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# Promethee methodology for multicriteria technology selection

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Abstract: The purpose of this paper is to present computational procedures and a general assessment of the usefulness of the Promethee methods in multi-criteria decision-making problems based on rankings of potential decision variants. The sources and genesis of the development of the Promethee I and Promethee II methods are analysed. The main assumptions and relationships used by the methods subject to analysis are described. An analysis of the fundamental ways of modelling a decision-maker's preferences and the forms of the preference function is also presented. Generalized types of criteria in multi-criteria decision support problems are classified. The main data structures and a set of actions for multi-criteria work technology selection are presented and described.

Keywords: multi-criteria decision analysis, work technology selection.



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## 1. Introduction

Technological progress and the growing complexity of work processes are giving rise to an increasing number of available technologies for their implementation (Gomaa, Vaculik et al 2021) (Gomaa, Jabi et al 2022) (Hatem Nawar 2021) (Katebi, Homami and Najmeddin 2022) (Liu et al 2021) (Qiao et al 2021) (Sojobi and Liew 2022). In many instances choosing the optimum technology is difficult as it depends on many different factors. The most prevalent technologies find most widespread use (Mohan et al 2022) (Tiza et al 2021) (Ushakov, Yarmolinsky and Yarkin 2021) (Knoth, Fufa and Seilskjær 2022), and this may preclude the application of modern or less known technologies (Bieliatynskyi et al 2021) (Goutam Mukherjee et al 2021) (Iturralde et al 2022) (Makul 2020) (Sánchez-Garrido, Navarro and Yepes 2022) (Walker, Venkatarama Reddy and Mani 2020). By supporting technology assessment and selection with appropriate computational methods, technologies can be selected, and projects can be planned more efficiently.

## 2. Multi-criteria optimisation methods

Multi-criteria optimisation methods can be classified in terms of the number of classification criteria (Dytczak 2010); (Trzaskalik 2014); (Kobryń 2014). For example, a classification of methods according to the purpose of the decision-making process allows one to identify the following: (1) methods that aggregate preferences into a synthetic criterion, (2) methods that use variant outranking relations, and

(3) other methods. Methods in the first group entail breaking down the model of the issue in question into less complex parts, and then evaluating the obtained variants in relation to single criteria (attributes). Information obtained in this manner is then aggregated. Methods in this group derive from multi-attribute value (MAVT) and utility (MAUT) theories. Methods in the second group determine a mutual outranking relationship for individual decision variants on the basis of a set of partial features, including differentiation and dominance thresholds. The third group brings together methods which rely on approaches other than preference aggregation and investigating outranking relations. Methods in this group include subgroups of Pairwise Criteria Comparison (PCC) methods, interactive methods, distance methods (TOPSIS, VIKOR), SMAA fuzzy methods as well as others.

The $Q$ decision matrix, which contains data necessary to evaluate the different decision options is an essential information structure in multi-criteria decision optimisation.

$$\boldsymbol{Q} = \begin{bmatrix} Q_{1.1} & Q_{1.2} & \cdots & Q_{1,n} \\ Q_{2.1} & Q_{2.2} & \cdots & Q_{2,n} \\ \cdots & \cdots & \cdots & \cdots \\ Q_{m,1} & Q_{m,2} & \cdots & Q_{m,n} \end{bmatrix} \tag{1}$$

Rankings of the individual decision options $i$ against the specified criteria $j$ constitute elements of matrix $Q_{i,j}$. The rows of the matrix represent the decision variants, while the columns are represented by the subsequent criteria.

An optimal solution is selected based on synthetic ratings of individual solutions $U_i$, formulated by aggregating partial ratings $Q_{i,j}$. There are three aggregation concepts: 1) single synthetic criterion, eliminating possible incomparability of solutions; 2) synthetic outranking, accepting incomparability; 3) synthetic dialogue-based ratings, obtained by trial and error.

The most widely used concept is that of a single synthetic criterion, based on the aggregation of partial ratings subject to a strong or weak preference and equivalence.

A variety of synthetic indicators are used in formulating synthetic ratings. Calculation formulas defining ratings of individual analysed decisions are determined using a specific synthetic indicator, called a utility function. According to (Szwabowski and Deszcz 2001) it is possible to use the indicators shown in Table 1. For a more extensive description of indicators for formulating synthetic evaluations in preference aggregation methods, see (Szwabowski and Deszcz 2001) and (Kobryń 2014).

**Table 1.** List of indicators for ranking synthetic decision alternatives (Szwabowski and Deszcz 2001)

| No. | Classification criterion | MCDA methods |
|---|---|---|
| 1 | multiplicative indicator | $U_i = \prod_{j=1}^{k} f_j(x_i)$ |
| 2 | corrected multiplicative indicator | $U_i = \prod_{j=1}^{k} w_j \cdot f_j(x_i)$ |
| 3 | summation indicator | $U_i = \sum_{j=1}^{k} f_j(x_i)$ |
| 4 | corrected summation indicator | $U_i = \sum_{j=1}^{k} w_j \cdot f_j(x_i)$ |
| 5 | Additive indicator | $U_i = \frac{1}{k}\sum_{j=1}^{k} f_j(x_i)$ |
| 6 | corrected additive indicator | $U_i = \frac{1}{k}\sum_{j=1}^{k} \left(w_j \cdot f_j(x_i)\right)$ |
| 7 | weighted additive indicator | $U_i = \frac{\sum_{j=1}^{k}\left(w_j \cdot f_j(x_i)\right)}{\sum_{j=1}^{k} w_j}$ |
| Note:<br>$f_j(x_i) > 0$ – a rating of the *i*-th variant with respect to *j*-th criterion,<br>$w_j$ – weight of criterion *j* | | |

## 3. Modelling preferences

Decision variants constituting potential solutions, can be identified directly, using the full range of partial rankings, or indirectly, by identifying the attributes and constraints for the solution sought. The formulation of aggregate rankings using a utility function to determine values for all the analysed variants, makes it possible to establish a multicriteria ranking of decision variants, taking into account the occurrence of a) equivalence of two decision variants and b) superiority of one decision variant over the other. (Roy 1990) presents an alternative approach, which takes into account variability and imprecision of decision-maker's ratings and preferences by completing and specifying a set of preference situations to include a) equivalence of two options; b) weak preference of one variant over the other; c) strong preference; and d) incomparability of the two decision variants. If two variants $a$ and $b$ are mutually comparable, the following preferential situations are allowed (Roy 1990); (Dytczak 2010):

- $a$ and $b$ are equivalent (denoted as $a$I$b$ or $a$~$b$),
- weak preference of $a$ over $b$ (denoted as $a$S$b$),
- strong preference of $a$ over $b$ (denoted as $a$P$b$ or $a \succ b$).

Incomparability of variants $a$ and $b$ is denoted as $a$N$b$.

The results of the comparisons of decision variant pairs can be graphically summarized on cognitive maps in the form of a Hasse diagram (Roy 1990), where points connected by arcs (edges) represent the mutual relation between these points. If the arcs pass through points $w_u$ and $w_v$ and are oriented from point $w_u$ to point $w_v$ then point $w_v$ is preferred (“better”) to point $w_u$. Weak preference and equivalence can be represented by arcs drawn is a different graphic style, such as dashed or dotted lines. Additionally, an undirected edge can represent equivalence, while the absence of an edge can represent incomparability.

## 4 Promethee methods

Promethee methods use the concept of outranking relations. Brans presented the basis for this method in 1982 (J. Brans 1982). He then developed the method together with Mareschal and Vincke, in (Brans and Vincke, Note—A Preference Ranking Organisation Method 1985); (Brans, Vincke and Mareschal 1986). In his work (J. Brans 1982) described Promethee I and Promethee II, the methods most widely applied. Promethee methods are primarily used to build a ranking of decision variants. These methods establish partial rankings (Promethee I) and a complete ranking (Promethee II). The following methods are also part of the Promethee family: Promethee III, IV, V and VI. The Visual Promethee software (PROMETHEE/GAIA 2019) which implements Promethee methods is also available.

Decision matrix $Q$ with elements $Q_{i,j}$ representing ratings of given decision variants $W_j$ with respect to given criteria $K_j$ is the starting point for a Promethee method analysis. The rows of the matrix represent decision variants, while the columns are represented by the subsequent criteria. Each criterion is then assigned a weight coefficient $\omega_j$, corresponding to its importance in the set of criteria defined by a decision maker. The following should hold true for weight coefficients: $\sum_{j=1}^{n} = 1$. We denote ratings of variant $i$ in terms of criterion $j$ as $Q_{i},_{j} = f_j(W_i)$.

We start the calculation by comparing the different variant pairs, taking into account their ratings. For each pair $(W_u, W_v) \in W$ , we will determine on that basis the difference of their ratings for criterion $j$, denoted as:

$$d_j(W_u, W_v) = f_j(W_u) - f_j(W_v) \tag{2}$$

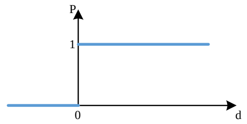
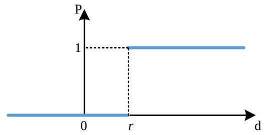
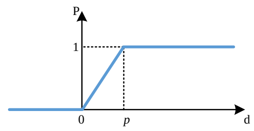
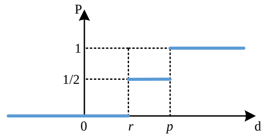
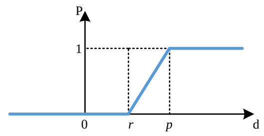
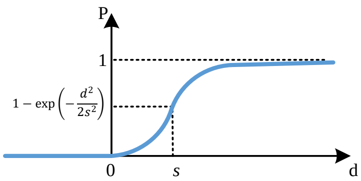
Based on calculated difference $d_j(W_u, W_v)$, with the help of the generalized criterion expressed by the preference function $P_j(W_u, W_v)$ for criterion $j$, we can investigate the preferences of a decision maker. The greater the difference $d_j(W_u, W_v)$, the more reasons for concluding that there is a preference for one variant over another. The preference function can be denoted as:

for stimulants $$P_j(W_u, W_v) = F_j\left[d_j(W_u, W_v)\right] \quad (3)$$
for destimulants $$P_j(W_u, W_v) = F_j\left[-d_j(W_u, W_v)\right] \quad (4)$$

The generalised criterion may come in different forms. As cited in: (Brans and Mareschal 2005) (Kobryń 2014), (Solecka 2013), in practical applications a number of generalised criteria types are in use, grouped according to the way the relation between the difference in the ratings of variants and the value of the preference function is formulated:

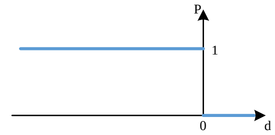
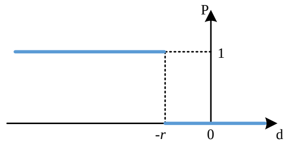
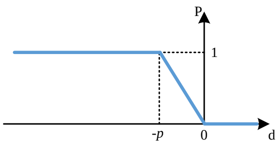
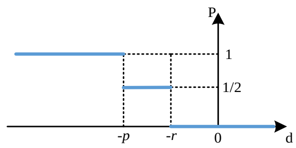
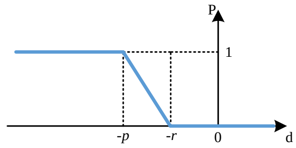
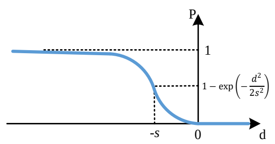
1) ordinary criterion;
2) quasi-criterion (U shape criterion);
3) criterion with a linear preference (V shape criterion);
4) level criterion;
5) criterion with a linear preference and an area of indifference;
6) Gaussian criterion.

**Table 2.** Stimulants - Preference function forms for different generalised criterion types (Kobryń 2014)

| Type of criterion | Working parameters | Preference function diagram | Preference function form |
|---|---|---|---|
| *1* | *2* | *3* | *4* |
| ordinary criterion | – |  | $P_j(d_j) = \begin{cases} 0 & d \le 0 \\ 1 & d > 0 \end{cases}$ |
| quasi-criterion (U shape criterion); | $r$ |  | $P_j(d_j) = \begin{cases} 0 & d \le r \\ 1 & d > r \end{cases}$ |
| criterion with a linear preference (V shape criterion) | $p$ |  | $P_j(d_j) = \begin{cases} 0 & d \le 0 \\ \frac{d}{p} & 0 < d \le p \\ 1 & d > p \end{cases}$ |
| level criterion | $r, p$ |  | $P_j(d_j) = \begin{cases} 0 & d \le 0 \\ \frac{1}{2} & r < d \le p \\ 1 & d > p \end{cases}$ |
| criterion with a linear preference and an area of indifference | $r, p$ |  | $P_j(d_j) = \begin{cases} 0 & d \le r \\ \frac{d-r}{p-r} & r < d \le p \\ 1 & d > p \end{cases}$ |
| Gaussian criterion | $s$ |  | $P_j(d_j) = \begin{cases} 0 & d \le 0 \\ 1 - \exp\left(-\frac{d^2}{2s^2}\right) & d > 0 \end{cases}$ |

Types of generalised criteria and the associated preference function for stimulants and destimulants according to (Kobryń 2014) are shown in Table 2 and Table 3. A simplified form of preference function $P_j(W_u, W_v)$ is used for the tables, i.e., $P_j(d_j)$. Criteria, with the exception of ordinary criteria, require additional variables to be taken into account. These include equivalence threshold $(r)$, preference threshold $(p)$ and variable $(s)$ determined experimentally according to a normal distribution. Variable $s$ is between $r$ and $p$ variables.

**Table 3.** Destimulants - Preference function forms for different generalised criterion types (Kobryń 2014)

| Type of criterion | Working parameters | Preference function diagram | Preference function form |
|---|---|---|---|
| *1* | *2* | *3* | *4* |
| ordinary criterion | – |   | $P_j(d_j) = \begin{cases} 0 & d \geq 0 \\ 1 & d < 0 \end{cases}$ |
| quasi-criterion (U shape criterion); | $r$ |   | $P_j(d_j) = \begin{cases} 0 & d \geq -r \\ 1 & d < -r \end{cases}$ |
| criterion with a linear preference (V shape criterion) | $p$ |   | $P_j(d_j) = \begin{cases} 0 & d \geq 0 \\ \frac{d}{p} & 0 > d \geq -p \\ 1 & d < -p \end{cases}$ |
| level criterion | $r, p$ |   | $P_j(d_j) = \begin{cases} 0 & d \leq 0 \\ \frac{1}{2} & r < d \leq p \\ 1 & d > p \end{cases}$ |
| criterion with a linear preference and an area of indifference | $r, p$ |   | $P_j(d_j) = \begin{cases} 0 & d \geq -r \\ \frac{d+r}{-p+r} & -r > d \geq -p \\ 1 & d < -p \end{cases}$ |
| Gaussian criterion | $s$ |   | $P_j(d_j) = \begin{cases} 0 & d \geq 0 \\ 1 - \exp\left(-\frac{d^2}{2s^2}\right) & d < 0 \end{cases}$ |

Once the types of preference functions for each generalized criterion have been determined and the values of these functions have been calculated, the next step in Promethee methods analyses is to determine the aggregate preference indices $\Pi(W_u, W_v)$ for each pair of decision variants. Indices are calculated according to the below formulae:

$$\Pi(W_u, W_v) = \sum_{j=1}^{n} w_j P_j(W_u, W_v) \quad (5)$$

$$\Pi(W_v, W_u) = \sum_{j=1}^{n} w_j P_j(W_v, W_u) \quad (6)$$

where $w_j$ stands for the weight of criterion $j$.

The aggregated preference indices $\Pi(W_u, W_v)$ determine the extent to which ranked variant $W_u$ is preferred (better than) variant $W_v$ for of all criteria.

The next stage of the analysis entails calculating preference flows usually denoted as $\Phi(W_u)$ for each variant $W_i$. A distinction is made between a positive preference flow $\Phi^+(W_u)$ and a negative preference flow $\Phi^-(W_u)$. Positive and negative flows are calculated according to the below formulae:

$$\Phi^+(W_u) = \frac{1}{m-1}\sum_{W_v \in W} \Pi(W_v, W_u), \tag{7}$$

$$\Phi^-(W_u) = \frac{1}{m-1}\sum_{W_v \in W} \Pi(W_u, W_v), \tag{8}$$

where $m$ stands for the number of decision variants subject to analysis.

A positive preference flow represents the extent to which variant $W_u$ outranks the other variants and expresses the strength of the given variant. Whereas a negative preference flow represents the extent to which variant $W_u$ is outranked by the other variants and expresses the weakness of the given variant.

Using flows $\Phi^+(W_u)$ and $\Phi^-(W_u)$ we then calculate the net preference flow for each variant according to the following formula:

$$\Phi(W_u) = \Phi^+(W_u) - \Phi^-(W_u). \tag{9}$$

According to (Brans and Mareschal 2005), net preference flows exhibit the following properties:

$$\begin{cases} -1 \le \Phi(W_u) \le 1 \\ \sum_{i=1}^{m} \Phi(W_u) = 0 \end{cases}. \tag{10}$$

Preference flows are used to generate partial rankings in the Promethee I method based on $\Phi^+(W_u)$ and $\Phi^-(W_u)$, and to generate a complete ranking in the Promethee II method based on $\Phi(W_u)$.

Promethee methods are based on the existence of an outranking relation between decision variants in the compared variant pairs $(W_u, W_v)$. The following outranking conditions apply:

a) $W_u P W_v$ – *preference* – variant $W_u$ outranks variant $W_v$,
b) $W_u I W_v$ – *equivalence* – variant $W_u$ is equivalent to variant $W_v$,
c) $W_u N W_v$ – incomparability – relation between variants $W_u$ and $W_v$ cannot be determined.

Positive and negative preference flows determine, in some cases, different ordering of decision variants in partial rankings, hence the final ranking lies at their intersection. Final relations in the Promethee I method are determined using the following relations as cited in: (Brans i Mareschal 2005):

$$W_u \mathrm{P} W_v \quad \text{if} \quad \begin{cases} \Phi^+(W_u) > \Phi^+(W_v) \quad \text{and} \quad \Phi^-(W_u) < \Phi^-(W_v) \\ \text{or} \\ \Phi^+(W_u) = \Phi^+(W_v) \quad \text{and} \quad \Phi^-(W_u) < \Phi^-(W_v), \\ \text{or} \\ \Phi^+(W_u) > \Phi^+(W_v) \quad \text{and} \quad \Phi^-(W_u) = \Phi^-(W_v) \end{cases} \tag{11}$$

$$W_u \mathrm{I} W_v \quad \text{if} \quad \Phi^+(W_u) = \Phi^+(W_v) \quad \text{and} \quad \Phi^-(W_u) = \Phi^-(W_v), \tag{12}$$

$$W_u N W_v \quad \text{if} \quad \begin{cases} \Phi^+(W_u) > \Phi^+(W_v) \quad \text{and} \quad \Phi^-(W_u) > \Phi^-(W_v) \\ \text{or} \\ \Phi^+(W_u) < \Phi^+(W_v) \quad \text{and} \quad \Phi^-(W_u) < \Phi^-(W_v) \end{cases}, \tag{13}$$

A complete ranking based on net preference flows, which reflects the balance between partial flows is generated within the scope of the Promethee II method. Hence, the larger the net flow of preferences, the better the decision variant. In this case we have two preference relations: preference $W_u \mathrm{P} W_v$ and equivalence$W_u \mathrm{I} W_v$. Mutual relations necessary to generate a complete ranking are determined on the following basis:

$$W_u \mathrm{P} W_v \quad \text{if} \quad \Phi(W_u) > \Phi(W_v), \tag{14}$$
$$W_u \mathrm{I} W_v \quad \text{if} \quad \Phi(W_u) = \Phi(W_v). \tag{15}$$

The structure of a complete ranking in the Promethee II method excludes situations where an incomparability relation occurs. Subsequent steps are determined by relations (14) and (15). According to relation (14), we find that variant $W_u$ outranks variant $W_v$ in variant pairs, while according to relation (15) we find an equivalence relation for the variants.

Based on net preference flow values $\phi(W)$, we generate a ranking according to the "The higher the value of $\phi(W)$, the higher the position of the variant in their ranking" principle. The variant with the highest$\phi(W)$ represents an optimal decision. The ordering obtained is considered decisive in terms of the position of the analysed decision variant in a complete ranking. For examples of practical application see, inter alia: publications: (Kobryń 2014), (Solecka 2013), (Trzaskalik 2014)

## 6. Conclusions

Multi-attribute variant models and the Promethee methods described herein used to support work technology selection, enable effective ranking analyses to be carried out in order to generate rankings of, for example, work technology variants. A simultaneous processing of multiple criteria when selecting an optimal variant represents a relatively comprehensive approach to optimal selection problem, compared to, for example, single-criteria solutions that only take into account a single aspect. It is also an approach that "mimics" to a greater extent the natural, intuitive flow of choices made by a decision-maker, based on an expectation of the highest possible benefits and a comparison of variants. The computational procedure for the Promethee I and Promethee II methods is relatively simple. It may be carried out using a spreadsheet or a freely available web based Visual Promethee type software, provided that reliable data are available to generate the output decision table $Q$.

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