the total number of columns."

4. Methodology [4]

The methodology of formulating the new algorithm for the selection of the best Covid-19 vaccination is divided into three phases. The first phase is identification [10]. In this phase, we have identified the various criteria influencing vaccination selection and the available vaccination as alternatives with the help of decision-makers who are experts in the medical field. Afterwards in the second phase, a questionnaire was designed to achieve the objectives of this study. For administering the survey a team of three decision-makers who are experts in the medical field was selected [4]. From the responses of decision-makers obtained, we built an initial fuzzy decision-making matrix by taking the average [4]. The third phase proposes an MCDM solution

based on the F-NoVaRM to prioritize the alternatives[4]. These phases are discussed in detail in the following sections.

5. Fuzzy Normalized Value-based Ranking Method (F-NoVaRM) [4]

Here in this paper, we have introduced a comparatively easier method to prioritize the alternatives based on the various criteria available. Also, we have developed an algorithm for the proposed method. The procedure steps which fall under the F-NoVaRM algorithm are presented as follows.

Step 1: Decide the ratings of alternatives as described in table 1. [4]

Some of the criteria used in the decision-making process may be cost criteria, which have a low potential in the study, while others may be benefit criteria, which have a high potential in the study [4]. In the present study, as per the suggestion obtained from the experts, we assumed C_2 and C_5 as the benefit criteria and C_1, C_3, and C_4 as the cost criteria [4].

Step 2: Construct an initial fuzzy decision matrix as follows: [4]

$$\widetilde{D} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & C_2 \ldots & C_n \end{array} \\ \begin{pmatrix} x_{11} & x_{12} \ldots & x_{1n} \\ x_{21} & x_{22} \ldots & x_{2n} \\ x_{31} & x_{32} \ldots & x_{3n} \end{pmatrix} \end{array} \tag{3}$$

Step 3: Compute the criteria weights by Pairwise Comparison Method.[4]

Step 4: Normalize the initial fuzzy decision matrix as follows: - [8]

For Benefit criteria,

$$C_j^* = \max_i \; c_{ij} \tag{4}$$

Now,
$$\bar{r}_{ij} = \left(a_{ij} \Big/ C_j^* , \; b_{ij} \Big/ C_j^* , \; c_{ij} \Big/ C_j^* \right) \tag{5}$$

For Cost criteria,

$$\bar{a}_j = \min_i \; a_{ij} \tag{6}$$

Now,
$$\bar{r}_{ij} = \left(\bar{a}_j \Big/ c_{ij} , \; \bar{a}_j \Big/ b_{ij} , \; \bar{a}_j \Big/ a_{ij} \right) \tag{7}$$

Step 5: Determine the degree of satisfaction by using the following equation:[4]

$$d_{ij} = \mathrm{Val}\,(a_{ij}, b_{ij} , c_{ij}) \tag{8}$$

Step 6: Calculate the score of each alternative by multiplying the degree by the corresponding weights of the criteria.[4]

Step 7: Compute the total score for each alternative.[4]

Step 8: Rank the alternatives in descending order.[4]

The framework of the methodology is presented by means of a flow chart (Fig.5)

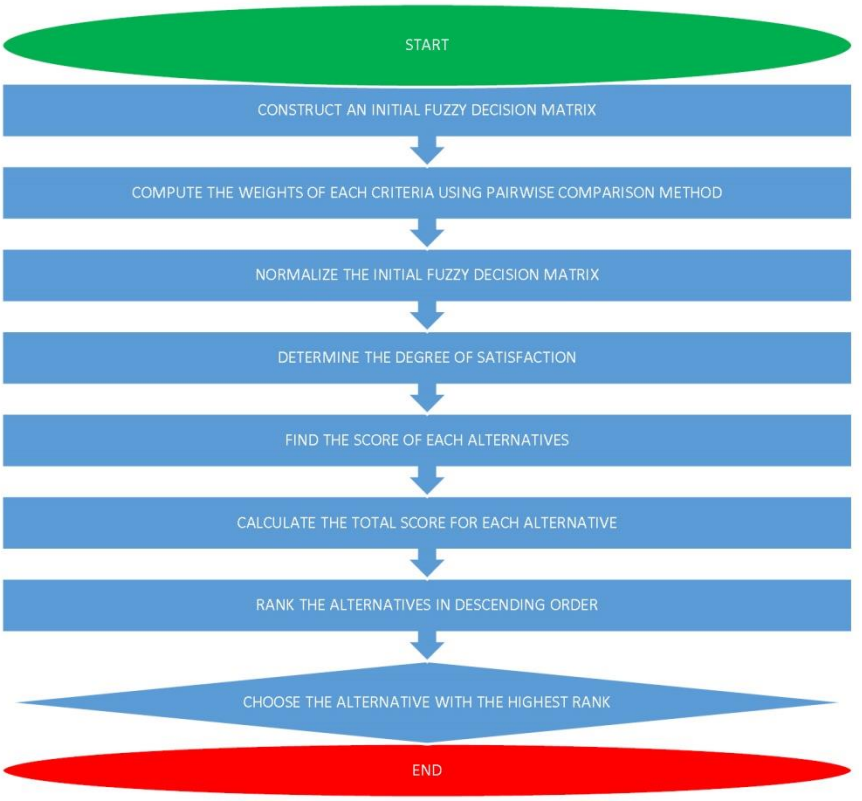


Figure 5
Framework of methodology [4]

6. Model construction

"Fuzzy modelling is concerned with constructing models that flexibly cope with heterogeneous data including those of linguistic and numerical character. The tools of fuzzy modelling enable the transformation of a linguistic description into an algorithm whose result is an action. The main theories applied in fuzzy modelling are fuzzy logic and the fuzzy set theory. In a fuzzy model, variables may represent fuzzy subsets of the universe." [Wiley Online Library].

Questionnaires are the most widely used instruments of data gathering. As mentioned earlier, a questionnaire survey was performed here. For conducting

the survey, we had selected a team of 3 decision-makers who are experts in the medical field. Here we have assumed A_1, A_2, and A_3, as the Covid vaccines, Covishield, Covaxin, and Sputnik respectively, and the various criteria as feasibility (C_1), efficacy (C_2), age (C_3) price (C_4) and the interval between the doses (C_5).

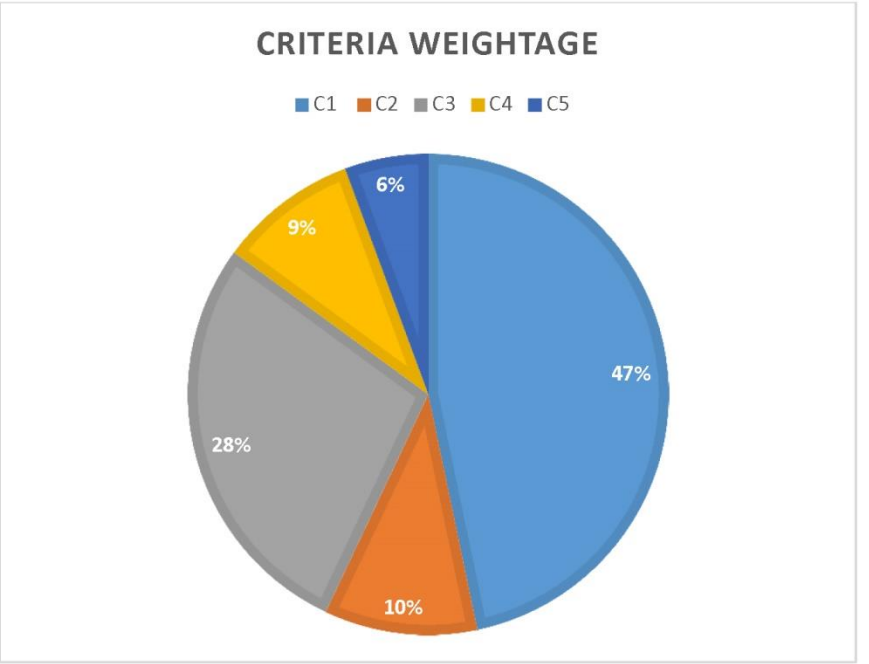


Figure 6
Pie chart depicting the criteria weightage

We took the average of the responses and constructed the initial fuzzy decision matrix as follows (Table 2):

Table 2
Initial fuzzy decision matrix

	C_1	C_2	C_3	C_4	C_5
A_1	(4, 6, 8)	(6, 8, 9)	(3, 5, 7)	(4, 6, 8)	(4, 6, 8)
A_2	(6, 6, 8)	(6, 8, 8)	(3, 5, 7)	(6, 8, 9)	(4, 6, 8)
A_3	(4, 6, 8)	(6, 8, 9)	(3, 5, 7)	(6, 8, 9)	(3, 5, 7)

By the Pairwise comparison method the criteria weights are obtained as $W(C_1) = 0.5, W(C_2) = 0.11, W(C_3) = 0.3, W(C_4) = 0.1, W(C_5) = 0.06$. (Fig. 6)

On normalizing the initial fuzzy decision matrix (Table 3),

Table 3
Normalized decision- matrix

	C_1	C_2	C_3	C_4	C_5
A_1	(0.50, 0.67, 1)	(0.67, 0.89, 1)	(0.43, 0.6, 1)	(0.5, 0.67, 1)	(0.5, 0.75, 1)
A_2	(0.5, 0.67, 0.67)	(0.67, 0.89, 0.89)	(0.43, 0.6, 1)	(0.44, 0.5, 0.67)	(0.5, 0.75, 1)
A_3	(0.5, 0.67, 1)	(0.67, 0.89, 1)	(0.43, 0.6, 1)	(0.44, 0.5, 0.67)	(0.38, 0.62, 0.88)

The degree of satisfaction (Table 4) and score matrix (Table 5) is as follows:

Table 4
Degree of satisfaction matrix

	C_1	C_2	C_3	C_4	C_5
A_1	0.69	0.87	0.64	0.69	0.75
A_2	0.64	0.85	0.64	0.52	0.75
A_3	0.69	0.87	0.64	0.52	0.62

Table 5
Score matrix

	C_1	C_2	C_3	C_4	C_5
A_1	0.35	0.10	0.19	0.07	0.04
A_2	0.32	0.09	0.19	0.05	0.04
A_3	0.35	0.10	0.19	0.05	0.04

Finally, the total scores obtained are Score $(A_1) = 0.75$, Score $(A_2) = 0.70$, Score $(A_3) = 0.72$ On arranging the scores in descending order, we get $\boldsymbol{A_1 > A_3 > A_2}$

Figure 7 shows the ranking of various types of vaccines based on the F-NoVaRM algorithm. The results indicate that the Covishield vaccine has got the highest score which shows that if we want to select the most suitable vaccine, the Covishield will be the best choice among all the other types of vaccines available. A C++ program for the algorithm can be found here https://onlinegdb.com/Tkky24vyJ [4].

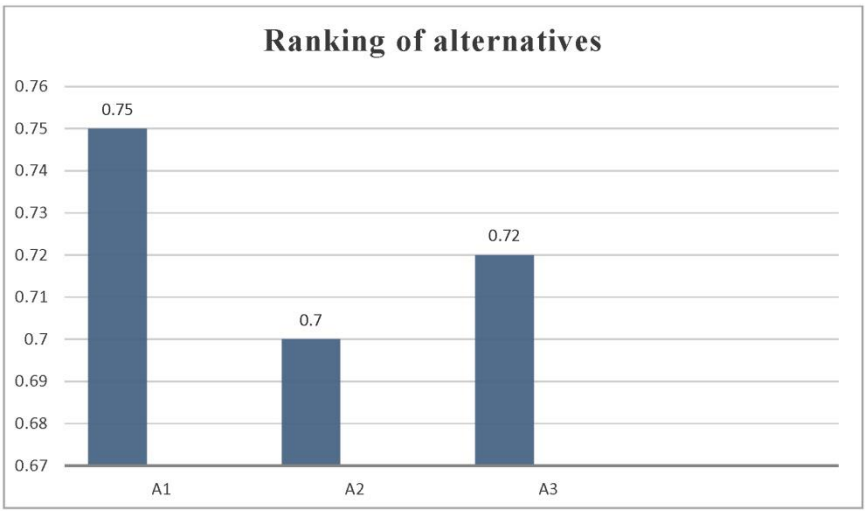


Figure 7
Ranking of alternatives

7. Conclusion

The development of the F-NoVaRM is the main contribution of this paper. The objective of our work is to introduce a comparatively easier fuzzy multi-criteria decision-making method that has the ability to select the best alternative. An algorithm based on a C++ program has also been developed and implemented. The ranking order of the alternatives according to the newly developed method is absolutely the same when using the other different MCDM methods. This shows that the proposed method has very high stability in ranking the alternatives. F-NoVaRM is a straightforward approach needing less computational effort. The proposed method provides very promising results and possibilities.

Data Availability

Upon request, the corresponding author is ready to provide the data that supported the study's conclusions.

Conflicts of Interest

The authors have no conflicts of interest.

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