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A NEW HYBRID MULTI-CRITERIA DECISION APPROACH FOR EVALUATING AND BENCHMARKING VACCINES

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Abstract- The outbreak of coronavirus has posed a significant threat to all sectors of life. Therefore, the World Health Organization (WHO) has urged a concerted effort to develop an effective vaccine to limit the spread of this virus among the population. Many vaccines have been produced in several countries in accordance with specified criteria. This study evaluated these vaccines using a variety of criteria. However, conflicting criteria provided a significant obstacle during the appraisal process. This article aims to evaluate and compare the COVID-19 vaccines currently licensed for emergency use worldwide. This study applied a novel hybrid multi-criteria decision approach by integrating the entropy method and MOORA technique to select the optimum vaccine. The methodology is down into two steps: 1) calculating weights for seven criteria, and 2) calculating the rank of eight COVID-19 vaccines. The findings showed that Johnson and Johnson vaccine is the best alternative, while the Pfizer-BioNTech vaccine is the worst. The study's implications helped countries to select the best vaccines for immunizing people and preventing the virus spread among them.

Keywords: COVID-19 Vaccines, Entropy Method, MOORA Method, Multiple Criteria, MCDM Techniques.

1. INTRODUCTION

The world is still under the influence of the pandemic, which has completely changed normal life. To avoid the rapid development of COVID-19, medical teams of epidemiologists must be established to combat this pandemic. The WHO was notified of the first infection case in Wuhan, China, in late December of 2019. Since then, the number of human infections has increased in numerous countries. As a result, the WHO has called for emergency meetings in all health centers and medical institutes around the world to combat this disease [1]. The WHO has also recommended companies follow basic strategies for these vaccines, which rely on mRNA, adenovirus vectors, inactivated viruses, and recombinant proteins, for inclusion in the licensing phase and emergency use in health centers [2]. Therefore, many medical institutes and pharmaceutical businesses applied for permission to produce the vaccine against the virus. Several vaccines were granted emergency authorization after completing Phase III trials [3], [4].

This study identifies innovative vaccines that have been agreed upon by the World Health Organization. Several COVID-19 vaccines were produced by numerous companies around the world recently after getting final approval to be used. While the most prominent vaccines such as Moderna was produced in USA, AstraZeneca in UK, Johnson and Johnson in the USA, Pfizer-BioNTech in Germany and USA, Sputnik V in Russia, Sinovac Biotech in China, Novavax in the UK, and finally COVAXIN Bharat Biotech in India, which has been widely accepted by users [4], [5]. According to the most recent statistics, millions of persons afflicted with the coronavirus have been immunized with various vaccines developed by several countries [6].

MCDM techniques relied on the identification and selection of alternatives based on multiple criteria [7-9]. These techniques were used to determine the best alternative as an ideal choice. Thus, MCDM techniques are regarded as a suitable solution for a variety of challenges in many sectors [10-12]. According to the literature, several studies have used MCDM methodologies [13-15]. S. Narayanamoorthy, et al. [16] suggested a novel intuitionistic fuzzy soft set (IFSS) approach that integrated with PROMETHEE-II technique to determine the order of preference structure to the COVID-19 vaccine. The intuitionistic fuzzy PROMETHEE approach was used in this study, and it was compared to other approaches based on the statistics of patients with this epidemic. I.M. Hezam, et al. [17] applied the AHP method to calculate the weights for each main-criteria and sub-criteria based on a set of parameters such as the woman's employment type, age, and health state. Furthermore, TOPSIS neutral was used to calculate the rank of each COVID-19 vaccination option.

Therefore, vaccination will be prioritized for patients and health staff. Uzun Dilber, et al. [18] used the fuzzy PROMETHEE technique to evaluate fifteen key vaccinations based on five major criteria. In this study, an EpiVacCorona vaccine was utilized to halt the outbreak of the COVID-19 pandemic based on specific criteria. Pezuk Seyda Kaya, and Guzide Senel [19] proposed a soft decision-making (SDM) method for ranking COVID-19 vaccine side effects.

To accomplish this study, decision-making processes were used with many sites at the same time. The SDM method can be used for different areas and can be proposed for future studies. S. Tanvir. et al, [20] used a methodology that combined the DEMATEL method with intuitionistic fuzzy sets (IFS) to identify the most significant issues for COVID-19 vaccine supply chains. The IFS theory dealt with the uncertainty of the principal issues, whereas the DEMATEL method dealt with the relative overlap of challenges for COVID-19 vaccine supply chains. S.F. Abdelwahab, et al., [21] proposed a novel vaccine selection decision-making model (VSDMM) by using the AHP technique to analyze diverse alternatives. This study used six COVID-19 vaccines as a case study to demonstrate their applicability with the proposed approach. As a result, this case could serve as a benchmark for our current study.

The outline of the paper was organized as following; the introduction and background for several COVID-19 vaccine was discussed in section 1. The research methodology based on a hybrid multi-criteria decision-making technique was applied in section 2. The results and discussions were presented in section 3. Finally, conclusion and future works discussed in section 4.

1.1. Overview of COVID-19 Vaccines

The world was exposed to the most dangerous epidemic called Coronavirus, which caused millions of infections and deaths among the world's population. Despite the coronavirus's threat to humans, various COVID-19 vaccines have been developed in many nations to combat this epidemic. The World Health Organization has given these vaccines full permission for emergency use, and then a population-wide vaccination campaign. This study selected eight vaccines produced by many health institutions and scientific laboratories worldwide. These vaccines are represented as alternatives based on multiple criteria. Figure 1, illustrate the group of COVID-19 vaccines. According to the literature, an overview of the most prominent vaccines produced recently.

- Pfizer-BioNTech Germany and USA: The vaccine was developed in collaboration between an American business named (Pfizer) and a German company called (BioNTech), then it was licensed for usage in April 2020.
- Moderna USA: This vaccine is considered one of the most important vaccines developed by Moderna Company. In addition, the NIAID and BARDA also contributed to the development process of the vaccine in the USA. This vaccine received final approval for use in July 2020.
- AstraZeneca UK: The vaccine was developed by Oxford University and AstraZeneca in the UK, then it will be available in December 2020.
- Johnson and Johnson USA: It is one of the pioneering vaccines that the Johnson Company in Leiden/ Netherlands, and the parent company in Belgium were developed. Essentially, this company is a part of the American Johnson and Johnson Company. In July 2020, this vaccine's use was officially approved.
- Sputnik V Russia: It is the first vaccine developed in Russia by the Russian Gamaleya Research Institute. This institute is specialized in epidemiology and microbiology. This vaccine received final approval for use in August of 2021.
- Sinovac Biotech China: The vaccine was developed by a Chinese pharmaceutical business for vaccine research, development, manufacturing, and commercialization, then it was approved for use in June 2021.
- Novavax UK: It is one of the important vaccines developed by Novavax Company and the Coalition for Epidemic Preparedness Innovations (CEPI). This vaccine received the final approval for use in January of 2021.
- COVAXIN Bharat Biotech India: It is the first vaccine produced by the Indian company Bharat Biotech. This company has collaborated with the Indian Council of Medical Research in developing this vaccine. This vaccine received final approval for use in January 2021.

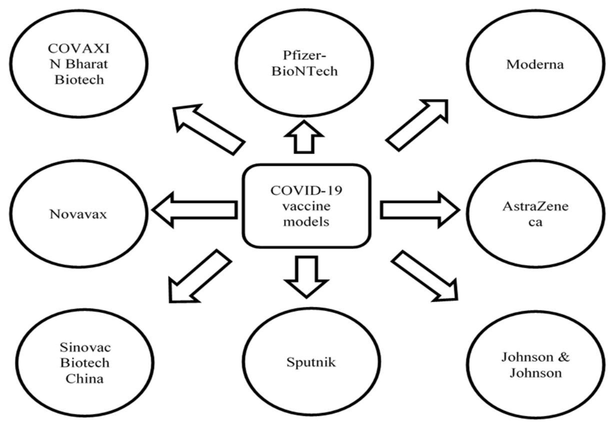

Figure 1. Overview of COVID-19 vaccine models

1.2. Data Collection for COVID-19 Vaccines

This section described the dataset collected from BioSpace as a life sciences information source [22]. The dataset included various types of COVID-19 vaccines, which are represented as alternatives in this study. Moreover, multi attributes for these vaccines have been identified as criteria. Table 1, shows the dataset used in this study. On the other hand, various measurements were defined for multiple criteria. These measurements can be used to calculate the values of each criterion in the decision matrix. Table 2, shows different measures for the criteria selected.

Table 1. Dataset of COVID-19 vaccines types

Criteria Alternative	Dose/ Iterations	Price/$	Vaccination Period (days)	Efficiency / Percentage %	Storage Temperature (°F)	Vaccination Age (year)	Active against Delta Variant
Pfizer-BioNTech	2	19.5	21	0.95	-94	12	1
Moderna	2	25	28	0.95	-4	12	1
AstraZeneca	2	4	28	0.7	46	18	0
Johnson & Johnson	1	10	28	0.72	46	18	0

Sputnik V	2	10	21	0.914	64	18	0
Sinovac Biotech	2	30	28	0.9125	46	18	0
Novavax	2	16	21	0.904	46	18	0
COVAXIN Bharat Biotech	2	2	28	0.70	46	18	0

Table 2. Multi criteria measures

Criteria	Measures
Dose	Number doses/ series (Iterations)
Price	Currency ($)
Vaccination period	Interval between doses (Days)
Efficiency	Percentage (%)
Storage temperature	Scale of temperature (°F)
Vaccination age	Number of years (year)
Active against Delta Variant	Numbers

2. METHODOLOGY

The research methodology is carried out using two primary MCDM techniques based on the dataset. The first method is entropy technique applied to compute the criteria weights were selected.

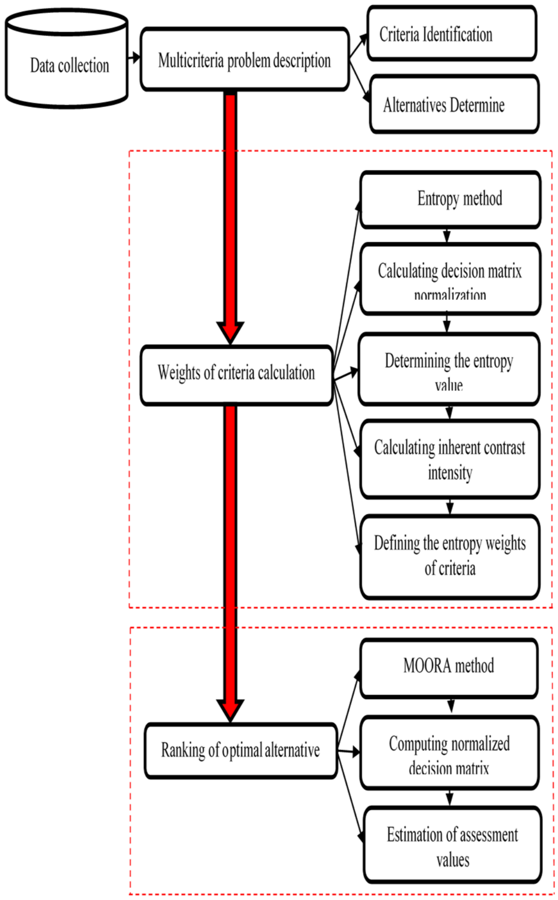

Figure 2. Framework for evaluating and benchmarking multiple COVID-19 vaccines

These criteria represented the attributes of COVID-19 vaccines that have obtained the final WHO approval. The second method is MOORA technique used to choose the best alternative among eight COVID-19 vaccines. Figure 2, shows the framework for evaluation and benchmark of multiple COVID-19 vaccines.

2.1. Entropy Method

The entropy method measures the degree of confusion in the system. This method is widely used in several fields, including healthcare, astronomy, and life sciences [10]. The fundamental idea behind computing the entropy weight is to identify increasing the value difference between the evaluation items for the same criterion, making it more essential. As a result, raising the importance of the criterion has a significant impact on the decision-making process [23]. The basic steps of the entropy approach are summarized as Equation (1).

$$DM = \left[X_{IJ}\right]_{m\times n} \quad (1)$$

where, used the entropy approach to calculate the weights of seven criteria selected.

Weights are calculated using the intraoperative weighting approach, which takes uncertainty into account. As a result, the acute weight distribution is less unpredictable than the broad distribution. This approach mathematically relies on the intensity of the relative value for the importance of criteria based on relative weights to distinguish data [24, 25]. Thus, the decision matrix (DM) includes diverse alternatives (eight varieties of COVID-19 vaccines; m) and selected criteria (seven criteria; n), which are represented in separate formulas as ith for alternatives and jth for criteria. The entropy approach is implemented to calculate the criteria weights in four steps as follows:

- Step 1: Calculating normalization of the decision matrix according to the formula:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad 1 \le i \le m \ , \ 1 \le j \le n \quad (2)$$

- Step 2: Determining the entropy value for each criterion using the following formula:

$$e_j = -k\sum_{i=1}^{n} p_{ij} \mathrm{In}\, p_{ij} \quad k = 1/\mathrm{In}\, m \ , \ 1 \le i \le n \quad (3)$$

- Step 3: Calculating inherent contrast intensity for each criterion using the following formula:

$$d_i = 1 - e_j \quad 1 \le j \le n \quad (4)$$

- Step 4: Defining the entropy weights of the criteria using the following formula:

$$W_j = d_j / \sum_{j=1}^{n} C_j \quad 1 \le j \le n \quad (5)$$

2.2. MOORA Method

A multi-objective optimization based on ratio analysis which is known MOORA method was proposed by Brauers and Zavadskas [26]. MOORA technique relies on two main types of features to be applied in the real world. The most prominent of these are beneficial attributes that have a maximum value, while non-beneficial attributes have a minimum value. It was used to choose the optimum COVID-19 vaccines based on beneficial and non-beneficial attributes [27].

As a first step, the decision matrix is used to compute the normalization values according to Equation (6), which is represented in x_{ij}, and the value within 0 and 1. Thus, the matrix is created, where m denotes the number of COVID-19 vaccines as alternatives and n is the number of criteria for these alternatives. The normalized values are expressed in ith alternative and jth as a criterion, which is deemed a positive value of (beneficial characteristic) and a negative value of (non-beneficial attribute). This approach includes two formulae, which are as follows [26], [28]:

- Step 1: Computing the normalized decision matrix using the following formula:

$$x_{ij}^* = x_{ij} / \sqrt{\sum_{i=1}^{m} x_{ij}^2} \quad i = 1, 2, ..., m \quad , \quad j = 1, 2, ..., n \qquad (6)$$

- Step 2: Estimation of assessment values using the Equation (7).

$$y_i = \sum_{i=1}^{m} w_j x_{ij} - \sum_{j=1}^{n} w_j x_{ij} \qquad (7)$$

3. RESULTS AND DISCUSSIONS

The findings achieved by using a multi-criteria decision-making technique to evaluate several COVID 19 vaccines are detailed in this section. These results have been implemented in two directions.

- First: The entropy approach was used to determine the criterion weights.
- Second, the MOORA approach is used to select the best alternative, which is represented by several COVID-19 vaccines.

In the first direction of the results, the entropy approach was implemented to calculate the criteria weights based on the dataset. The dataset included seven important criteria related to the vaccines used in this study. Further analysis, the decision-making methods were used to evaluate the performance of various alternatives based on the decision matrix. According to Equation (1), the DM included both alternatives and criteria to be evaluated. In several steps, the weights were calculated using the entropy approach (described in Section 2.1). The first step is to calculate the normalizing value using the formula defined in Equation (2). The second stage in calculating entropy values was based on Equation (3). The third stage involves computing the inherent contrast intensity of each criterion depending on Equation (4). Finally, the weights of the criteria were calculated based on Equation (5). Thus, the DM included a variety of values calculated using statistical operations as follows:

- The first value was calculated the summation for each criterion (*sum*)
- The second value was calculated the entropy values (e_j)
- The third value was calculated of the inherent contrast intensity ($1 - e_j$)
- Finally, the weights were assigned for each criterion (w_j)

Table 3 shows the weights of criteria calculated by entropy method. The weights were adopted as input in the MOORA method to calculate the rank for each alternative in the next section.

Table 3. Calculating of Criteria Weights Using Entropy Method

Criteria	dose	price	vaccination period	Efficiency	Storage temperature	vaccination	Active against Delta Variant
sum	-1.946	-1.753	-1.099	-1.503	-1.501	-0.693	-1.792
e_j	-0.936	-0.843	-0.528	-0.723	-0.722	-0.333	-0.862
$1-e_j$	1.9358	1.8432	1.5283	1.7229	1.7218	1.3333	1.8617
w_j	0.1620	0.1543	0.1279	0.1442	0.1441	0.1116	0.1558

In the second direction of the results, the MOORA approach was used to rank several alternatives based on the weights of the criteria that were recently calculated. The DM included two types of criteria with beneficial and non-beneficial attributes. Beneficial attributes are subjectively defined for criteria such as vaccination time, vaccine effectiveness, storage temperature, vaccination age, and vaccine efficacy against a delta variable. Whereas, non-beneficial attributes include the quantity of dosage and the price of each vaccine, which are determined objectively. Thus, the MOORA method was implemented through two main steps. The first step is to perform the normalization operation according to Equation (6). The second step is to perform the summation operation according to Equation (7) based on beneficial and non-beneficial values to determine the best alternative by calculating the order of all values. The most highly recommended alternative is a high-value vaccine, which is listed first. The vaccine with the lowest value is listed in the eighth position as the worst recommended alternative. The relevance of each alternative is indicated by the rank given to the alternatives in the dataset, which ranged from 1 to 8. The MOORA method was used to rank several COVID-19 vaccines in Table 4.

Table 4. Calculating the ranking of COVID19 vaccines using MOORA method

Alternatives	Dose	Price	Vaccination period	Efficiency	Storage temperature	Vaccination	Active against Delta Variant	SUM	Rank
Pfizer-BioNTech	0.060177	0.061651	0.037101	0.056944	-0.08822	0.028348	0.110186	0.0225	8
Moderna	0.060177	0.07904	0.049468	0.056944	-0.00375	0.028348	0.110186	0.1020	5
AstraZeneca	0.060177	0.012646	0.049468	0.041958	0.043173	0.042521	0	0.1043	3
Johnson and Johnson	0.030088	0.031616	0.049468	0.043157	0.043173	0.042521	0	0.1166	1
Sputnik	0.060177	0.031616	0.037101	0.054786	0.060442	0.042521	0	0.1031	4
Sinovac Biotech	0.060177	0.094848	0.049468	0.054696	0.043173	0.042521	0	0.0348	7
Novavax	0.060177	0.050586	0.037101	0.054186	0.043173	0.042521	0	0.0662	6
COVAXIN Bharat Biotech	0.060177	0.006323	0.049468	0.041958	0.043173	0.042521	0	0.1106	2

A prior study was used as a benchmark for our research to validate the results. The MOORE approach, which is known for its accuracy, was used in this study. Table 4, shows the final results by applying Equation (7). The estimate of evaluation values for each alternative was computed, and the total of the values was used to determine their ranking. According to the specified criteria, the best alternative was the Johnson and Johnson vaccine, while the worst alternative was the Pfizer vaccine. The remaining alternatives were ranked according to their degree of relevance using the MOORA approach. On the other side, (S.F. Abdelwahab, et al.) addressed the same case study. They used the AHP method to evaluate the alternatives based on the opinions of the two experts. However, their results were based on the responses of two experts in order to identify the best alternative. The first response selected AstraZeneca as the best alternative and Sputnik V as the worst, whereas the second response identified Moderna as the best alternative and Sputnik V as the worst. In this study, the results may help decision-makers in evaluating and selecting the optimal COVID-19 vaccine based on the hybrid method given in this study, which helps in distinguishing between alternatives based on multiple criteria.

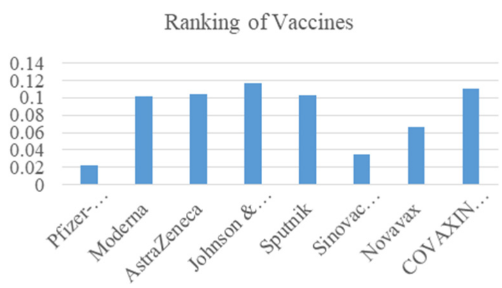

Figure 3. Shows the ranking of the COVID-19vaccines

4. CONCLUSION

The critical challenge faced the governments and health institutions is how to prevent the spread of the COVID-19 epidemic among humans. Various vaccines have been produced that have effectively contributed to preventing the spread of the epidemic worldwide. In this study were adopted eight COVID-19 vaccines as alternatives and seven attributes as criteria were selected to create the decision matrix. A hybrid approach was applied to evaluate and benchmark to address the decision problem. In this paper, the most appropriate decision-making methods have been applied to choose the optimal alternative based on the integrated entropy approach and MOORA method. According to the results, the best alternative chosen is Johnson and Johnson vaccine, while the Pfizer-BioNTech vaccine is the worst. The study limitations were identified due to insufficient information about the COVID-19 vaccines that have received final approval, as well as limited criteria for these vaccines. However, some anther methods such as AHP, TOPSIS, and VIKOR, can be used in future studies.

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