Criteria Assessment for Covid-19 Vaccine Selection via BWM

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Abstract. The aim of this study is to discover the supreme and other most important criteria that count in decision making considering vital uncertainties associated with certain parameters, risks, and costs for individuals in order to select the right Covid-19 vaccine based on a set of remarkable criteria. A survey study for assessment according to the given most important criteria based on expert opinion is conducted through the Best-Worst Method (BWM). A form including pairwise comparison vectors was sent to the participants in order to reveal priorities against their subjective decision-making criteria for vaccine selection. The essence of the study addresses that the efficacy criterion has the highest score and it is followed by the other given criteria such as storage requirements, incorporated vaccine technology, and international acceptance criterion. Participants tend to prioritize the origin and price of the vaccine behind all other criteria. Long-sought Covid-19 vaccine and its alternatives with different disclosed criteria of them have led to increasing indecision of people who have an opportunity to choose individually and the government officials who are responsible for country-wide procurement and policymakers; as a result, criteria evaluation is a challenging task. To solve the mentioned multi-criteria decision-making (MCDM) problem, BWM is newly employed in vaccine selection problems and its robust approach reveals the subjective priority of the criteria.

Keywords: Covid-19 · Vaccine selection · Criteria evaluation · Best-worst method

1 Introduction

Since the fourth quarter of 2019, the Covid-19 pandemic has spread rapidly from the Chinese town of Wuhan to the rest of the world, which results in numerous deaths and cases. The number of these deaths and cases is growing day by day. Throughout the world, numerous preventative and therapeutic methods are being researched in order to eradicate the pandemic. As of now, no definite preventive and therapeutic method that is universally accepted has been revealed. However, with emergency use approval, some preventive methods (vaccination researches) have been partially implemented in some countries or globally. However, none of them have a feature in which they are undeniably superior. As a result, the selection of vaccines has become an important issue for both states and the general public, as vaccines differ in terms of their weaknesses/threats, side

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effects, and benefits. Because of its characteristics, this problem is unavoidable, urgent, underserved, and unworkable.

One of the current problems is the selection of vaccine alternatives developed against the Covid-19 pandemic. However, as it is known, the processes of obtaining vaccines do not work on an individual basis but are based on the governmental processes of the countries. In cases where the possibility of having more alternatives, citizens are concerned about the question of individual preference. Especially in Turkey so far, there are two vaccine alternatives as BioNTech and Sinovac which have become a decision-making problem for the people to be vaccinated [1]. It is expected that the diversity of vaccine alternatives could increase in time. Therefore, the selection of the most appropriate vaccine that the individuals would like to get becomes a research question. Besides before deciding the vaccine alternatives, it is necessary to determine the criteria that are given importance on an individual basis. Selecting a vaccine is naturally a subjective decision because each vaccine has different advantages and disadvantages.

Taking into account the theoretical gap in the literature, the purpose of this paper is to evaluate and prioritize the vaccine selection criteria via Best-Worst Method (BWM) which is one of the multi-criteria decision-making methods. There are a limited number of studies solely focused on the Covid-19 vaccine selection problem.

Vaccines are pharmaceutical products that provide absolute or partial immunity to a specific illness, reducing transmission and alleviating symptoms in a significant portion of the population. Vaccination programs have proven to be the most effective means of preventing widespread irreversible illnesses [2]. The disease can spread from infectives to susceptibles. Some infected individuals could get recovered by vaccination such as rabies [3].

Vaccines are also products, and their coordination joins differ from broad coordination. Any inappropriate activity during the time spent on virus chain coordinations of immunizations may fundamentally alter the nature of vaccines and jeopardize vaccine use security. This establishes a safe and powerful immunization cold chain coordination provider for significant vaccine undertakings critical to ensuring the safety of refrigerated vaccines. The expert's sensitivity to any change in the overall performance of the alternative supplier is also taken into account [4].

According to Pooripussarakul et al. [5], using a multiple-criteria approach to prioritize vaccines could help to increase transparency and accountability in the decision-making process. The most extreme sickness, high fever rate, and high illness trouble were the most notable coefficients for model levels selected by all respondents. This indicated that respondents are more likely to choose an immunization that can prevent the most severe infection with high illness trouble and low wellbeing.

There is no specific evidence, the choices by singular countries to stop their delivery for some vaccines. There were also some cases of unexpected side effects in vaccine recipients, including severe sickness and even fatality. European regulators investigated these cases. The European Medicines Agency's Pharmacovigilance Risk Assessment Committee has proposed the vaccines should keep on being utilized meanwhile given the danger Covid presents to wellbeing [6, 7].

The rest of the paper is organized as follows: the methodology section explains the BWM and presents relevant literature, the application section figures out the findings of the study and the conclusion section discusses the results.

2 Methodology

The field of multi-criteria decision-making comprises plenty of methods based on various principles such as pairwise comparison, compromise ranking, ratio-based. Each principle has its advantages and disadvantages. BWM proposed by Rezaei [8] is one of the multi-criteria decision-making methods that depend on pairwise comparisons. However, the methods that utilize pairwise comparisons are prone to conclude with inconsistent judgments. According to Rezaei [8], one of the reasons for this problem is the unstructured way used for comparisons. To eliminate this drawback Rezaei [8] developed a technique that requires fewer comparisons with more consistent judgments.

After introducing BWM to the literature, it has attracted the attention of many researchers. Many studies have been published both in the field of application and in theoretical terms. A comprehensive bibliometric study for BWM has been conducted by Mi et al. [9]. The firstly proposed version of BWM is structured on a non-linear min-max model. However, since the non-linear version may result in multiple optimal solutions, Rezaei [10] developed a linear BWM model which provides unique solutions. Besides, various modifications of BWM have been proposed in the literature for group decision-making as well. For instance, Safarzadeh et al. [11] developed an approach that includes two models to combine weights and mathematical relation to group consistency ratio. Mohammadi and Rezaei [12] developed a Bayesian BWM as a probabilistic group decision-making model to aggregate the judgments of decision-makers. Moreover, supplier selection [13], evaluation of service quality [14], web service selection [15], evaluation of firms' research and development performance [16], supply chain network design [17] are some of the application studies published in the literature.

As a structured way for evaluating the criteria of the related problem, the steps of the linear BWM are described below. Assume that there are n numbers of criteria $(C_1, C_2, \ldots, C_n)$ to decide the performance of alternatives. The decision-maker (DM) should follow the main steps summarized as follows [8]:

- DM identifies the most important criterion and the least important criterion as best and worst criterion respectively among n criteria.
- In BWM, pairwise comparisons are structured as vector-based. DM fills two vectors that include comparison scores for criteria by using a 1–9 scale. The first vector (BO) includes comparison scores of the best criterion against the other criteria, whereas the second vector (OW) constitutes comparisons of all criteria against the worst criterion. The comparison vectors are shown below:

$$BO = (a_{B1}, a_{B2}, \ldots, a_{Bn}) \tag{1}$$

$$OW = (a_{1W}, a_{2W}, \ldots, a_{nW})^T \tag{2}$$

where a_{Bj} indicates the comparison value of the best criterion against criterion j and a_{jW} indicates the comparison value of the criterion j against the worst criterion. In addition, it is obvious that the comparison value of the best/worst criterion against itself equals 1, i.e. a_{BB} and a_{WW}.

- Unlike methods that depend on matrix-based comparisons like AHP, it is not required to make n^2 comparisons in BWM. Rather $(2n - 3)$ numbers of reference comparisons are utilized to calculate each weight of criteria. The relationship between comparison scores and the weights are identified as follows:

$$a_{Bj} = \frac{w_B}{w_j} \tag{3}$$

$$a_{jW} = \frac{w_j}{w_W} \tag{4}$$

- The optimal weights of criteria $(w_1^*, w_2^*, \ldots, w_n^*)$ can be obtained by nonlinear BWM that minimizing the maximum absolute difference and satisfying non-negativity and sum conditions. However, since the nonlinear model could result in multiple optimal solutions, Rezaei [10] proposed a linear form given below:

$$\min \xi^L$$

Subject to

$$\left|w_B - a_{Bj} w_j\right| \leq \xi^L \, for \, all \, j$$

$$\left|w_j - a_{jW} w_W\right| \leq \xi^L \, for \, all \, j$$

$$\sum\nolimits_j w_j = 1 \tag{5}$$

$$w_j \geq 0 \, for \, all \, j$$

After obtaining the optimal weights $(w_1^*, w_2^*, \ldots, w_n^*)$ and ξ^{L*}, the consistency of the comparisons should be checked. The consistency ratio developed by Rezaei [10] depends on the output of the BWM optimization model. However, according to Liang et al. [18], linear BWM model does not have an effective output-based consistency measurement. Different consistency scales are also developed in other BWM variants [18]. Besides output-based measurements, Liang et al. [18] developed an immediate feedback mechanism called input-based measurement about the consistency of preferences for decision makers. One of the outstanding feature of input-based measurement is that this measurement is model-independent which can be applied for linear, non-linear, multiplicative BWM. The calculation of the input-based consistency ratio (CR^I) is as follows [18]:

$$CR^I = max CR_j^I \tag{6}$$

where

$$CR_j^I = \begin{Bmatrix} \frac{|a_{Bj} * a_{jW} - a_{BW}|}{a_{BW} * a_{BW} - a_{BW}} & a_{BW} > 1 \\ 0 & a_{BW} = 1 \end{Bmatrix} \tag{7}$$

CR^I is the global input-based consistency ratio for all criteria whereas CR_j^I is a local measurement which shows the consistency associated to individual criterion. The global measurement depends on the maximum ratio among criteria. For this reason, the measurement of the consistency is more sensitive compared to output-based approach.

Moreover, the question of in which degree of the consistency ratio the evaluations can be accepted is another important issue in the related literature. Although having consistency ratio close to 0 is considered as consistent, there should be a threshold. According to the Monte Carlo simulations, Liang et al. [18] presents the thresholds for both input-based and output-based consistency ratios by considering scales and the number of criteria. The input-based thresholds are provided in Table 1 as below [18].

Table 1. Thresholds for different combinations using input-based consistency measurement

Scales	Criteria						
	3	4	5	6	7	8	9
3	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667
4	0.1121	0.1529	0.1898	0.2206	0.2527	0.2577	0.2683
5	0.1354	0.1994	0.2306	0.2546	0.2716	0.2844	0.2960
6	0.1330	0.1990	0.2643	0.3044	0.3144	0.3221	0.3262
7	0.1294	0.2457	0.2819	0.3029	0.3144	0.3251	0.3403
8	0.1309	0.2521	0.2958	0.3154	0.3408	0.3620	0.3657
9	0.1359	0.2681	0.3062	0.3337	0.3517	0.3620	0.3662

3 Application

In this study, instead of evaluating alternatives, criteria that are given importance in the selection of alternatives is presented. The criteria that are considered in the selection of vaccines have been determined in the light of experts in consensus as follows. We have consulted individuals, a group of 8 experts in the field of health and social sciences with an unstructured form. Since the criteria to be included in the study have both financial and medical dimensions, the area of expertise has not been limited to the health dimension only. While social scientists reveal the criteria of origin and price; medical scientists have highlighted criteria of efficacy, storage requirements, and vaccine technology. Lastly, because of the recent social and political implications, the international acceptance criterion has been included by the authors. The most prominent criteria are given in Table 2 with their descriptive expressions.

Table 2. Criteria for the vaccine selection

Criteria	Descriptive expression
Efficacy	Intensive care protection rate, Disease protection rate etc.
Storage requirements	Room temperature, +4 °C, −20 °C, −70 °C etc.
Vaccine technology	Inactivated, mRNA, Viral vector etc.
Origin	Domestic, Europe, China, Russia, USA
Price	Free, Contribution margin, Paid
International acceptance	Vaccine passports, Full approval or emergency use approval by countries

In this study, decision-makers/participants are individuals living in Turkey who are older than 18 years old but not against to get vaccinated. It is aimed to present a decision model that individuals can follow when faced with the problem of Covid-19 vaccine selection for themselves or individuals with whom they are a parent (children) / guardian (mother, father, sibling, relative).

A question form has been prepared including BWM comparison vectors (best-to-others and others-to-worst) and 5 demographic questions and sent invitations to 150 candidates. The number of participants who filled the form and submitted has reached 118 and 58 of them are included as consistent evaluations. However, since consistency is very important in pairwise comparisons, the consistency of each participant has been calculated. According to the thresholds for input-based consistency measurements provided in [18], the evaluations with a consistency ratio above 0.3337 (9-point scale and 6 criteria, see Table 1) have been excluded from the study. The profile of the consistent participants is given in Appendix.

The preferences are evaluated individually and the weights of each criterion are calculated. The geometric mean of the weights for each criterion from the sample is provided in Table 3.

Table 3. Geometric mean of the weights

Efficacy	Storage Requirements	Vaccine Technology	Origin	Price	International acceptance
0.2957	0.1047	0.1451	0.0753	0.0751	0.1515

The “Efficacy” criterion has the highest score and it is followed by the other given criteria such as “International Acceptance” and “Vaccine Technology” criterion. Participants tend to prioritize the “Origin” and “Price” of the vaccine behind all other criteria. Table 4 shows the distribution of the preferences for rankings in terms of criterion base.

Table 4. Ranking preferences (Criterion basis)

Criteria	Rank					
	1	2	3	4	5	6
Efficacy	**45**	5	2	0	3	3
Storage requirements	10	11	7	10	5	**15**
Vaccine technology	**16**	**15**	12	10	4	1
Origin	3	8	10	8	**15**	**14**
Price	5	5	8	13	**13**	**14**
International Acceptance	14	16	**18**	5	2	3
Total	93	60	57	46	42	50

In Table 4, each row shows the number of participants who rank the related criterion as the given rank number in each column. 45 out of 58 participants considered "Efficacy" as the best criterion. "Vaccine Technology" was positioned as the first and the second by 16 and 15 participants respectively. Furthermore, "International Acceptance" criterion was evaluated in third place by 18 participants. In addition, approximately equal number of participants rated "Storage Requirements", "Origin" and "Price" in the last place. For this reason, it can be concluded that there is no priority among these criteria.

4 Discussion

According to the results, the "Efficacy" criterion was chosen as the best criterion, and the "International acceptance" criterion was placed as the third most important criterion by the majority. Considering the percentages for other criteria also possible to make a ranking. However, when the rates are examined, it is seen that they do not have much superiority over each other. The prioritization of the criteria was also compared in terms of demographic characteristics. However, no significant difference was found in the selection of the criteria in terms of gender, age, occupation group, education level, and marital status. We may conclude that the choice of criteria occurs independently of demographic characteristics.

Sallam [22] examines the scope of Covid-19 vaccine refusal and emphasizes the importance of building trust in vaccination efforts. Kreps et al. [21] studies the public attitudes of Covid-19 vaccination and findings represent higher degrees of vaccine efficacy increases individuals' willingness. On the other hand, wide incidence of side effects [23] and Emergency Use Authorization to fast-track the vaccine increase hesitancy of vaccination. Similarly, Vaccine Technology as a selection criterion shows itself for acceptance and hesitancy criterion in our study. Additionally, International Acceptance is another important criterion for decision makers according to our study since it is obvious that the vaccine status will play a particular role in people traveling to many different regions of the world in near future.

Subjective evaluations are examined among decision-makers on an individual basis. The reflection of the communities who pay for the vaccine can be analyzed statistically. According to the survey of 1096 adult Americans a co-pay decreases the willingness [21]. In our study, price seems not a primary concern for them compared to other criteria. Priorities of the global organizations, countries and governments may differ from those of individuals to be vaccinated, especially considering cost per person in terms of delivering the certain vaccines for as many people as possible.

Although Covid-19 studies attract too much attention in the literature, there is a limited number of studies that handle Covid-19 with MCDM. Therefore, our study that evaluates vaccine selection criteria through BWM will contribute to the literature.

Since vaccination led to significant declines in the morbidity and mortality associated with most vaccine-preventable diseases [20], the findings have implications for public health strategies in terms of planning and preparation for vaccination programs and intending to decrease hesitancy by providing for decision makers and individuals with the right vaccine for them regarding the criteria of decision alternatives. Edwards et al. states that the public health response during a pandemic is critical and communication needs to be enhanced [19]. It can be interpreted that vaccines as decision alternatives and criteria as vaccine properties is critical in terms of transparency and communication. This study contributes to current efforts by examining the vaccine selection criteria.

5 Conclusion

In this study, the determination and evaluation of the criteria for Covid-19 vaccine selection are conducted. Although many physicians clarify possible drawbacks or advantages of alternatives, selecting a vaccine is naturally a subjective decision. For this reason, this study is presented to reveal the criteria that are considered most in deciding the most convenient Covid-19 vaccine. In case of having the opportunity to select the most appropriate vaccine, deciding on which vaccine is better becomes a research question. Eventually, this study demonstrates the high importance of efficacy of the vaccine. All selected vaccine criteria reflect their importance and in parallel with the concerns studies in literature.

It is worth noting that it is not possible to make inferences for the community with multi-criteria decision-making methods. For this reason, subjective evaluations are examined on an individual basis. If the trend of the society is desired to be analyzed, statistical tools should be used. For further studies, a comparison can be made with the results obtained here, by performing a similar study with the experts in the field of health. In addition, the study can be redesigned in a way to reveal what the demands of society are.

Appendix

Appendix 1. Profile of the participants

Gender	Male			Female			
	51.72%			48.28%			
Age	18–39			40–59			
	79.31%			20.69%			
Education	Undergraduate	Graduate		Master		PhD	
	1.72%	51.72%		39.66%		6.9%	
Marital Status	Single			Married			
	55.17%			44.83%			
Occupation	Student	Unemployed	Education	Military-Security	Health	Service	Others
	18.97%	1.72%	20.69%	17.24%	6.9%	5.17%	29.31%

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