

Full Paper

Modified approach to PROMETHEE for multi-criteria decision-making

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Abstract: This paper presents a modification of PROMETHEE for multi-criteria decision-making. The authors of PROMETHEE have defined six generalised preference functions in order to express their preferences for particular criteria. A modified approach to PROMETHEE is based on the Universal preference function which replaces the six proposed functions and generates an unlimited number of other preference functions. By applying this method, we can express all the complexity of selecting preference functions in the problems of optimisation by PROMETHEE.

Keywords: multi-criteria decision-making, universal preference function, PROMETHEE

INTRODUCTION

Practical managerial problems set diverse requirements, which are often of different relative importance and are differently sensitive to changes of input and output variables. Therefore, managerial decision-making requires the use of multiple criteria methods. A number of different criteria provide a comprehensive insight in accordance with the requirements set by decision-makers. The criteria may appear in different units and can often be of different relative importance and with different requirements for maximisation or minimisation.

A method by the name of PROMETHEE (Preference Ranking Organisation Method for Enrichment Evaluations) has been developed by Brans and Vincke [1] and Brans *et al.* [2]. The authors of PROMETHEE developed four variants of this method: PROMETHEE I provides a partial ranking alternative, PROMETHEE II provides a complete order, PROMETHEE III gives an interval order and PROMETHEE IV is used for a continuous set of alternatives. These methods have been constantly improved [3].

Some of the important directions of multi-criteria methods are the inclusion of fuzzy mathematical programming [4-8] and the formation of integrated hybrid models and other methods

of multi-criteria decision-making [9-12]. By combining different methods of multiple criteria, many authors highlight the importance of multi-criteria methods [13-16].

The development of methodology of multi-criteria decision-making has resulted in the formation of a large number of models and different approaches [17-20]. Multi-criteria methods are used by many authors as the basis for different approaches to the formation of new models: an interactive aggregation-desegregation approach [21], visualisation methods [22-23], a multiple-criteria decision analysis (MCDA) model based on multi-graded dominance relations [24], a method based on stochastic dominance degrees [25], and many others. PROMETHEE is one of the MCDA methods frequently applied in a wide range of multi-criteria decision-making processes [26-31].

The novelty of this paper is in the implementation of expanded modified access to PROMETHEE by the introduction of Universal preference function, which enables the definition of a practically unlimited number of functions that can be used as the preference function. The modification is reflected in the expansion of the possibilities of expressing the intensity of preferences within the criteria, according to which a comparison is performed. These extensions make it easier for the decision-makers to determine the intensity of subjective preferences, speed and preference limits. This allows a greater dispersion of the values of preference index of compared alternatives in the range 1 to 0. In this way, the ranking procedure in the case of close rank positions, without clear quantitative preference, is facilitated.

METHODS

The following multi-criteria problem is being considered:

$$\text{Max } \{k_1(a), k_2(a), \dots, k_p(a) \mid a \in A\} \quad (1)$$

where A is a finite set of possible alternatives $\{a_1, a_2, a_3, \dots, a_n\}$ and $\{k_1, k_2, \dots, k_p\}$ is a set of selected evaluation criteria. The data for problem-solving are usually recorded in an evaluation table (Table 1).

Table 1. Evaluation table

Alternative	Criteria					
	k_1	k_2	...	k_j	...	k_p
a_1	$k_1(a_1)$	$k_2(a_1)$	...	$k_j(a_1)$	...	$k_p(a_1)$
a_2	$k_1(a_2)$	$k_2(a_2)$	...	$k_j(a_2)$	...	$k_p(a_2)$
...
a_j	$k_1(a_j)$	$k_2(a_j)$	...	$k_j(a_j)$	...	$k_p(a_j)$
...
a_n	$k_1(a_n)$	$k_2(a_n)$	...	$k_j(a_n)$	...	$k_p(a_n)$

The preference structure in this case is based on pairwise comparisons. The authors of this method [1] introduced the functions of preferences. They are mathematical functions by which decision-makers can express preferences for certain criteria. $P(a, b)$ is a preference function of alternative a in relation to alternative b , which is defined by:

$$P(x) = \begin{cases} P(a, b) & x \geq 0 \\ P(b, a) & x \leq 0 \end{cases}, \quad x = k(a) - k(b) \quad (2)$$

where $0 \leq P(a, b) \leq 1$ and $P(a, b) \neq P(b, a)$. The potential preferences can be expressed using the following relations:

$P(a, b) = 0$	no preference, indifference	
$P(a, b) \sim 0$	weak preference	$k(a) > k(b)$
$P(a, b) \sim 1$	strong preference	$k(a) \gg k(b)$
$P(a, b) = 1$	strict preference	$k(a) \gg \gg k(b)$

Graphically, the preference function (2) can be presented as follows (Figure 1):

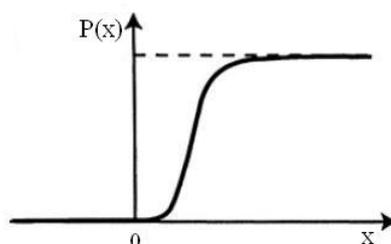


Figure 1. General form of preference function

The authors of PROMETHEE [1] introduced six generalised preference functions defined by expressions (3-8). The parameters p and q are the limits of preferences. Graphical interpretation of these functions is presented in Figure 2.

$$\text{Type I. Usual criterion: } P(x) = \begin{cases} 0, & x \leq 0 \\ 1, & x > 0 \end{cases} \quad (3)$$

$$\text{Type II. Quasi-criterion: } P(x) = \begin{cases} 0, & x \leq p \\ 1, & x > q \end{cases} \quad (4)$$

$$\text{Type III. Criterion with linear preference: } P(x) = \begin{cases} 0, & x < 0 \\ \frac{x}{p}, & 0 \leq x \leq p \\ 1, & x > p \end{cases} \quad (5)$$

$$\text{Type IV. Level criterion: } P(x) = \begin{cases} 0, & x \leq q \\ \frac{1}{2}, & q < x \leq p \\ 1, & x > p \end{cases} \quad (6)$$

Type V. Criterion with linear preference and indifference area:

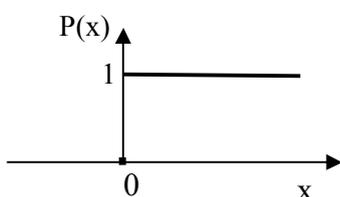
$$P(x) = \begin{cases} 0, & x \leq q \\ \frac{(x-q)}{(p-q)}, & q < x \leq p \\ 1, & x > p \end{cases} \quad (7)$$

$$\text{Type VI. Gaussian criterion: } P(x) = \begin{cases} 0, & x \leq 0 \\ \frac{-x^2}{1 - e^{-2\sigma^2}}, & x > 0 \end{cases} \quad (8)$$

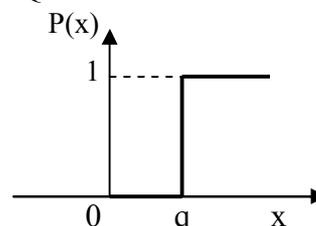
Depending on the particular problem, the decision-maker has the option to choose one of the six general types of preference function. In addition to the visual approach, which is provided to the decision-makers, preference functions enable the expressing of different importance of criteria in certain areas of multi-criteria space. Faster growth of a function means a greater expression of

preferences in individual segments. Expression of preferences is one of the most sensitive elements in the process of multi-criteria decision-making. Therefore, many authors pay great attention to this stage [32-35]. It is often based on knowledge and experience of the decision-makers, preference measuring methods and subjective factors.

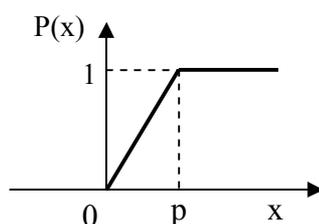
a) Type I. Usual criterion



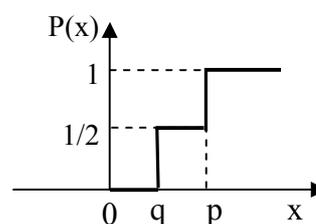
b) Type II. Quasi-criterion



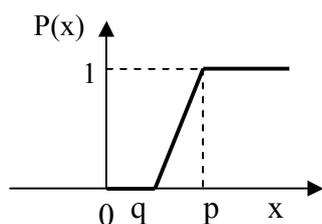
c) Type III. Criterion with linear preference



d) Type IV. Level criterion



e) Type V. Criterion with linear preference and indifference area



f) Type VI. Gaussian criterion

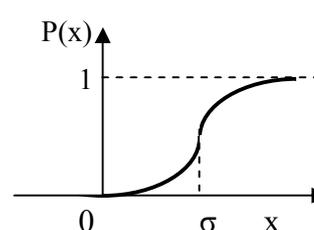


Figure 2. Generalised preference functions [1]

In further proceeding, values of preference index are calculated for each pair of compared alternatives (a , b) on the basis of certain preference functions and parameters:

$$IP(a, b) = \frac{1}{\sum_{i=1}^k Z_i} \sum_{i=1}^k P_i(a, b) \cdot Z_i \quad 0 \leq IP(a, b) \leq 1 \quad (9)$$

where $P_i(a, b)$ is the preference function and Z_i is the relative importance of the i -th criterion.

Based on the preference index, the values are determined for each of the compared alternatives:

- The values of the outgoing flow $\phi^+(a)$ (synthetic measure of preference of alternatives in relation to all the others in the set of criteria K):

$$\phi^+(a) = \sum_{x \in K} IP(a, x) \quad (10)$$

- The values of the incoming flow $\phi^-(a)$ (which shows how all the other compared alternatives outperform alternative a):

$$\phi^-(a) = \sum_{x \in K} IP(x, a) \quad (11)$$

- The values of the net flow $\phi(a)$ (complete ranking of alternatives):

$$\phi(a) = \phi^+(a) - \phi^-(a) \tag{12}$$

This paper presents a modification of PROMETHEE by the introduction of the Universal preference function, which is a unique mathematical model that combines the generalised functions and allows the formation of an unlimited number of others. Taking into account a large number of different functions that can be generated from it, the decision-maker is provided with a significantly improved preference system. The modification of PROMETHEE is reflected in the expansion of the possibilities of expressing the intensity of preferences within the criteria, according to which a comparison is performed.

RESULTS AND DISCUSSION

Modified PROMETHEE

A modified approach to PROMETHEE is based on the Universal preference function that replaces the six proposed functions and generates an unlimited number of other preference functions. The Universal preference function is defined as:

$$P(x) = \begin{cases} m \frac{|x|^\alpha}{p^\alpha} & |x| \leq p \\ m + \frac{1-m}{(q-p)^\beta} (|x|-p)^\beta, & p < |x| \leq q \\ 1, & |x| > q \end{cases} \tag{13}$$

where m is a parameter, p and q are borders of preference, α and β are parameters of preference intensity changes (0 < α < ∞; 0 < β < ∞).

In general, preference function y=P(x) is not decreasing for ∀x ≥ 0 and for ∀x ∈ ℝ 0 ≤ P(x) ≤ 1. Some specific points of preference changes are as follows (Figure 3):

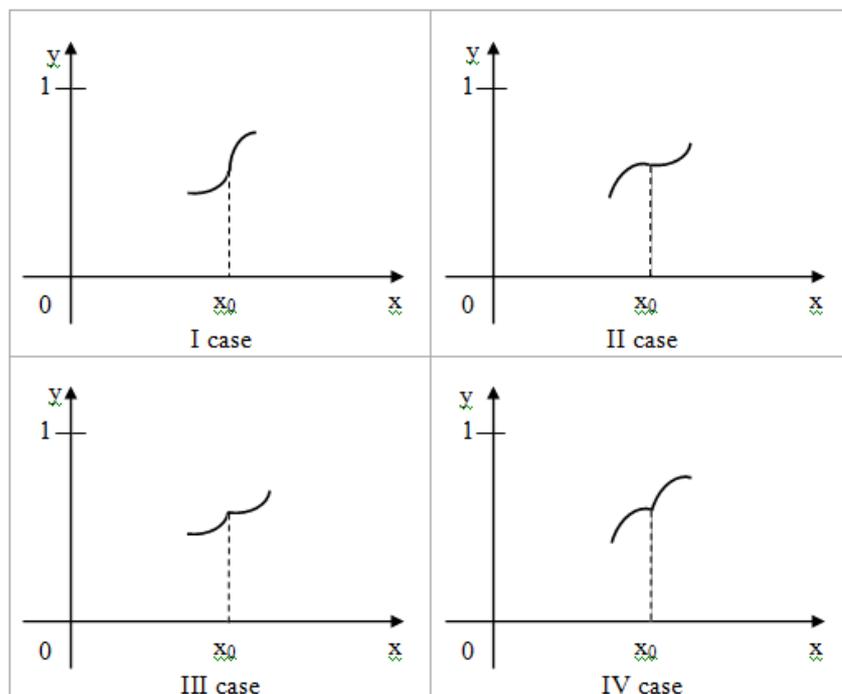


Figure 3. Some characteristic changes of preferences

The first two cases are the limits of continuous preference changes of I and II types. In the first case preference is changing at point x_0 . In the second case the speed of preference is changing from decreasing to increasing. The other two types are borders with sudden changes of preferences of type I and II. In the third case the preference rate increases to the point x_0 and then increases again, while in the fourth case it decreases to the point x_0 and then again decreases. Therefore, at point x_0 the speed changes in intensity (a decrease in the first case and an increase in the second case).

The generalised preference functions are obtained from the previous function (13) as follows.

1) Usual criterion:

$$P(x) = \begin{cases} 0 & x = 0 \\ 1 & x > 0 \end{cases} \quad (14)$$

can be replaced with:

$$P(x) = \begin{cases} \frac{|x|^\alpha}{p^\alpha} & |x| \leq p \\ 1 & |x| > p \end{cases} \quad (15)$$

which is obtained from (13) by setting $m=1$, $p=q$, $0 < \alpha < \infty$. When $\alpha \rightarrow 0$ one of the six generalised criteria, Usual criterion, is obtained (Figure 4).

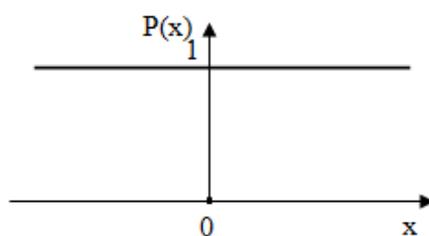


Figure 4. Graph of preference function of Usual criterion

2) Quasi-criterion:

$$P(x) = \begin{cases} 0 & x \leq q \\ 1 & x > q \end{cases} \quad (16)$$

In this case when $m=1$, $p=q$, $0 < \alpha < \infty$ in (13):

$$P(x) = \begin{cases} \frac{|x|^\alpha}{p^\alpha}, & |x| \leq p \\ 1, & |x| > p \end{cases} \quad (17)$$

Letting $\alpha \rightarrow \infty$ in (17), the known generalised criterion, Quasi-criterion, is obtained (Figure 5).

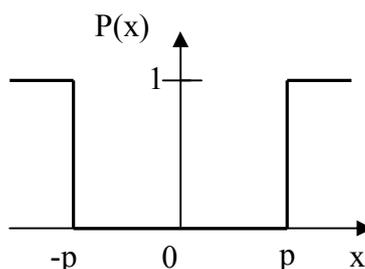


Figure 5. Graph of preference function of Quasi-criterion

3) Criterion with linear preference:

$$P(x) = \begin{cases} \frac{x}{p}, & x \leq p \\ 1, & x > p \end{cases} \quad (18)$$

By the replacement of following parameters $m=1$, $p=q$, $0 < \alpha < \infty$ in (13), we get:

$$P(x) = \begin{cases} \frac{|x|^\alpha}{p^\alpha}, & |x| \leq p \\ 1, & |x| > p \end{cases} \quad (19)$$

For $\alpha=1$, the known criterion (one of the generalised criteria), Criterion with linear preference, is obtained (Figure 6a). By changing the parameter α in (19), the following modifications can be obtained. For $\alpha > 1$, more significant preference is obtained near the preference border defined by p (Figure 6b). For $\alpha < 1$, the obtained criterion emphasises the importance of the higher initial preference for any slightest differences in the criterion space (Figure 6c).

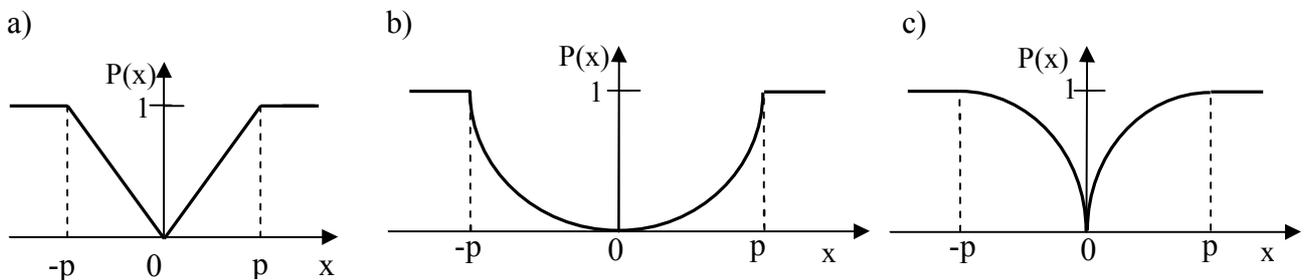


Figure 6. Graphs of preference functions of Criterion with linear preference and its modifications

4) Level criterion:

$$P(x) = \begin{cases} 0 & x \leq q \\ 1/2 & q < x \leq p \\ 1 & x > q \end{cases} \quad (20)$$

can be replaced with:

$$P(x) = \begin{cases} \frac{|x|^\alpha}{2p^\alpha}, & |x| \leq p \\ \frac{1}{2} + \frac{1}{2} \left(\frac{|x| - p}{q - p} \right)^\beta & p < |x| \leq q \\ 1 & |x| > q \end{cases} \quad (21)$$

The function (21) is obtained directly from (13) by setting $m=1/2$. Letting $\alpha \rightarrow \infty$ and $\beta \rightarrow \infty$ in (21), a generalised criterion, Level criterion, is obtained (Figure 7a). By changing parameter β in (21), the following modifications of Level criterion can be obtained: for $\beta > 1$, indifference area is obtained up to the preference change parameter p while the prominent preference growth is obtained near the border of preference q (Figure 7b); for $\beta=1$, indifference area is obtained up to the preference change parameter p while the linear growth is obtained from the border of preference p to the border of preference q (Figure 7c); for $\beta < 1$, indifference area is obtained up to the preference

change parameter p while the prominent preference growth is obtained after the parameter p (Figure 7d).

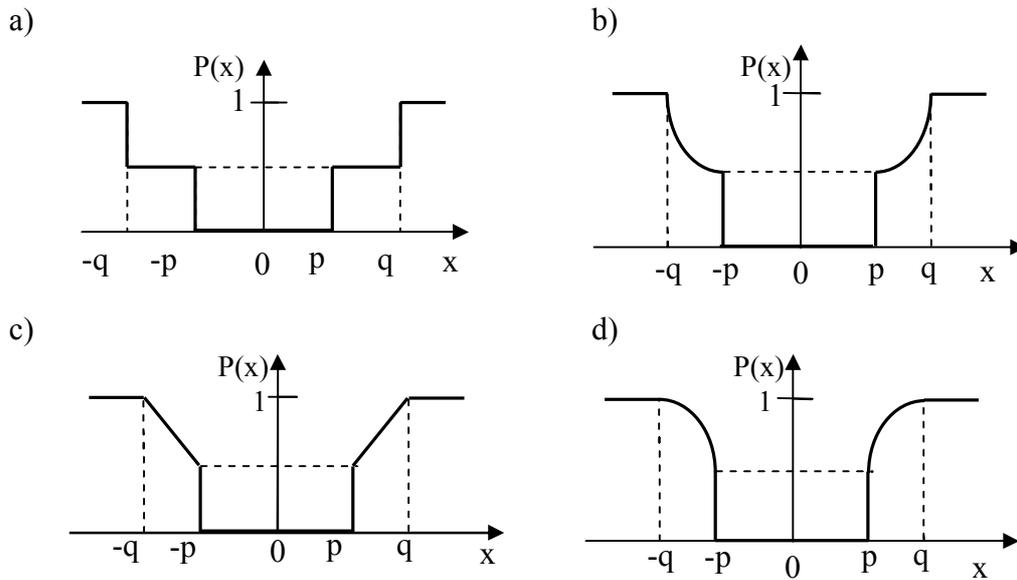


Figure 7. Graphs of preference functions of Level criterion and its modifications

5) Criterion with linear preference and indifference area:

$$P(x) = \begin{cases} 0, & x \leq q \\ \frac{(x-q)}{(p-q)}, & q < x \leq p \\ 1, & x > p \end{cases} \quad (22)$$

can be replaced with:

$$P(x) = \begin{cases} 0, & |x| \leq p \\ \left(\frac{|x|-p}{q-p} \right)^\beta & p < |x| \leq q \\ 1 & x > q \end{cases} \quad (23)$$

which was obtained from (13) by setting $m=0$.

Criterion with linear preference and indifference area is obtained from (23) using parameter $\beta=1$ (Figure 8a). For $\beta > 1$, the function gives a distinct preference near the preference border of q (Figure 8b). For $\beta < 1$, the area of indifference is obtained up to p while the prominent growth of preference is obtained for values higher than parameter p , but only in its nearest vicinity (Figure 8c).

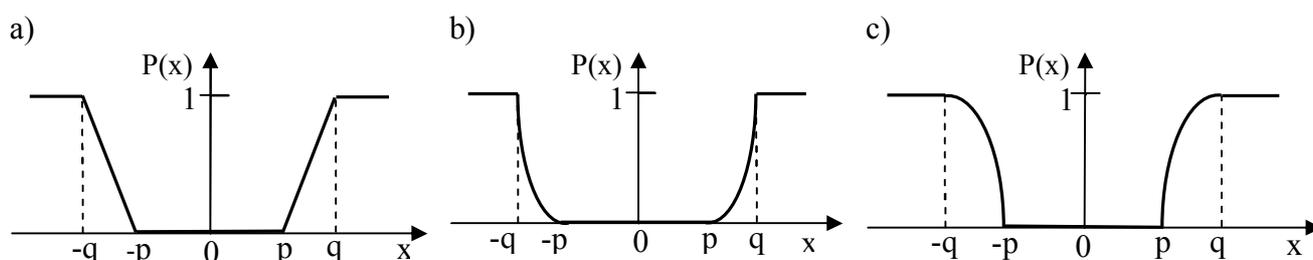


Figure 8. Graph of preference function of linear preference and indifference area and its modification

6) Gaussian criterion:

The preference function which can approximate the preferences presented by the Gaussian criterion can be obtained by using Universal preference function (13) and changing the appropriate parameters. A function which emphasises the importance and higher intensity of preference growth in the region of parameter p , which changes the preference intensity, is obtained for $\alpha > 1$ and $\beta < 1$ (Figure 9).

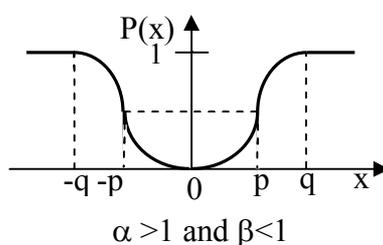


Figure 9. Characteristic appearance of Universal preference function

By changing the parameters of Universal preferential function (13), it is possible to get a number of other preference functions (presented in Figure 10). For $\alpha > 1$ and $\beta > 1$, the obtained function gives a distinct preference when the value of independent variable is approaching parameter p and parameter q (Figure 10a). For $\alpha < 1$ and $\beta < 1$, the obtained function highlights the preference for each of the smallest initial differences and for small values greater than p (Figure 10b). For $\alpha < 1$ and $\beta > 1$, the obtained function highlights the prominent preferences for the smallest initial differences and in the nearest vicinity of parameter q (Figure 10c).

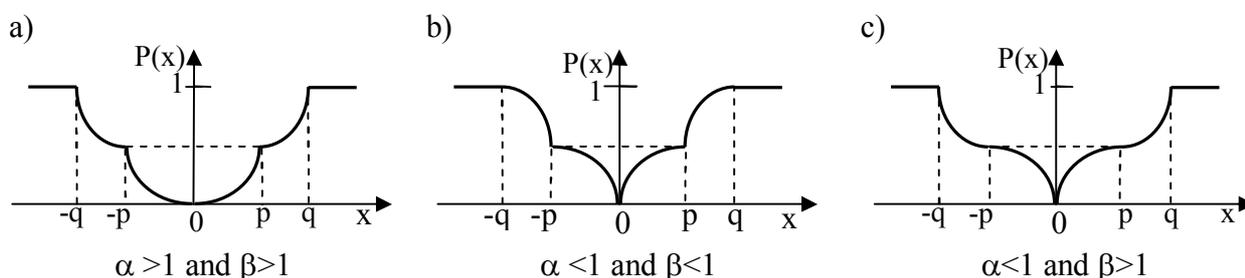


Figure 10. Some other types of preference functions

Based on Universal preference function (13) and dependent on the parameter change, it is possible to obtain different preference functions. Some of the characteristic shapes of this function, in accordance with the change of parameter α , are illustrated in Figure 11. The influence of

parameter change of α and β on possible shapes of Universal preference function is presented in Figure 12.

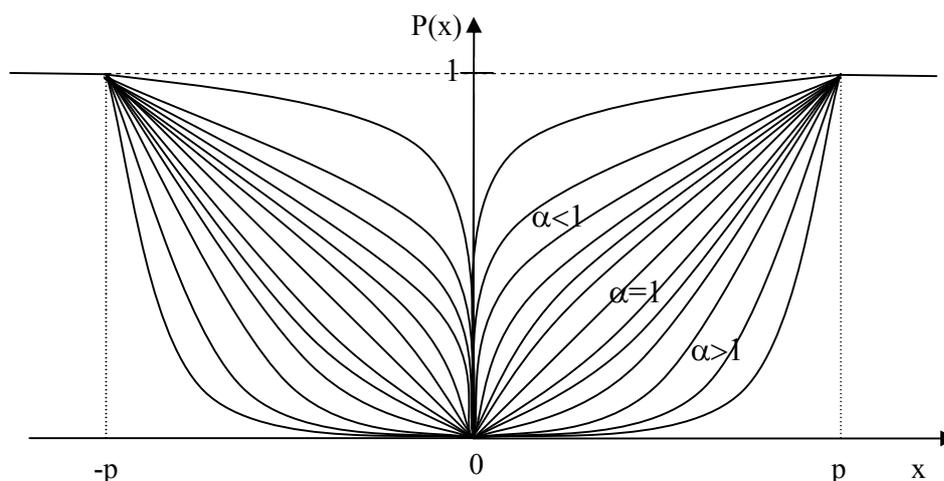


Figure 11. Different appearance options of Universal preference function in accordance with change of parameter α

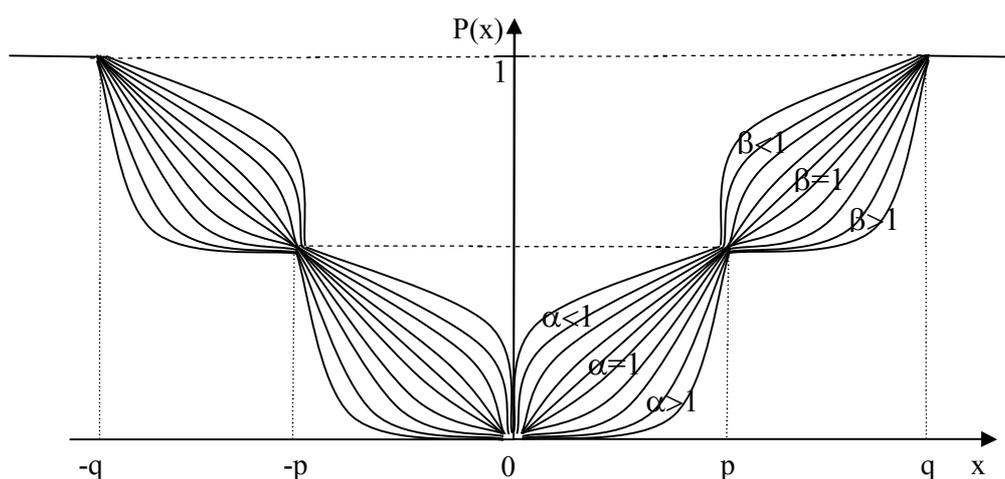


Figure 12. Some characteristic shapes of Universal preference function in accordance with the change of parameters α and β

Case Study

In order to verify the model in a case study, we have formed the basis for multi-criteria decision-making (Table 2) for the purpose of choosing the best investment project in a tool factory located in Cacak, Serbia. We compared five different design solutions (a_1, a_2, a_3, a_4, a_5) evaluated in a system of five criteria (economy, technical dependence, technology, logistics and environment) with various demands for extremisation (maximisation or minimisation).

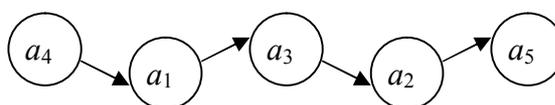
The result was obtained by PROMETHEE II, using the usual type of generalised criterion for all the criteria (without the use of modified PROMETHEE). Values of the net flow, $\phi(a)$, for each of the considered alternatives are presented in Table 3. The resulting graph of alternatives, obtained by using the usual type of generalised criterion for all criteria, is presented in Figure 13.

Table 2. Initial values of realised example

Criterion	Request	Alternative					
		a_1	a_2	a_3	a_4	a_5	
k_1	Economy	max	200	185	180	215	250
k_2	Technical dependence	min	15	12	16	21	20
k_3	Technology	max	35	26	28	20	10
k_4	Logistics	max	82	85	94	108	105
k_5	Environment	min	4	4	3	2	5

Table 3. Values of the net flow of alternatives

Alternative	a_1	a_2	a_3	a_4	a_5
$\phi(a)$	0.2	-0.2	0.00	0.8	-0.8

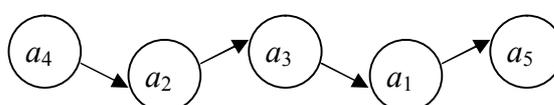
**Figure 13.** Graph of alternatives obtained by the usual type of generalised criterion

By using Universal preference function and by selecting the parameters, the rank of alternatives may be altered. While analysing the technological criteria in the considered example, the need for specific expression of its preference was established. In the following calculation, only one preference function (of the technological criterion) was changed while the others maintained the usual type of generalised functions. The values of the parameters of this function are: $m=0.5$, $\alpha=1.5$, $\beta=0.5$, $p=20$, $q=35$. The illustrated preference function emphasises the importance and greater rate of preference growth around the parameter of preference change $p = 20$.

This function was selected with the presumption of favoured alternatives whose values belong to the range of faster function growth. Also, the alternatives whose values are farther from this range (to a greater or lesser extent) should be given lower priority. Values of the net flow, $\phi(a)$, for each of the considered alternatives in this case is shown in Table 4. The resulting graph of alternatives, obtained by using Universal preference function, is presented in Figure 14.

Table 4. Values of the net flow of alternatives obtained by using Universal preference function

Alternative	a_1	a_2	a_3	a_4	a_5
$\phi(a)$	-0.27	-0.12	-0.26	0.94	-0.29

**Figure 14.** Graph of alternatives obtained by Universal preference function

The above example clearly shows that the alternatives are favoured in proportion to the growth of preference function. This causes a change of ranking positions of alternatives a_1 and a_2 , while alternative a_4 remains in the first position regardless of the change of preferential function. The use of the proposed functions opens up a wide range of possibilities of expressing subjective preferences of decision-makers in the whole criterion space. The generation of a large number of different forms of new preferences (as previously discussed) allows the expression of preferences which would not be possible by using only six generalised criteria.

CONCLUSIONS

The Universal preference function enables a successful expression of preferences made by individual criteria, taking into account essential characteristics of different criteria. Based on the Universal preference function, it is possible to define practically unlimited number of functions that can be used as preference functions. Determining the parameters that define the proposed preference function, the decision-maker can express both certain specific problems and his/her preferences of the used criteria. By using this function, all the complexity of preference functions in optimisation problems of the PROMETHEE can be expressed. It should be emphasised that this unique feature allows the formation of all generalised criteria and at the same time the formation of many new ones.

The modification of the PROMETHEE represents the expansion of possibilities for expressing the intensity of preferences within the criteria according to which a comparison is performed. Further research trends would include statistical investigation of the results of application of the Universal preference function in multi-criteria decision-making in relation to the generalised criteria.

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