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Research Article

The analysis of risk assessment for the transmission of COVID-19 by using PROMETHEE and ELECTRE methods

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ABSTRACT

Multi-Criteria Decision Making (MCDM) methods help researchers in solving many problems in terms of numerical analysis. However, MCDM methods have not been very popular in the health sector. In this study, five ones of Turkey's most intense and highly populated cities were selected and the risk of the spread of Covid-19 disease was evaluated on the basis of seven criteria. The PROMETHEE and the ELECTRE methods were conducted to rank the cities in terms of the spread of Covid-19. The PROMETHEE method correctly ranked the most risky city as Istanbul, but ELECTRE ranked Istanbul the second most risky. The results of the methods are compared with real data. PROMETHEE gave more convenient results than ELECTRE. Also, this paper offers a new field of study to the literature.

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INTRODUCTION

Multi-Criteria Decision Making (MCDM) is a set of methods that form a sub-branch of Decision Science and incorporate different approaches. MCDM is based on the process of modeling the decision process according to the criteria and analyzing it in a way that maximizes the benefit of the decision maker at the end of the process.

ELECTRE and PROMETHEE are the most commonly used methods for decision making while considering the current literature. Within the scope of this study, two different technical evaluations were taken: ELECTRE and PROMETHEE. These methods have taken a wide place in the literature, but generally they are seen to be applied in renewable energy and supplier selection. Some of the studies are summarized in the following of the text.

Castro[1] emphasized that PROMETHEE V guarantees the maximum overall satisfaction attainable, unlike other heuristic approaches. His proposal is to use the multicriteria method PROMETHEE V, based on a fuzzy outranking relationship. The analysis of the advantages of the method

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is illustrated with an application to an actual case. The assessment criteria are the following ones: scanner, desktop hardware, executive information system, mammography system, physician answering system, osteoporosis centre. In this article, it is concluded that it allows modeling the comparisons of alternatives by means of six different preference functions and makes possible sorting the advantage relationships. Hatami-Marbini and Tavana [2] proposed an expanded fuzzy ELECTRE I method, taking into account the uncertainty of a group of decision making techniques, the handicaps of inconclusive and linguistic assessments. Özcan et al. [3] applied AHP, TOPSIS, ELECTRE and Gray Theory to the warehouse selection problem, which has a wide range of applications with multi-criteria decision making methodologies, and is presented as a case study in the retail industry. Their work has shown how to choose the best warehouse location among many alternatives.

Khandan et al. [4] performed an assessment and analysis of the safety climate in order to select the best work shift group in an Iranian petrochemical company in 2010. It was designed in that a safety climate questionnaire was distributed among 151 workers. In this study, six factors of the safety climate in five shift work groups were evaluated. They used the ELECTRE method to find the best work shift group. Using the ELECTRE method, the most effective shift group in a related company. This study showed the importance of attention to positive safety attitude promotion between employees.

Sánchez-Lozano and his friends [5] proposed the use of a Geographic Information System (GIS) to the municipality of Torre Pacheco in the southeast of Spain to identify the best land suitable for setting up photovoltaic solar farms. Potential locations were classified according to multiple evaluation directions using the ELECTRE-TRI method. In another similar study, they tried to choose the best places to build solar photovoltaic farms on the coast of Murcia [6]. The southeast of Spain was used as a sample. The suitable locations for the placement of such facilities are determined by a Geographic Information System (GIS) to solve the problem. The weights of the criteria were determined by the Analytical Hierarchy Process (AHP), and then the appropriate locations were evaluated and classified using TOPSIS and ELECTRE. They also made a comparison assessment between the two methods. Seddiki et al. [7] presented a PROMETHEE V method for the thermal renovation of heritage buildings. The authors conducted a real-life case study in Algeria and provided suggestions on what they could do to reduce energy consumption in buildings. Nassereddine et al. [8] addressed the problem of public transport passengers in Tehran and evaluated their satisfaction levels using a questionnaire. An integrated MCDM approach has been proposed to evaluate public transport systems based on Delphi, group analytical hierarchy process (GAHP) and PROMETHEE. As a result, the most important public transportation systems in Tehran are the metro, the taxi, BRT, the bus and the minibus. Mousavi et al. [9] presented a new decision model based on the generalized ELECTRE method in a fuzzy environment for use in the energy sector and demonstrated the feasibility and applicability of the proposed model as two real case studies. Kumar et al. [10] have developed a framework to analyze the operational performance of cellular mobile phone service providers in the Delhi workspace of India. In their work, they use a fuzzy ELECTRE approach to compare the performance of cellular mobile phone service providers. The findings of the study indicate that Airtel and Reliancecommunications performed first, while Vodafone and Idea were found to be in second place. Research analysis has been limited to only GSM (Global System for Mobile) service providers in the Delhi workspace, including Ghaziabad, Noida, Faridabad and Gurgaon.

Govindan et al. [11] conducted a study on economic and green characteristics for supplier selection in green purchasing and thus proposed a hybrid approach that combines the Revised Simos (RS) procedure and PROMETHEE methods. First of all, the priority weights of the criteria were determined by RS and then Promethee was applied for ranking. They have implemented their model in the Indian food industry and have shown that their applied method is effective. Lopes et al. [12] suggested a multi-criteria technique to measure the competitiveness of tourism destinations. They applied PROMETHEE and GAIA methods within the scope of a competitiveness study of eight different touristic places in the Northern Portugal region. As a result of the analysis, the Porto region ranked first in the ranking, followed by Cávado and Douro. The authors help to show the strengths and weaknesses of such an analysis, destinations to be chosen in the tourism industry, and allow them to identify their true competitors and other destinations that are most similar to them.

Haddad and Sanders [13] presented a group of candidate methods proposed to decision makers for their problems. A sensitivity analysis was applied to the proposed candidate methods group to analyze the robustness of the outputs in the case of risk and uncertainty. According to the results, PROMETHEE II has been shown to provide more stable results under uncertainties. Ostovare and Shahraki [14] aimed to evaluate the status of websites and services provided by five-star hotels. Therefore, the initial criteria and sub-criteria for evaluation were determined using the fuzzy Delphi method. The weight of the criteria was calculated using the Shannon entropy method, and finally the PROMETHEE and GAIA methods were used to rank and improve the visual aids of the websites. According to the results, among the four criteria determined for the evaluation of hotel websites, customer orientation was the most important criterion, followed by marketing, security and technology. De Souza Barbose et al. [15] aimed to evaluate the performance of electricity distribution services using a single global index based on multi-criteria decision analysis. Their proposed approach ensures that service quality is sorted into three dimensions: feed continuity, voltage compatibility, and customer satisfaction. The difficulty of collecting various indicators into a single global index was overcome by the Analytical Hierarchy Process (AHP) and PROMETHEE methods. This ranking made it easier to evaluate the performance of distributors, thereby improving the quality of services provided by public services.

Ezbakhe and Perez-Foguet [16] presented the ELECTRE III model in their studies, where the uncertainty in performance scores was expressed as lower or upper limits and then added to the discrimination thresholds of the model. They applied their method to evaluate renewable energy sources such as hydro, wind, geothermal, solar and biomass in Turkey and selected five main criteria for the assessment: technological, technical, economic, environmental and socio-political. The results of the study show that wind energy is the best alternative for Turkey.

MCDM has not been able to attract sufficient attention for applications in the health sector. There are very few studies in the field of health. In particular, it is not possible to find studies on disease risk ranking. Thokala and Duenas [17] began with an introduction to the advantages and disadvantages of multi-criteria decision making approaches in their article. The objectives of this article were to analyze the application of multi-criteria decision making approaches in health technology assessment. A framework utilizing a value matrix was developed to include quantifiable components. This framework was also linked to a qualitative assessment including components of decision to provide a tool for combining health technology assessment, multi attribute decision analysis, values, and ethics. Hatami-Marbini et al. [18] presented the ELECTRE method for safety and health assessment in HWR facilities. They indicated the application of the proposed model for safety and health assessment in Hazardous Waste Recycling facilities. The method considered quantitative data and qualitative decisions provided by three decision makers in a real case study. The decision makers considered six conflicting qualitative and quantitative attributes with varying precise and indefinite measurements. The application involved a complex study conducted for the Environmental Health Department to assess the safety and health of eight facilities. The model proposed in this study does not imply a deterministic approach to decision making.

Amaral and Costa [19] described the application of the PROMETHEE II method to support decision making and resource management in an Emergency Department. The method is used to find possible alternatives to solve a particular bottleneck in an emergency department. This method is used for this study because its outranking approach is considered suitable for the decision context of hospital services. This method was validated with experimental data from a Brazilian public hospital. The ranking showed the best alternatives to be applied to improve the throughput of patients in the hospital. Six months after implementing the best alternatives, the waiting time during periods of overcrowding had been reduced. The PROMETHEE II method proved to be a rational tool to support choosing the best alternative to solve bottlenecks related to overcrowding in related departments. The paper concludes with a discussion of the method applied and suggestions for future studies.

Mishra et al. [20] have focused on analyzing the data set using an artificial neural network with a sigmoid activation unit in order to perform a metric analysis study. The aim of this study was to discover the best fitting parameter values for optimal performance of the given data. In this regard, fourteen challenges for healthcare waste management have been identified. Furthermore, PROMETHEE II has been employed to evaluate the contrary impact of these challenges. Their research shows that “improper segregation practices”, “hospital administrators’ accountability” and “low level of awareness and training programs” are the least significant factors, while “reuse of healthcare waste illegitimately” is the most important challenge experienced by Indians.

Silva et al. [21] used constructivist approaches in four differentiated ways. These approaches are identification of the context and decision makers, development of the models, analysis of results and decision support recommendations. The result of the interaction between the various criteria enabled a clear and coherent decision model. The objective of their study was to investigate the decision preferences among nursing managers with emphasis on the safety of the child patient. They seek to understand and support decisions on how to prioritize actions in the attributions of nursing. It is quantitative research, with sampling by convenience, and with an approach based on the Multiple Criteria Decision Analysis methodology operationalized by the algorithm PROMETHEE.

Jamshidiantehrani et al. [22] aimed to identify and determine the importance of factors influencing the agility of pharmaceutical companies in the COVID-19 pandemic using Multi-Criteria Decision Making Methods. This research has identified and prioritized the factors affecting the agility of the supply chain of pharmaceutical companies.

Ghorui et al. [23] investigated the risk factors involved in the spread of Covid-19, and they applied the Fuzzy Analytic Hierarchy Process to find out the weights, and finally, Hesitant Fuzzy Sets with TOPSIS was applied to identify the major risk factors. The results showed that the long duration of contact with the infected person is the most important risk factor. They showed the utility of the Multi Criteria Decision Making (MCDM) tools in the evaluation of the most important risk factors.

METHODOLOGY

ELECTRE

The ELECTRE (Elemination and Choice Translating Reality English) method is the multiple decision making method first introduced by Beneyoun in 1966 [24]. The method is based on binary superiority comparisons between alternative decision points for each criterion. Besides, since ELECTRE is based on dominance or dominance relationships, a measure of efficiency and importance of each criterion is determined. The decision maker should especially determine the compliance and non-compliance limits. The steps of the method are as follows:

Step 1: Create Decision Matrix(A)

Decision matrix includes the alternatives and the criteria.

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}$$

m indicates the number of the alternatives and n indicates the number of the critera.

Step 2: Calculate the Standart Decision Matrix (X)

The Standard Decision Matrix is created as seen in Eq. (1).

$$x_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}} \tag{1}$$

Step 3: Create the Weighted Standard Decision Matrix (Y)

The importance of each criterion may differ for the decision maker. The Y matrix is calculated to reflect these importance differences to the ELECTRE solution.

$$Y_{ij} = \begin{bmatrix} w_1x_{11} & w_2x_{12} & \cdots & w_nx_{1n} \\ w_1x_{21} & w_2x_{22} & \dots & w_nx_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ w_1x_{m1} & w_2x_{m1} & \cdots & w_nx_{mn} \end{bmatrix}$$

Step 4: Determine the Concordance (C) And Discordance (D) Sets

Y matrix is used to determine the concordance sets, the alternatives are compared with each other in terms of each criterion and the sets are determined by the relationship shown in the Eq. (2):

$$C_{kl} = \{j, y_{kj} \geq y_{lj}\} \tag{2}$$

Step 5: Create the Concordance Matrix (C) and Discordance Matrix (D)

Concordance matrix (C) is formed by using concordance sets. Matrix C is $m * m$ in size and does not take the value in case of the k is equivalent to l. The elements of the matrix C are calculated by the relationship shown in Eq(3).

$$c_{kl} = \sum_{j \in C_{kl}} w_j \tag{3}$$

The elements of the discordance matrix (D) are calculated by Eq. (4).

$$d_{kl} = \frac{\max\limits_{j \in D_{kl}} |y_{kj} - y_{lj}|}{\max\limits_{j} |y_{kj} - y_{lj}|} \tag{4}$$

Step 6: Form the Concordance-Dominance Matrix (F) and the Discordance-Dominance (G) Matrix

The concordance-dominance matrix (F) is mxm in size and the elements of the matrix are obtained by comparing the concordance threshold value with the elements of the concordance matrix. The concordance threshold value is obtained from Eq. (5).

$$\underline{c} = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} c_{kl} \tag{5}$$

The elements of the matrix F gets the binary values as 1 or 0, and the elements in the diagonal of the matrix does not take the value as it shows the same alternatives. The remaining elements are calculated as in Eq. (6).

$$f_{kl} = \begin{cases} 1, & c_{kl} \geq \underline{c} \\ 0, & c_{kl} < \underline{c} \end{cases} \tag{6}$$

The discordance-dominance matrix (G) is also $m * m$ in size and the elements of the matrix are obtained by comparing the discordance threshold value with the elements of the discordance matrix. The discordance threshold value is obtained from Eq. (7).

$$\underline{d} = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} d_{kl} \tag{7}$$

The elements of the matrix Ggets the binary values as 1 or 0, and the elements in the diagonal of the matrix does not take the value as it shows the same alternatives. The remaining elements are calculated as in Eq. (8).

$$g_{kl} = \begin{cases} 1, & g_{kl} \geq \underline{d} \\ 0, & g_{kl} < \underline{d} \end{cases} \tag{8}$$

Step 7: Create the Aggregate Dominance Matrix (E)

The elements of E is calculated by reciprocal multiplication of f_{kl} and g_{kl}.

$$E_{ij} = \begin{bmatrix} f_{11} \times g_{11} & f_{12} \times g_{12} & \cdots & f_{1n} \times g_{1n} \\ f_{21} \times g_{21} & f_{22} \times g_{22} & \dots & f_{21} \times g_{21} \\ \vdots & \vdots & \ddots & \vdots \\ f_{m1} \times g_{m1} & f_{m2} \times g_{m2} & \cdots & f_{mn} \times g_{mn} \end{bmatrix}$$

E matrix is also the final matrix. If the value of e_{12} is equivalent to 1, it indicates that first alternative is superior to second alternative.

PROMETHEE

The PROMOTHEE method consists of 2 main stages: PROMOTHEE I (partial order) and PROMOTHEE II (exact order) [25]. The PROMETHEE method is based on binary comparisons of alternatives according to criteria such as in ELECTRE. The main difference that distinguishes the PROMOTHEE method from other multi-criteria decision making methods is that it takes into account the importance weights of the criteria and the internal relationships between each criterion. The PROMETHEE method includes 7 steps, from the beginning to the final stage. The process of PROMETHEE is given the following, respectively.

Step 1: Create Decision Matrix (F)

The decision matrix includes the alternatives and the criteria. This step is similar to most multi-criteria decision-making methods.

$$F_{ij} = \begin{bmatrix} f_1(A) & f_2(A) & \cdots & f_n(A) \\ f_1(B) & f_2(B) & \dots & f_n(B) \\ \vdots & \vdots & \ddots & \vdots \\ f_1(C) & f_2(C) & \cdots & f_n(C) \end{bmatrix}$$

Step 2: Determine the Preference Function

Preference functions are determined to represent the structure and internal relationship of the criteria. The PROMETHEE method does not determine an internal absolute benefit, either on the basis of alternatives and independently, neither for the whole nor for each criterion. Instead, it makes comparisons of the alternatives according to the criteria with binary comparisons. The conditions are involved in the decision-making process when determining the preference functions.

The following conditions are considered at determining the preference functions [26]:

- If there is no preference for the relevant criterion for the decision maker, the preference function of this criterion should be the First Type (usual) preference function.
- If the decision maker wants to prefer alternatives with a value above the value determined by the relevant criterion, the preference function should be the Second Type (U type) preference function.
- If the decision maker wants to prefer alternatives with a value above average in terms of a criterion, but does not want to neglect values below this value, the preference function should be the Third Type (V type) preference function.
- If it is preferred in a definite range of values for a criterion, the preference function should be the Fourth Type (level) preference function.
- If the decision maker prefers alternatives with above-average values, the preference function should be the Fifth Type (linear) preference function.
- If the deviation values of the relevant criterion are significant for the decision maker, the preference function should be the sixth type (Gaussian) preference function.

Binary comparisons of alternatives are conducted by considering the preference functions for each criterion and the common preference functions are determined. The common preference function is calculated as seen in Eq. (9) where A and B indicate two alternatives.

$$P(A,B) = \begin{cases} 0, & f(A) \leq f(B) \\ p[f(A) - f(B)], & f(A) > f(B) \end{cases} \quad (9)$$

Step 4: The preferences indices for each alternative pair are determined using the common preference functions (as seen in Eq. (10)).

$$\pi(A,B) = \sum_{i=1}^{k} (w_i P_i(A,B)) \quad (10)$$

Step 5: Positive and negative superiority values are determined for the alternatives by using Eq. (11-12).

$$\Phi^+ = \frac{1}{n-1} \sum \pi(A,x) \quad (11)$$

$$\Phi^- = \frac{1}{n-1} \sum \pi(x,A) \quad (12)$$

Step 6: Partial sequence is determined with PROMETHEE I. There are three possible situations as seen in Eq. (13-15).

$$A \text{ is superior to } B: \begin{cases} \Phi^+(A) > \Phi^+(B) \text{ and } \Phi^-(A) < \Phi^-(B) \\ \Phi^+(A) > \Phi^+(B) \text{ and } \Phi^-(A) = \Phi^-(B) \\ \Phi^+(A) = \Phi^+(B) \text{ and } \Phi^-(A) < \Phi^-(B) \end{cases} \quad (13)$$

$$incomparable: \begin{cases} \Phi^+(A) > \Phi^+(B) \text{ and } \Phi^-(A) > \Phi^-(B) \\ \Phi^+(A) < \Phi^+(B) \text{ and } \Phi^-(A) < \Phi^-(B) \end{cases} \quad (14)$$

$$A \text{ and } B \text{ are indistinguishable}: \{\Phi^+(A) = \Phi^+(B) \text{ and } \Phi^-(A) < \Phi^-(B) \quad (15)$$

Step 7: The full priorities are determined with PROMETHEE II for each alternative as seen in Eq. (16) and the exact ranking is done.

$$\Phi(A) = \Phi^+(A) - \Phi^-(A) \quad (16)$$

CASE STUDY

In this study, the risk sequencing has been made for the spread of Covid-19 disease. Thus, 5 metropolitan cities were selected from the first 10 cities where the first cases were intense in Turkey. These are Ankara, Bursa, Istanbul, Izmir and Samsun. The criteria selected as a result of the brainstorming are: Number of Population (NP), Number of Shopping Centers (NSC), Air Quality (AQ), Number of Incoming-Outgoing Passengers (NOP), Alcohol-Cigarette Consumption Rates (ACR), Urban Transport Mobility (UTM), and Population Density (PD). It should be noted that the point to be ordered for risk is for the Covid-19's spread (Fig. 1).

The relationships between Covid-19 and environmental factors were resistant to the potentially con-founding effects of air pollution and population [27]. The total number of cases and deaths were significantly related to the levels of the population of the different countries. Overall, the median age of the country and average temperature are positively related to the number of deaths from the virus [28].

Number of Population (NP): As the number of people increases, the level of interaction between people will increase. Therefore, it was thought that the number of people may be important for a disease transmitted through breathing. The data belongs to the year 2019, and was obtained from the Turkish Statistical Institute [29]. Residents living in areas with high population density, such as metropolitan cities, have a higher probability of coming into close contact with other cities, and consequently, any contagious disease is expected to spread quickly in dense areas [30].

Number of Shopping Center (NSC): Socialization is thought to be a factor that increases interaction between people. Shopping malls are one of the important places for this socialization. Especially due to the structure of the ventilation systems, there may be more risk than the environment in open air.

Air Quality (AQ): As the risk patient groups for Covid-19, those with respiratory failure were identified. Air quality is also an important factor affecting the respiratory system. Due to the changes in air quality that may occur in the quarantine process, this data was determined for January 2020. As mentioned in [31], it clearly appears that there are notable differences in terms of the rate of spread and mortality in the outbreaks of COVID-19 in different countries around the world. These differences have raised important questions related to the influence of atmospheric factors on the spread of COVID-19 and on its mortality rate.

Number of Incoming-Outgoing Passengers (NOP): Mobility from outside to the city can be as important as mobility within the city. International or out-of-town trips should also be taken into account, especially considering that the first cases come from another location.

Alcohol-Cigarette Consumption Rates (ACR): Since the connection between Covid-19 and alcohol and cigarette consumption has not been definitively proven as it is a very new disease, it is that the course of the disease in people who consume alcohol and cigarettes is faster in general judgment.

Urban Transport Mobility (UTM): The public transportation is the most common type of transportation in urban life. The interaction between people increases due to the lack of social distancing and bad ventilation conditions in public transport. This intensity is maximized, especially on weekdays and during working hours.

Population Density (PD): Population density can be as important as the number of population-related mortalities in this context. After a detailed correlation and regression analysis of infection and mortality rates due to Covid-19 at the district level, they found a moderate association between Covid-19 spread and population density in their study.

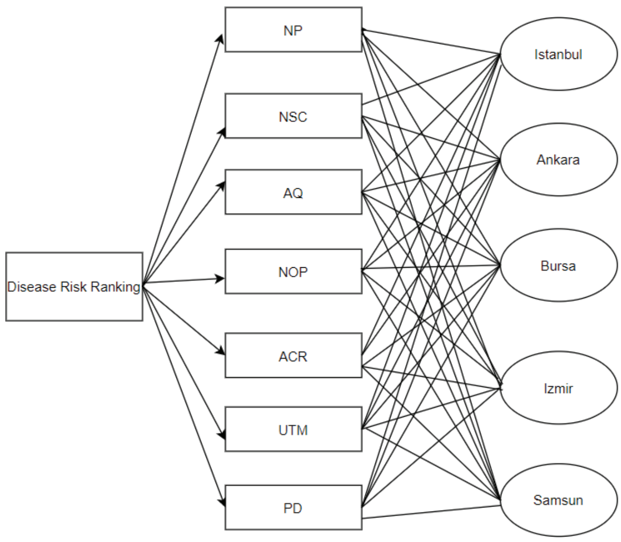

Figure 1. The decision hierarchy of the disease risk ranking.

Application of Promethee Method to Covid-19 Prevalence Risk

PROMETHEE is one of the decision making methods used in the study. Visual Promethee Academic program was benefited for the implementation of the PROMETHEE method [32]. Table 1 shows the decision matrix.

Table 2 shows the preference functions. Preference functions and criteria weights were decided by brainstorming. These parameters may vary depending on the decision maker.

In the light of the decision matrix, the preferences of the decision maker for each criteria were as follows:

- Population differences between 200000-30000 for NP are important for the decision maker.
- 2 units of difference are important for the decision making in the criterion of NSC.
- 1 unit difference for AQ is important for the decision maker.

Table 1. Decision Matrix for PROMETHE

	Ankara	Bursa	Istanbul	Izmir	Samsun
NP	5639076	3056120	15519267	4367251	1348542
NSC	38	15	114	24	6
AQ	2	2	1	2	2
NOP	16740003	242571	1025755606	13410378	1735522
ACR	4	5	4	5	4
UTM	20	18	17	17	18
PD	230	293	2987	364	148

Table 2. Preference Functions

NP	NSC	AQ	NOP	ACR	UTM	PD
Linear	U shape	V shape	V shape	U shape	U shape	Linear

- For the decision maker, 40000 unit differences are considered for NOP.
- For the decision maker, 2 units for ACR and
- 3 unit differences are considered important for UTM.
- For the decision maker, 20-30 unit differences are important for PD.

Table 3 shows the superiority values. Partial rankings are determined by the PROMETHEE I method using the obtained positive and negative superiority values. This partial ranking is shown in Figure 2. In particular, Istanbul dominated over others. Finally, the final ranking is shown in Figure 3.

Tablo 3. Superiority Values

Cities	Rank	Φ	Φ^+	Φ^-
Ankara	2	0,1667	0,4167	0,2500
Bursa	4	-0,2593	0,2037	0,4630
Istanbul	1	0,4815	0,6296	0,1481
Izmir	3	0,1296	0,3981	0,2685
Samsun	5	-0,5185	0,0741	0,5926

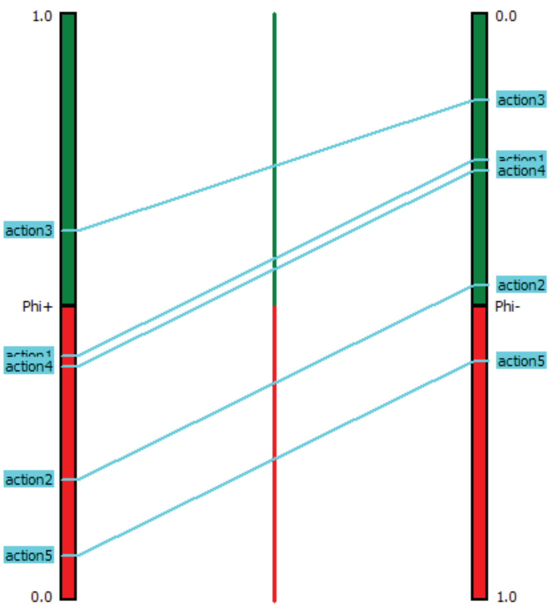

Figure 2. PROMETHEE I rank

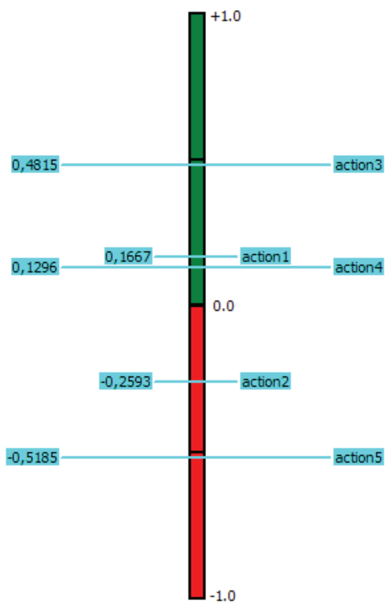

Figure 3. PROMETHEE II rank

PROMETHEE I and PROMETHEE II present the same results. The PROMETHEE II method generates the exact order by using the results of PROMETHEE I. Accordingly, the full priorities have been calculated and the exact rank is formed according to the priorities which are shown in Table 4.

Table 4. PROMETHEE Final Rank

Cities	Rank	PROMETHEE 2
Istanbul	1	0,4815
Ankara	2	0,1667
Izmir	3	0,1296
Bursa	4	-0,2593
Samsun	5	-0,5185

As a result of the ranking process, Istanbul has been defined as the most risky region. Ankara is followed by Istanbul. Izmir is the third most risky city, but there is no obvious superiority to Ankara. Bursa is the second city with the lowest risk, and Samsun is the most risk-free city.

Application of ELECTRE Method to Covid-19 Prevalence Risk

Another method of decision making used in the study is the ELECTRE method. Table 5 shows the decision matrix.

Weights are defined in order to define the relationship between the criteria, these are shown in Table 6. Table 6 also shows the weights for PROMETHEE method.

The XLSTAT 2020 plug-in was used for the application of the ELECTRE method. The ELECTRE method basically consists of the creation of 3 tables, which are the Concordance Matrix, Discordance Matrix, and Superiority Matrix.

Table 5. Decision Matrix for ELECTRE

	Ankara	Bursa	İstanbul	İzmir	Samsun
NP	5639076	3056120	15519267	4367251	1348542
NSC	38	15	114	24	6
AQ	2	2	1	2	2
NOP	16740003	242571	1025755606	13410378	1735522
PD	230	293	2987	364	148
ACR	4	5	4	5	4
UTM	20	18	17	17	18

Table 6. Weights

Criterion	Weight
NP	5
NSC	3
AQ	4
NOP	4
PD	5
ACR	2
UTM	4

Table 7 shows the concordance matrix that shows the superiority of concordance between alternatives.

When looking at the Izmir line in the Ankara column, it is seen that Ankara has a superiority value to İzmir of 0.741. In general, it is seen that high values are in Ankara. This is unlike the results obtained with the PROMETHEE method.

Another important matrix is the discordance matrix and is shown in Table 8. The matrix that makes the final decision created by obtaining these two matrices is the superiority matrix given in Tables 9-10.

Table 7. Concordance Matrix

	Ankara	Bursa	Istanbul	Izmir	Samsun
Ankara	1,000	0,407	0,630	0,259	0,000
Bursa	0,741	1,000	0,630	0,704	0,296
Istanbul	0,370	0,370	1,000	0,222	0,370
Izmir	0,741	0,296	0,778	1,000	0,148
Samsun	1,000	0,704	0,630	0,852	1,000

Table 8. Discordance Matrix

	Ankara	Bursa	Istanbul	Izmir	Samsun
Ankara	0,000	0,000	0,839	0,000	0,000
Bursa	0,161	0,000	1,000	0,129	0,015
Istanbul	0,000	0,000	0,000	0,000	0,000
Izmir	0,033	0,000	0,871	0,000	0,000
Samsun	0,147	0,017	0,985	0,114	0,000

Table 9. Superiority Matrix

	Ankara	Bursa	Istanbul	Izmir	Samsun
Ankara	0	0	0	0	0
Bursa	0	0	0	0	0
Istanbul	0	0	0	0	0
Izmir	0	0	0	0	0
Samsun	1	0	0	0	0

Tablo 10. Final outranking

Cities	Rank
Ankara	1
Bursa	2
Istanbul	2
Izmir	2
Samsun	3

Table 11. Comparisons

Cities	Actual Data	Rank	PROMETHEE Rank	ELECTRE Rank
Ankara	44576	2	2	1
Bursa	34460	3	4	2
İstanbul	140192	1	1	2
İzmir	24572	4	3	2
Samsun	12495	5	5	3

Ankara was in the highest risk group, according to the results. Even more interesting, Istanbul, Bursa and Izmir were equally risky, but this is not possible. The up-to-date data is officially available in the weekly status report of the Ministry of Health between 19.10.2020 and 25.10.2020. Total case number data was obtained from this report [33]. However, looking at the weekly actual data, it is noticed that there is no good ranking (Table 11).

It is obvious that Istanbul is the most risky city. PROMETHEE offered a more realistic ranking according to the actual ranking. PROMETHEE allows more intervention into the method with the parameters of preference functions for the criteria. Therefore, its conclusions may be more realistic. In the results found by PROMETHEE, only Izmir and Bursa did not rank parallel to the real values. It is logical that PROMETHEE chose the second risky Ankara when considering the fact that Ankara is the capital of Turkey. But Electre proposed Ankara as the most risky city, although the most riskiest city is Istanbul. This handicap may be caused by the fact that socialization opportunities are not sufficiently introduced in the criteria definition stage. Both methods correctly predicted the risk of the province of Samsun. In general, it can be said that PROMETHEE is a more effective method for the current problem compared to ELECTRE.

CONCLUSIONS AND FUTURE WORKS

In this study, five ones of Turkey's most intense and highly populated cities were selected, and the risk of the spread of Covid-19 disease was evaluated on the basis of seven criteria. These 7 criteria are natural criteria such as geographical, social and economic, which do not depend on the individual in the transmission of the disease among individuals. Due to the insufficiency of what is known about Covid-19 disease that emerged in late 2019, the selected criteria and evaluations are open for improvement with more data which is obtained by time. There were not any studies on the evaluation of the spread risk of a disease in cities with different geographical and demographic factors. Therefore, this study is an original work and may be the basis for future studies.

Istanbul is the city where both population density and social interaction are the most intense. It attracts more tourists from abroad than other cities. Therefore, Istanbul seems like the most risky region. Besides, Istanbul is seen as the city where the spread is the most intense when real data is considered. The PROMETHEE method correctly ranked the most risky city, but ELECTRE ranked Istanbul the second most risky. However, the number of cases is quite higher in Istanbul. In the PROMETHEE method, there is a chance of intervention with the preference functions and the parameters determined for these functions. Therefore, it can offer more flexible ranking than ELECTRE. Indeed, PROMETHEE has given better results in the other rankings. PROMETHEE was wrong only in the Bursa and Izmir rankings.

Ankara is the capital and is higher than Izmir in terms of the number of passengers and population. Therefore, the PROMETHEE method may have been misled due to weights and preference functions assigned to criteria. Ankara is the second most risky region, while PROMETHEE predicted correctly, ELECTRE considered Ankara more risky than Istanbul. It seems that the result of the PROMETHEE method is more accurate than the ELECTRE method when compared to actual values. Samsun is the only city that both methods correctly predicted.

This paper demonstrates that multi-criteria decision making methods might be used for risk assessment of spread in Covid-19 or similar diseases with high risk of transmission. The sections that are most open to development in this study are the selection of criteria and the determination of the weights. In future studies, it can yield more consistent results by adding novel, different and improved criteria. Therefore, all cities can be evaluated without restrictions on the number of cities for future work.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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