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Research Article

Using PROMETHEE Method for Multi-Criteria Decision Making: Applications and Procedures

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Abstract

PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) is one of the main MCDM methods helping decision-makers to investigate a set of alternatives considering different criteria. This method is particularly useful when the decision-makers need to compare a set of alternatives based on multiple criteria. The PROMETHEE method has been applied in various fields, including business, finance, hydrology, and water management. In business, for instance, PROMETHEE can be used to evaluate different investment opportunities based on various criteria such as return on investment, risk, and strategic fit. In water management, PROMETHEE can be used to evaluate alternative strategies for water allocation or pollution control, considering factors such as environmental impact, cost, and social acceptability. Different versions of PROMETHEE have been developed, each with its own specific characteristics and requirements. This paper describes the steps of the PROMETHEE I and II procedures, which are among the most widely used versions of the method. The PROMETHEE I procedure is used for ranking alternatives based on a single criterion, while PROMETHEE II is used for ranking alternatives based on multiple criteria.

Introduction

Decision-making is a crucial aspect of human existence. All of these choices are evaluated against each other, often based on the decision maker's preferences, past experiences, and other information at hand. Technically, a decision may be described as an action plan intended to address a particular decision issue or a choice made in light of the facts at hand [1]. It should be noted that it is now generally accepted to extend the procedure of decision support beyond the classical framework of single-goal optimization detailed on the set of acceptable solutions [2], considering the systematics of the decision situation itself and the classical framework of single criterion optimization. This addition enables one to approach multi-criteria issues with an emphasis on finding a solution that sufficiently balances a wide range of often-at-odds objectives [3,4]. The decision-making process needs to always be included when discussing any choice. A complicated brain process called decision-making seeks to find a desired outcome while taking many factors into account. This process may be illogical or logical, and on the other hand, it may make explicit or implicit assumptions that are impacted by a variety of elements, including social, cultural, biological, and physiologic influences. Any of these factors, together with authority and risk levels, may influence how difficult a decision-making process is. Nowadays, economic theories, computer tools, algebra, mathematical equations, and a variety of statistics that automatically calculate and estimate the answers to decision-making questions may be used to solve complicated decision-making difficulties [5].

Manifold criteria and alternatives must be considered to evaluate a complex decision-making problem. For this, different multi-criteria decision aid (MCDA) methods can be used to support decision-makers in different fields. During the last decades, these methods are between fast-growing fields of operational research. These methods can be used for several application areas such as business, management, engineering, etc. Several MCDA methods are developed that PROMETHEE (Preference Ranking Organization Method for enrichment evaluation) family are among the main techniques that can assist to evaluate the criteria in both qualitative and quantitative ways [6]. This method was introduced first by Brans (Brans, 1982) in 1982, and further was extended by Vincke and Brans in 1985 [7]. The main pillars of this method are:

1. Enriching the preference structure with several functions for preference, and the dominance relation of the alternatives (considering each criterion).
2. Decision aiding as a result of partial/complete rankings [6].

Similar to ELECTRE, PROMETHEE is an outranking method that uses several iterations to gain the ranking between a finite alternative set. The ranking process (both conception and application) is very simple compared with other multi-criteria decision making (MCDM) methods that this point results in increasing the number of decision-makers who used this method to address their complex problems year by year. Also, many researchers investigate the sensitive aspects of this method in their studies [7]. In this method, different preference functions can be used based on the characteristics of the criteria that are used to eliminate the scaling effect of the criteria. This point is the main merit of the PROMETHEE method. The preference function as well as the threshold values used in the PROMETHEE process should be selected based on the perspectives of the decision-makers for each specific problem [6].

The family of the PROMETHEE method includes several techniques. First, PROMETHEE I, and II were developed for partial and complete ranking; respectively. Then, other versions were introduced. For example, PROMETHEE III is used for ranking based on intervals. The PROMETHEE IV is used when the decision-makers face a continuous set of viable solutions for both partial and complete ranking, and the problems that include segmentation constraints can be addressed by the PROMETHEE V method. The other version known as the PROMETHEE VI, GDSS, and GAIA (Geometrical Analysis for Interactive Aid) can be used for the representation of the human brain, group decision making, and graphical representation; respectively. The GAIA is a visual interactive module that can be used when the decision problem is very complicated. Also, the most recent versions, PROMETHEE TRI and CLUSTER are developed for sorting problems and nominal classification; respectively. All these versions are successful MCDM methods according to their user-friendly form and mathematical properties [7]. The next sections are provided to represent the application areas, advantages, and disadvantages of the PROMETHEE methods more specifically. The final section also introduces the process steps and algorithms of the PROMETHEE I and II methods briefly.

Application Areas

In recent years, there has been a noticeable increase in the number of unusual crises. Not only do these occurrences impede the growth of the economy and society, but they also constitute a significant risk to the stability of human means of subsistence. As a result, given the current circumstances, it is essential to place an emphasis on enhancing the capacities of emergency management organizations and minimizing the negative impacts that are brought on by calamities. Since the circumstances surrounding emergency decision-making are prone to variation, risk, and uncertainty, it is necessary to devise a variety of emergency management strategies that may be applied to a wide range of scenarios. An important issue that requires prompt resolution is determining, from among several potential options, which course of action will provide the best results [8].

The asymmetry and complexity of big group decision problems, as well as the differences in the decision makers' own knowledge level, life experience, and research direction, all contribute to the fact that it is difficult for decision-makers to make accurate assessments of decision options when they are under the time pressure of the decision process. Traditional decision problems do not have these characteristics [8]. The PROMETHEE methods have manifold application areas ranging from environmental management to business, finance, hydrology, and water management [9]. Behzadian, et al. proposed a detailed review of application areas of the PROMETHEE. They categorized the studies that used this decision-making method into nine different sub-groups. They recognized "Environment Management" as the most popular application area among the sub-categories. The results of this comprehensive literature review on the application areas of the PROMETHEE are summarized in Table 1, to give you a better overview.

Table 1: PROMETHEE Application Areas [7].

No.	Category	Description
1	Environment Management	The articles are about Environmental Impact Assessment (EIA), Life Cycle Assessment (LCA), land-use planning, and waste management.
2	Hydrology and Water Management	The papers are related to the assessment of water management strategies, irrigation planning, and sustainable water resources planning.
3	Business and Financial Management	This category focus on general and portfolio management, measurement of the performance, and analysis of the investment.
4	Chemistry	The topics cover areas related to the samples in the experimental environments, and chemical material evaluation and ranking.
5	Logistics and Transportation	The topics related to transportation, location problems, outsourcing, and suppliers' selection were reviewed in this category.
6	Manufacturing and Assembly	Mainly related to the aspects of manufacturing systems and planning, maintenance programming, and assembly line planning
7	Energy Management	This topic focuses on the studies on the selection and evaluation of the energy generation or alternatives for exploitation
8	Social	The studies related to the social studies that are not considered in the seven previous categories are in this sub-group.
9	Other topics	Other application areas are government, design, sports, medicine, agriculture, and education fields.

Advantages and Disadvantages

The PROMETHEE method like other MCDM methods offers many advantages for the decision-making processes, for example, according to the literature the main merit of this method is the easy-to-use and simple outranking process. Although, the demerits are negligible. The disadvantages can be overcome by using hybrid and integrated PROMETHEE-based models [6]. In this section, the main advantages and disadvantages are listed in Table 2 [1,9,10].

Table 2: Advantages and disadvantages of the PROMETHEE Methods.

Advantages of the PROMETHEE	Disadvantages of the PROMETHEE
It has an easy-to-use and clear structure.	This technique does not offer clear methods or guidelines to assign the weights.
The proportionate assumption for the criteria is not required.	Determining the thresholds can be problematic.
It can be used to solve complex problems, and it eliminates the scaling effects between the criteria.	It is not possible to identify the weaknesses and strengths of the alternatives directly, as the results just show how much each alternative outranks the others but do not show the lowest performances of the alternatives considering a certain criterion.
It has a user-friendly software package (e.g., DECISION LAB)	In the PROMETHEE process, the generalized criteria should be determined which can be difficult for inexperienced users.
It offers a good visual projection as the final step in the decision-making process for the problem when it is compared to some other MCDM methods such as AHP.	It may face a rank reversal issue, and adding a new alternative or eliminating one of them can reverse the previous ranking for some of them.
This method requires much fewer inputs compared with some other techniques.	PROMETHEE does not provide this structuring possibility. In the case of many criteria (more than seven), it may become very difficult for the decision-maker to obtain a clear view of the problem and evaluate the results.

Process Steps of the PROMETHEE I Method (Partial Ranking)

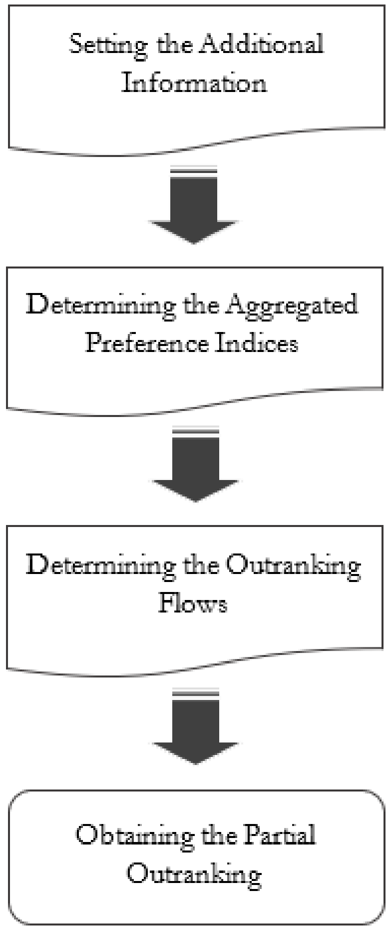


Figure 1: PROMETHEE I Process Steps.

The information is provided by an appropriate MCDM method using pairwise comparison to determine the weather.

1) an alternative (A_k) is preferred to the other one (A_l)

2) A_k and A_l are indifferent.

3) A_k and A_l are incomparable.

Of course, the aim of these methods is to minimize the number of incompatibilities between pairs of alternatives as much as possible, but it is also important to be realistic in this regard as eliminating all incompatibilities can make the decision-making process more disputable. The PROMETHEE methods belong to the outranking family of MCDM methods and work based on pairwise comparison. The process steps of the PROMETHEE method are shown in (Figure 1).

Step 1: Setting the Additional Information

These methods require two sets of additional information including information within each criterion, and between the criteria. The weights of the relative importance of criteria $\left(w_j, \sum_{j=1}^{n} w_j = 1\right)$ are considered as the information between the criteria. These weights are not dependent to the measurement units of the criteria and have non-negative values. The weights are used to show the importance of each criterion over others. Determining the weights are between the challenges decision-makers can face. Although the PROMETHEE methods do not offer clear methods to determine the weights (as discussed in the disadvantages of these methods), some of the PROMETHEE software such as DECISION LAB and PROMCALC give the ability to experience several sets of weights before fixing them using their specific sensitivity tools.

Information within each criterion is related to the information provided for obtaining the preference function. This function determines the preference of an alternative over another one (considering the pairs of alternatives) for observed deviations between the evaluations of two alternatives on a specific criterion. The $d_j(A_k, A_l)$ is "the amplitude of deviations between the evaluations of two alternatives for criterion $j(j=1,2,..,n)$" and it is given as:

$$d_j(A_k, A_l) = X_j(A_k) - X_j(A_l) \qquad (1)$$

where $X_j(A_k)$ and $X_j(A_l)$ are "the evaluations of the alternatives considering the specific criterion (here shown as j)". The value of the deviation can show the preference of the alternatives in the pairs. That is to say, the smallest the deviations, the smallest the preference between two alternatives. If decision-maker considers that the deviation is negligible, then it can be considered as no preference. The preference function when the criteria should be maximized can be shown as:

$$p_j(A_k, A_l) = F\left[d_j(A_k, A_l)\right] \forall A_k, A_l \in A, and\ 0 \le p_j(A_k, A_l) \le 1 \qquad (2)$$

and when the criteria should be minimized (cost criteria):

$$p_j(A_k, A_l) = F\left[-d_j(A_k, A_l)\right] \qquad (3)$$

the value of the preference can be described as:

$p_j(A_k, A_l) = 0$ means that A_k and A_l are indifferent.

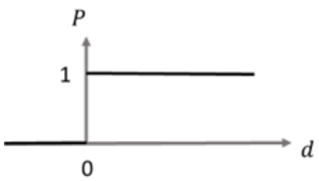
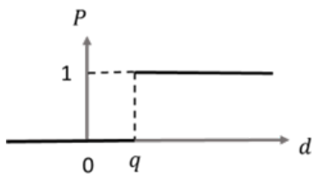
$p_j(A_k, A_l) \simeq 0$ means a weak preference.

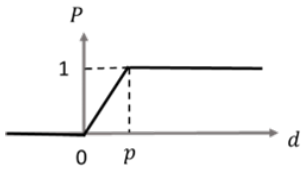
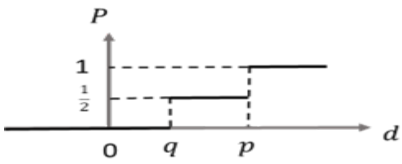
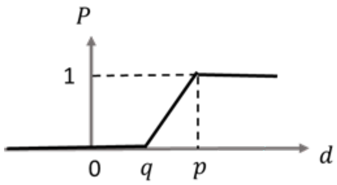
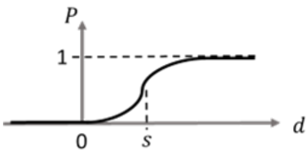
$p_j(A_k, A_l) \simeq 1$ means a strong preference.

$p_j(A_k, A_l) = 0$ means a strict preference.

The set of $\left(X_j(\ldots), p_j(A_k, A_l)\right)$ known as the "generalized criterion" related to the criterion j, and can have different forms, some of the equations for "generalized criteria" are shown and listed in Table 3.

Table 3: The Generalized Criteria [6].

Type	Preference Function	Definition	Parameters S
Type I: Usual Criterion		$p(d) = \begin{cases} 0\ if\ d \le 0 \\ 1\ if\ d > 0 \end{cases}$	-
Type II: U-shape criterion		$p(d) = \begin{cases} 0\ if\ d \le q \\ 1\ if\ d > q \end{cases}$	q

Type	Preference Function	Definition	Parameters S
Type III: V-shape criterion		$p(d)=\begin{cases} 0\ if\ d\le 0 \\ \frac{d}{p}\ if\ 0<d\le p \\ 1\ if\ d>0 \end{cases}$	
Type IV: Level criterion		$p(d)=\begin{cases} 0\ if\ d\le 0 \\ \frac{1}{2}\ if\ q<d\le p \\ 1\ if\ d>p \end{cases}$	p,q
Type V: V-shape with indifference preference		$p(d)=\begin{cases} 0\ if\ d\le q \\ \frac{d-q}{p-q}\ if\ q<d\le p \\ 1\ if\ d>p \end{cases}$	p,q
Type VI: Gaussian criterion		$p(d)=\begin{cases} 0\ if\ d\le 0 \\ 1-e^{\frac{-d^2}{2s^2}}\ if\ d>0 \end{cases}$	s

In Table 3, three threshold values are defined as p,q, and s which are strict preference threshold, indifference threshold, and an intermediate value between q, and ; respectively. The six functions listed in Table 3 are between commonly used types, but additional generalized criteria can be also considered.

Step 2: Determining the Aggregated Preference Indices

After providing the evaluation values of the alternatives for each criterion, the weights, and the generalized criteria, the aggregated preference indices and outranking flows should be determined in this step. For this, the following equation can be applied:

$$\begin{cases} \pi(A_k,A_l)=\sum_{j=1}^{n} p_j(A_k,A_l)w_j \\ \pi(A_l,A_k)=\sum_{j=1}^{n} p_j(A_l,A_k)w_j \end{cases} \quad (4)$$

$\pi(A_k, A_l)$ and $\pi(A_l, A_k)$ are positive values showing the degree that an alternative is preferred to another one over all the criteria. The following relations can be considered for π values:

$$\pi(A_i, A_i)=0, i=1,2,\dots,m;$$

$$0\le\pi(A_k, A_l)\le 1;$$

$$0\le\pi(A_l, A_k)\le 1;$$

$$0\le\pi(A_k, A_l)+\pi(A_l, A_k)\le 1;$$

$\pi(A_k, A_l)\sim 0$ means a weak global preference of A_k over A_l;

$\pi(A_k, A_l)\sim 1$ means a strong global preference of A_k over A_l.

It must be mentioned that $\pi(A_k, A_l)$, $\pi(A_l, A_k)$, $p_j(A_k, A_l)$, and $p_j(A_l, A_k)$ are real numbers without units and they are not dependent on the scales of the criteria. Calculating the π values between all pairs of the alternatives helps to gain a graph called "the valued outranking graph" which includes the alternative nodes and two arcs between each pair of alternatives (Figure 2).

Step 3: Determining the Outranking Flows

The number of alternatives is m,, therefore, each alternative faces $m-1$ alternatives, which must be considered in the outranking. This step aims to introduce two values named positive outranking flow $(\varphi^+(A_i))$, and negative outranking flow $(\varphi^-(A_i))$, to gain how an alternative (A_i) outranks all the other alternatives or is outranked by all of them; respectively. So the higher $\varphi^+(A_i)$, and the lower $\varphi^-(A_i)$, the better the alternative. The $\varphi^+(A_i)$ is the power and the outranking character of the alternative, on the other hand, $\varphi^-(A_i)$ is the weakness and the outranked character of A_i. An example is shown in (Figure 3). The $\varphi^+(A_i)$, and $\varphi^-(A_i)$ are obtained as follows:

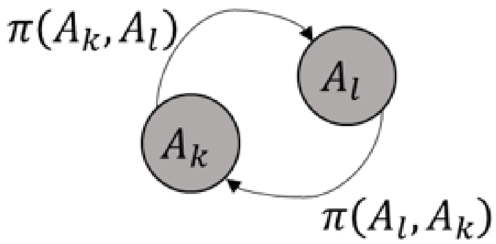


Figure 2: Valued Outranking Graph.

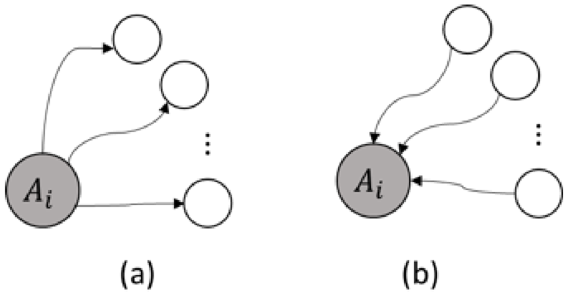


Figure 3: Positive and Negative Outranking Flows.

$$\varphi^{+}(A_i) = \frac{1}{m-1}\sum_{A_x \in A} \pi(A_i, A_x) \qquad (5)$$

$$\varphi^{-}(A_i) = \frac{1}{m-1}\sum_{A_x \in A} \pi(A_x, A_i) \qquad (6)$$

After determining the positive and negative outranking flows, the relations of the pairs of alternatives can be determined using the following step.

Step 4: Obtaining the Partial Outranking

In this step, the positive and negative outranking flows are used to determine the partial outranking as the result of the PROMETHEE I method. As the same rankings are not induced by both flows, the PROMETHEE I uses the following relations (Equation 7) to determine the preference, indifference, and incomparability of the alternatives:

$$\begin{cases} A_k P^I A_l \text{ iff } \begin{cases} \varphi^{+}(A_k) > \varphi^{+}(A_l) \text{ and } \varphi^{-}(A_k) < \varphi^{-}(A_l), \text{ or} \\ \varphi^{+}(A_k) = \varphi^{+}(A_l) \text{ and } \varphi^{-}(A_k) < \varphi^{-}(A_l), \text{ or} \\ \varphi^{+}(A_k) > \varphi^{+}(A_l) \text{ and } \varphi^{-}(A_k) = \varphi^{-}(A_l); \end{cases} \\ A_k I^I A_l \text{ iff } \varphi^{+}(A_k) = \varphi^{+}(A_l) \text{ and } \varphi^{-}(A_k) = \varphi^{-}(A_l) \\ A_k R^I A_l \text{ iff } \begin{cases} \varphi^{+}(A_k) > \varphi^{+}(A_l) \text{ and } \varphi^{-}(A_k) > \varphi^{-}(A_l), \text{ or} \\ \varphi^{+}(A_k) < \varphi^{+}(A_l) \text{ and } \varphi^{-}(A_k) < \varphi^{-}(A_l); \end{cases} \end{cases} \qquad (7)$$

$A_k P^I A_l$, $A_k I^I A_l$, and $A_k R^I A_l$ propose the preference, indifference, and incomparability of A_k over A_l using the PROMETHEE I. Furthermore, the following results can be obtained by analyzing these relations:

1. $A_k I^I A_l$ means that "both negative and positive flows are equal".

2. $A_k P^I A_l$ means that "the higher power of A_k is associated with a lower weakness of A_k with regards to A_l", but $A_k R^I A_l$ means that "the higher power of one alternative is associated with the lower weakness of another alternative".

3. $A_k R^I A_l$ can happen when the A_k is good on some criteria sets, and A_l is bad on it, and also reversely A_l is good on other sets on which A_k is bad on it. Therefore, the decision-maker cannot obtain consistent information from both flows, and decide which alternative is better in this situation.

4. This method gives a classification of the various alternatives to the decision-makers.

5. This method is not able to classify all the alternatives, and some alternatives can remain incomparable.

PROMETHEE II Method (Complete Ranking)

To eliminate the limits of the PROMETHEE I related to choosing the better alternative in some cases, the PROMETHEE II was developed based on introducing a net outranking flow. The first three steps of the PROMETHEE II are similar to the former method, but the outranking step is different as it includes obtaining the net outranking flow as a balance between negative and positive flows using the following equation:

$$\varphi\left(A_k\right)=\varphi^{+}\left(A_k\right)-\varphi^{-}\left(A_k\right) \quad (8)$$

If $\varphi\left(A_k\right)>0,$, this alternative is more outranking the others (on all criteria), and in contrast, when $\varphi\left(A_k\right)<0,$, it is more outranked by others. The net outranking is used to rank the alternatives simply and clearly. That is to say, the higher the net outranking flow, the better the alternative. In the PROMETHEE II two relations (Equation 9) are investigated between the pairs of alternatives that make them comparable. However, considering the difference in the flows (Equation 8), more information can be lost as it gives more disputable results. Therefore, using both PROMETHEE I and II methods together is recommended in real-world problems.

$$\begin{cases} A_k P^{II} A_l \text{ iff } \varphi\left(A_k\right)>\varphi\left(A_l\right) \\ A_k I^{II} A_l \text{ iff } \varphi\left(A_k\right)=\varphi\left(A_l\right) \end{cases} \quad (9)$$

In addition, it is beneficial to add, the net outranking flows possess the following properties:

$$\begin{cases} -1\leq\varphi\left(A_k\right)\leq 1 \\ \sum_{A_x\in A}\varphi\left(A_x\right)=1 \end{cases} \quad (9)$$

Finally, this method gives a simple and clear way to gain a complete rank for the alternatives [6,11-14].

Conclusion

In conclusion, this paper's survey sheds light on the concept of the PROMETHEE method, its usefulness in different application areas, and the advantages and disadvantages of using this method. The process steps of both the partial and complete ranking by the PROMETHEE method were carefully described, highlighting their similarities and differences. While both methods have an easy-to-understand structure, the PROMETHEE II method's use of net outranking flows in the final outranking step provides a more precise rank between the alternatives, making it easier to select the best option. Ultimately, understanding the PROMETHEE method and its various applications can aid decision-makers in making more informed decisions by providing them with a systematic and objective approach to assessing multiple criteria alternatives.

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Conflict of Interest

No conflict of interest.

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