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A PREFERENCE RANKING ORGANISATION METHOD†

(The PROMETHEE Method for Multiple Criteria Decision-Making)

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Principles for a new family of outranking methods are given. The main aim of the proposed PROMETHEE approach is to be as easily understood as possible by the decision-maker. It is based on extensions of the notion of criterion. Six possible extensions are considered. These extensions can easily be identified by the decision-maker because the parameters to be defined (at most 2) have an economic significance. A valued outranking graph is constructed by using a preference index. Two possibilities are considered to solve the ranking problem by using this valued graph. PROMETHEE I provides a partial preorder and PROMETHEE II a total preorder on the set of the possible actions.
(MULTI CRITERIA DECISION MAKING)

1. Introduction

Let us first consider the unicriterion problem

$$\operatorname{Max}\{ f(a) \mid a \in K \}, \tag{1.1}$$

K being a set of possible actions or solutions and $f: K \to \mathbb{R}_1$ a criterion differentiating these actions. In this paper K will be finite and of small size. Criteria to be minimized could equally well be considered. The problem induces on the actions of K a *total preorder* (complete and transitive relation). It is a *well stated problem* because the determination of an optimal solution $\tilde{a}$ so that $f(\tilde{a}) \geqslant f(a)$, $\forall a \in K$, has sense. We obtain a complete graph by considering the actions of K as nodes and, for all a and $b \in K$, and arc(ab) if $f(a) \geqslant f(b)$.

On the other hand, the multicriteria problem

$$\operatorname{Max}\{ f_1(a), f_2(a), \dots, f_h(a), \dots, f_k(a) \mid a \in K \}, \tag{1.2}$$

$f_h(a)$, $h = 1, 2, \dots, k$ being k criteria, in general will not induce a total preorder on K. The problem is no longer well stated because the notion of optimal solution has no sense; in general there exists no solution $\tilde{a}$ so that $f_h(\tilde{a}) \geqslant f_h(a)$, $\forall a \in K$, $\forall h$. Such problems, however, have a real economic meaning and have often to be solved.

Let a and b be two actions of K so that $f_h(a) \geqslant f_h(b)$, $\forall h \in \{1, 2, \dots, k\}$, one at least of the inequalities being strict, we then say that *a dominates b*. We consequently obtain on K a partial order (transitive relation) called *dominance order*. If the actions of K are again supposed to be the nodes of a graph, the arc(ab) being considered if a dominates b, we obtain the *dominance graph*. The dominance order is in general very poor even when only a few criteria are considered, so that the dominance graph has not many arcs. It frequently happens that the dominance order is empty.

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In order to support the decision-maker who must solve multicriteria problems, three kinds of methods were essentially considered: aggregation methods using utility functions, interactive methods and outranking methods. In this paper we are interested only in the last ones.

The dominance relation associated to a multicriteria problem is based on the *unanimity* of the points of view ($\forall h$). It is usually so poor that it cannot be used for solving the problem. Therefore many authors have proposed outranking methods in order to *enrich* the dominance relation. This enrichment is often based on a majority principle (and no longer on the unanimity of the points of view).

The outranking methods consist of a compromise between the too poor dominance relations and the excessive ones generated by utility functions. Every outranking method includes two phases:

—the construction of an outranking relation,

—the exploitation of this relation in order to assist the decision-maker.

These two phases may be treated in different ways and many methods have been proposed according to the kind of the problems and the concrete cases considered.

The most significant methods in this area are due to B. Roy. In the last years, the ELECTRE I, II, III and IV methods (Brans et al. 1975, Hugonnard and Roy 1982, Roy 1968, 1973, 1977a, b, 1978) have been proposed. These methods are relatively well known and were successfully used to solve different concrete problems. However the ELECTRE methods are rather intricate because they require a lot of parameters, the values of which are to be fixed by the decision-maker and the analyst. Some of them have a real economic meaning so that their values can be fixed clearly. Nevertheless, some others (such as concordance discrepancies and discrimination thresholds) playing an essential role in the procedures only have a technical character and their influence on the results is not always well understood. Moreover in some of the ELECTRE methods the notion of "degree of credibility" is rather difficult for practitioners.

In order to avoid these difficulties we propose in this paper a modified approach which is very simple and easily understood by the decision-maker. It is based on extensions of the notion of criterion. These extended criteria can easily be built by the decision-maker because they represent the natural notion of intensity of preference, and the parameters to be fixed (maximum 2) have a real economic meaning. A valued outranking graph is then considered by using a preference index. Two possibilities are offered to solve the ranking problem. PROMETHEE I provides a partial preorder and PROMETHEE II a total preorder on the set of possible actions (Brans 1982).

2. Principles of the PROMETHEE Methods

The methods we propose in this paper may be characterized as follows:

1. *Extension of the Notion of Criteria*

The classical notion of criterion implies on K a "$\{I, P\}$ preference structure". Indeed, if f is a criterion, we then have:

$$\begin{aligned} a\, P\, b \quad &\text{iff} \quad f(a) > f(b), \\ a\, I\, b \quad &\text{iff} \quad f(a) = f(b), \end{aligned} \tag{2.1}$$

where P and I respectively denote preference and indifference. Such a modelisation of the preferences of the decision-maker implies that no distinction in strict preference is made for small or large deviations between $f(a)$ and $f(b)$. Moreover the notion of indifference is necessarily transitive. We know that these implications are in general not realistic.

For these reasons, some authors, such as B. Roy (1977a), have introduced the notions of quasi-criterion and pseudo-criterion. The quasi-criterion has been defined to consider a larger area of indifference and the pseudo-criterion to take into account an area of hesitation between indifference and preference. These extensions were used successfully in the ELECTRE methods. Nevertheless, these methods request some parameters such as concordance, discordance and discrimination thresholds which are not easily understood by practitioners.

In the PROMETHEE methods, we also suggest modifying the modelisation of the preferences of the decision-maker by considering, for each criterion, some possible extensions. But the disadvantages of usual, quasi and pseudocriteria will only be accepted when considered by the decision-maker. Other extensions will also be accepted. For some of them, the intransitivity of indifference will be allowed; for others, it will be possible to pass smoothly from indifference to strict preference contrary to quasi-criteria. We therefore will use the notion of intensity of preference for introducing different extensions of the notion of criterion. The main feature of the PROMETHEE methods is that each possible extension will be very clear and easily understood by the decision-maker.

2. *Valued Outranking Relation*

Some authors have already suggested valued outranking relations for treating a decision problem in a multicriteria framework (see, for instance, Hugonnard and Roy 1982, Roy 1973, 1977b).

In the PROMETHEE methods, we also consider such a relation; moreover, the proposed relation is less sensitive to small modifications and its interpretation is easy.

3. *Exploitation of the Outranking Relation*

We will consider a particular exploitation of the valued outranking relation, especially for the case in which the actions have to be ranked from best to weakest. The PROMETHEE I method provides a partial ranking of the actions. If needed, a complete ranking can be obtained by PROMETHEE II.

3. Extension of the Notion of Criterion

This extension is based on the introduction of a preference function giving the preference of the decision-maker for an action a with regard to b. This function will be defined separately for each criterion; its value will be between 0 and 1. The smaller the function, the greater the indifference of the decision-maker; the closer to 1 the greater his preference. In case of strict preference, the preference function will be 1.

Let us consider a multicriteria problem as defined in (1.2), each criterion having to be maximized. Let $f(\cdot)$ be a particular criterion and a and b two particular actions of K. The associated *preference function* $P(a,b)$ of a with regard to b will be defined as:

$$P(a,b)=\begin{cases}0 & \text{if} \quad f(a)\leqslant f(b),\\ p[f(a),f(b)] & \text{if} \quad f(a)>f(b).\end{cases} \tag{3.1}$$

For concrete cases, it seems reasonable to choose for $p(\cdot)$ functions of the following type:

$$p[f(a),f(b)]=p[f(a)-f(b)] \tag{3.2}$$

depending on the difference between the values $f(a)$ and $f(b)$. Our feeling is that the six following types of functions cover most of the cases occurring in practical applications. For each criterion, only a few parameters (maximum 2) have to be identified by the decision-maker. This seems an easy task in view of the fact that each parameter has a real economic meaning.

In order to indicate clearly the areas of indifference in the neighbourhood of $f(b)$, we write:

$$x = f(a) - f(b), \tag{3.3}$$

and we represent graphically the function $H(x)$ so that:

$$H(x) = \begin{cases} P(a,b), & x \geqslant 0, \\ P(b,a), & x \leqslant 0. \end{cases} \tag{3.4}$$

Type I: *Usual Criterion*

In this case:

$$p(x) = \begin{cases} 0 & \forall x \leqslant 0, \\ 1 & \forall x > 0; \end{cases} \tag{3.5}$$

there is indifference between a and b only when $f(a) = f(b)$. As soon as these values are different the decision-maker has a strict preference for the action having the greatest value. His preference function equals then 1 and $H(x)$ is given by Figure 1. If the decision-maker identifies the criterion $f(\cdot)$ as being of Type I, no particular parameter has to be defined. This type does not include an extension; it just gives the opportunity to the decision-maker to use the criterion in its usual sense when required.

Type II: *Quasi-Criterion*

Let $p(x)$ be:

$$p(x) = \begin{cases} 0, & x \leqslant l, \\ 1, & x > l. \end{cases} \tag{3.6}$$

In this case, and for the particular criterion $f(\cdot)$, a and b are indifferent as long as the difference between $f(a)$ and $f(b)$ does not exceed l; if not the preference becomes strict. This type of extended criterion emphasizes the notion of semiorder considered by D. Luce. $H(x)$ is given by Figure 2.

When the decision-maker identifies the criterion $f(\cdot)$ as being of Type II, only the parameter l has to be defined.

Type III: *Criterion with Linear Preference*

Let $p(x)$ be:

$$p(x) = \begin{cases} x/m, & x \leqslant m, \\ 1, & x \geqslant m. \end{cases} \tag{3.7}$$

Such an extension of the notion of criterion allows the decision-maker to prefer progressively a to b for progressively larger deviations between $f(a)$ and $f(b)$. The intensity of preference increases linearly until this deviation equals m, after this value the preference is strict. In this case $H(x)$ is given by Figure 3.

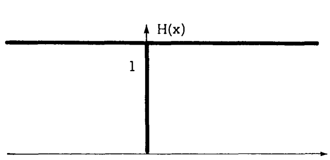

FIGURE 1. Criterion of Type I.

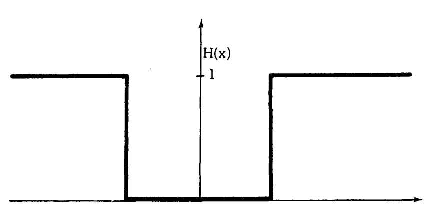

FIGURE 2. Criterion of Type II.

If the decision-maker considers that a particular criterion is of Type III, he has only to define the value m from which strict preference is considered.

Type IV: *Level-Criterion*

Let $p(x)$ be:

$$p(x)=\begin{cases}0, & x \leqslant q,\\ 1/2, & q < x \leqslant q+p,\\ 1, & x > q+p.\end{cases} \tag{3.8}$$

In this case, a and b are considered as indifferent when the deviation between $f(a)$ and $f(b)$ does not exceed q, between q and $q+p$ the preference is weak (1/2), after this value the preference becomes strict. This extension may be compared with the pseudo-criterion introduced by B. Roy, although we consider here the weak preference as an intensity and not as a hesitation between indifference and strict preference. $H(x)$ has the form depicted in Figure 4. The decision-maker can easily fix q and p when it is his feeling that the particular criterion $f(\cdot)$ is of Type IV. Criteria with more than two levels can also be considered for instance when several given norms seem relevant.

Type V: *Criterion with Linear Preference and Indifference Area*

This time we consider for $p(x)$:

$$p(x)=\begin{cases}0, & x \leqslant s,\\ (x-s)/r, & s \leqslant x \leqslant s+r,\\ 1, & x \geqslant s+r.\end{cases} \tag{3.9}$$

In this case the decision-maker considers that a and b are completely indifferent as long as the deviation between $f(a)$ and $f(b)$ does not exceed s. Above this value the preference grows progressively until this deviation equals $s+r$. $H(x)$ is then given by Figure 5. Two parameters have to be defined when a particular criterion has been identified as being of this type.

Type VI: *Gaussian Criteria*

Let $p(x)$ be:

$$p(x)\begin{cases}0, & x \leqslant 0,\\ 1-e^{-x^2/2\sigma^2}, & x \geqslant 0.\end{cases} \tag{3.10}$$

If a particular criterion is of the Gaussian type, the preference of the decision-maker still grows with the deviation x. The value of σ may be easily fixed according to the experience obtained with the Normal Distribution in Statistics. The value of σ is the distance between the origin and the point of inflexion of the curve. $H(x)$ then is given by Figure 6.

In this particular case only the value of σ has to be defined by the decision-maker.

In this paper we consider the thresholds l, m, p, q, r, s and σ as being constant. In

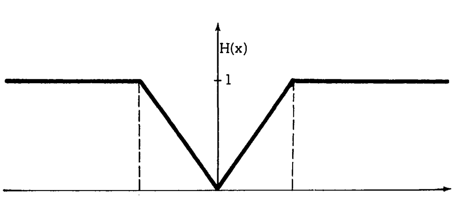

FIGURE 3. Criterion of Type III.

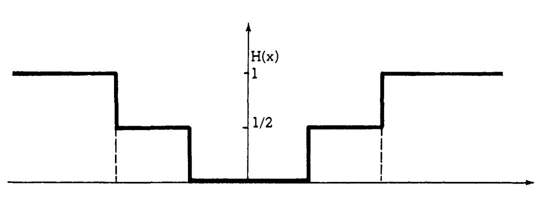

FIGURE 4. Criterion of Type IV.

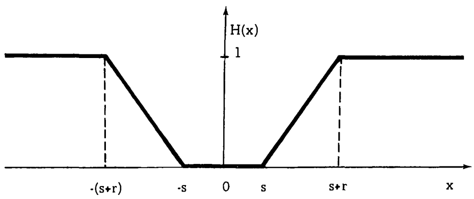

FIGURE 5. Criterion of Type V.

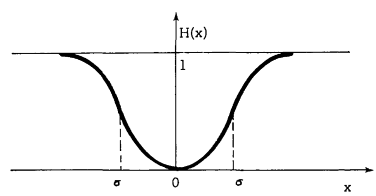

FIGURE 6. Criterion of Type VI.

this case the functions $H(x)$ are symmetrical with respect to 0, but there would be no difficulty in considering variable thresholds.

When a particular multicriteria problem of type (1.2) has to be treated the decision-maker has to decide which of the different criteria types he should use and the value of the possible corresponding thresholds. We believe that the nature of the criteria and the value of the thresholds can be fixed according to the economic meaning attached to them in each particular case.

We also think that the six types considered are sufficient to treat most of the cases encountered in practice. Of course, more sophisticated preference functions could also be considered. It is also clear that some of the criteria presented here are particular cases of others. For example, a criterion of Type V with $r = 0$ is a quasi-criterion.

4. Valued Outranking Graph

a. *Preference Index*

For each couple of actions $a, b \in K$, we first define a preference index for a with regard to b over all the criteria. Suppose every criterion has been identified as being of one of the six types considered so that the preference functions $P_h(a,b)$ have been defined for each $h = 1, 2, \ldots, k$. Let

$$\pi(a,b) = \frac{1}{k} \sum_{h=1}^{k} P_h(a,b) \tag{4.1}$$

be such a preference index. It is clear that this index gives a measure of the preference of a over b for all the criteria: the closer to 1, the greater the preference. Of course, other indices could possibly be considered. For example, we suppose here that all the criteria have the same importance. If it is not the case, one can introduce a weighted preference index.

b. *Valued Outranking Graph*

The graph, the nodes of which are the actions of K, so that for all $a, b \in K$ the arc (ab) has the value $\pi(a,b)$, will be called *valued outranking graph.*

The original dominance graph has thus been considerably enriched, but this enrichment is not as excessive as with utility functions, corresponding simply to the fact that the arcs are valued. On the other hand, if a dominates b, $\pi(b,a) = 0$, but $\pi(a,b)$ is not necessarily equal to 1 because a can be better than b for each criterion without the preference being strict.

5. Exploitation of the Outranking Graph

The valued outranking graph, when obtained, offers the decision-maker much valuable information. But this graph has still to be used in order to solve the particular decision problem. Different problems can be considered.

It is a *ranking problem* if the decision-maker wants to rank the actions of K from the best to the weakest one. In this case the problem consists in using the valued outranking graph to build a total preorder on K, or possibly a partial preorder if a total one seems excessive.

It is a *choice problem* if the decision-maker has to select the best actions in K. As there is in general no best solution in a multicriteria problem, the problem will be to determine in K a set of good actions.

Many methods may be considered to face these problematics. In this paper we suggest two techniques for solving the ranking problem. A set of good actions can of course be obtained from the ranking to solve a choice problem.

a. *PROMETHEE* I: *Ranking the Actions by a Partial Preorder*

Let us therefore consider the valued outranking graph and let us define, for each node a, the outgoing flow

$$\phi^{+}(a) = \sum_{x \in K} \pi(a,x), \tag{5.1}$$

and the incoming flow

$$\phi^{-}(a) = \sum_{x \in K} \pi(x,a). \tag{5.2}$$

The larger $\phi^{+}(a)$, the more a dominates the other actions of K. The smaller $\phi^{-}(a)$, the less a is dominated. Let us first define the two total preorders (P^{+}, I^{+}) and (P^{-}, I^{-}) such that:

$$\begin{array}{lll} a\,P^{+}\,b & \text{iff} & \phi^{+}(a) > \phi^{+}(b), \\ a\,P^{-}\,b & \text{iff} & \phi^{-}(a) < \phi^{-}(b); \end{array} \tag{5.3}$$

$$\begin{array}{lll} a\,I^{+}\,b & \text{iff} & \phi^{+}(a) = \phi^{+}(b), \\ a\,I^{-}\,b & \text{iff} & \phi^{-}(a) = \phi^{-}(b). \end{array} \tag{5.4}$$

We then obtain the following partial preorder $(P^{(1)}, I^{(1)}, R)$ by considering their intersection:

$$\begin{cases} a \text{ outranks } b \ (a\,P^{(1)}\,b): & \text{if } \begin{cases} a\,P^{+}\,b \text{ and } a\,P^{-}\,b, \\ a\,P^{+}\,b \text{ and } a\,I^{-}\,b, \\ a\,I^{+}\,b \text{ and } a\,P^{-}\,b, \end{cases} \\ a \text{ is indifferent to } b \ (a\,I^{(1)}\,b); & \text{if } a\,I^{+}\,b \text{ and } a\,I^{-}\,b, \\ a \text{ and } b \text{ are incomparable } (a\,R\,b) & \text{otherwise.} \end{cases} \tag{5.5}$$

This is the PROMETHEE I partial relation. It offers the decision-maker a graph in which some actions are comparable, while some others are not. This information can be used fruitfully in concrete applications for making decisions. See for instance the example below.

b. *PROMETHEE* II: *Ranking the Actions by a Total Preorder*

Suppose a total preorder (complete ranking without incomparabilities) has been requested by the decision-maker. We then can consider for each action $a \in K$ the net-flow

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a), \tag{5.6}$$

which can easily be used for ranking the actions:

$$\begin{array}{lll} a \text{ outranks } b \ (a\,P^{(2)}\,b) & \text{iff} & \phi(a) > \phi(b), \\ a \text{ is indifferent to } b \ (a\,I^{(2)}\,b) & \text{iff} & \phi(a) = \phi(b). \end{array} \tag{5.7}$$

This is the PROMETHEE II complete relation. All the actions of K are now completely ranked but this relation is also poorer in information and less realistic because of the balancing effects between outgoing and incoming flows.

6. Numerical Application

Let us consider a multicriteria problem (1.2) for which 6 criteria are taken into account and K consisting in 6 possible actions. The criteria f_1, f_3, f_4 and f_5 have to be minimized, f_2 and f_6 maximized.

The actions $a_1 a_2 a_3 a_4 a_5 a_6$ are for instance possible installations; for each of them we have: $f_1(\cdot)$ being the number of workers requested, $f_2(\cdot)$ the daily production expressed in number of pieces, $f_3(\cdot)$ the purchase price expressed in million \$, $f_4(\cdot)$ the maintenance costs also expressed in million \$, $f_5(\cdot)$ the number of surface units needed for the installation of the equipment and $f_6(\cdot)$ a measure of the quality of the pieces produced. The data of the problem are given in Table I.

In the left-hand part of Table I the original data are given. In the right-hand part the decision-maker has pointed out the type of each criterion and the values of the corresponding parameters. This part can possibly be determined interactively between the decision-maker and the analyst. We then have successively:

$$p_1(x) = \begin{cases} 0, & x \leqslant 10, \\ 1, & x > 10; \end{cases} \tag{6.1}$$

$$p_2(x) = \begin{cases} \dfrac{1}{30}x, & x \leqslant 30, \\ 1, & x \geqslant 30; \end{cases} \tag{6.2}$$

$$p_3(x) = \begin{cases} 0, & x \leqslant 5, \\ (x-5)/45, & 5 \leqslant x \leqslant 50, \\ 1, & x \geqslant 50, \end{cases} \tag{6.3}$$

$$p_4(x) = \begin{cases} 0, & x \leqslant 1, \\ 1/2, & 1 < x \leqslant 6, \\ 1, & x > 6; \end{cases} \tag{6.4}$$

$$p_5(x) = \begin{cases} 0, & x = 0, \\ 1, & x > 0; \end{cases} \tag{6.5}$$

$$p_6(x) = 1 - e^{-x^2/50}, \qquad x \geqslant 0. \tag{6.6}$$

Using (3.1), (3.3) and (4.1) in the right way according to whether the criterion has to be minimized or maximized we obtain for $\pi(a_i, a_j)$, $i, j = 1, 2, \ldots, 6$, the values found in Table II.

TABLE I

Criteria	Min Max	a_1	a_2	a_3	a_4	a_5	a_6	Type of Criteria	Parameters
$f_1(\cdot)$	min	80	65	83	40	52	94	II	$l = 10$
$f_2(\cdot)$	max	90	58	60	80	72	96	III	$m = 30$
$f_3(\cdot)$	min	60	20	40	100	60	70	V	$s = 5; r = 45$
$f_4(\cdot)$	min	5.4	9.7	7.2	7.5	2	3.6	IV	$q = 1; p = 5$
$f_5(\cdot)$	min	8	1	4	7	3	5	I	—
$f_6(\cdot)$	max	5	1	7	10	8	6	VI	$\sigma = 5$

TABLE II

Values of $\pi(a_i, a_j)$

	a_1	a_2	a_3	a_4	a_5	a_6
a_1	—	0.296	0.250	0.268	0.100	0.185
a_2	0.462	—	0.389	0.333	0.296	0.500
a_3	0.236	0.180	—	0.333	0.056	0.429
a_4	0.399	0.505	0.305	—	0.223	0.212
a_5	0.444	0.515	0.487	0.380	—	0.448
a_6	0.286	0.399	0.250	0.432	0.133	—

TABLE III

Data For Preorders P^+ *and* P^-

	a_1	a_2	a_3	a_4	a_5	a_6
$\phi^+(a)$	1.099	1.980	1.234	1.644	2.274	1.500
$\phi^-(a)$	1.827	1.895	1.681	1.786	0.808	1.744

These values determine the outranking graph, each arc (a_i, a_j) having the value $\pi(a_i, a_j)$.

Let us first suppose that a partial relation would be useful to the decision-maker. We therefore apply the PROMETHEE I technique. According to (5.1) and (5.2) we complete Table III.

It is then easy to obtain the preorders P^+ and P^- the intersection of which is:

$$a_5P^{(1)}a_1, a_5P^{(1)}a_2, a_5P^{(1)}a_3, a_5P^{(1)}a_4, a_5P^{(1)}a_6, a_3P^{(1)}a_1, a_4P^{(1)}a_1,$$

$$a_4P^{(1)}a_6 \quad \text{and} \quad a_6P^{(1)}a_1;$$

so that the partial PROMETHEE I preorder can be illustrated by Figure 7.

The relation obtained is of course transitive. Some actions are comparable, others are not. For instance, a_2 and a_1 are not comparable. Looking at the original data we indeed see that equipment a_1 is one of the most productive (90 pieces a day) and a rather expensive one (60 million \$) while a_2 is the smallest (only 58 pieces a day) and also the cheapest one (20 million \$). It is clear that such installations are totally different in size and therefore cannot easily be compared by the decision-maker. It is one of the advantages of the method to bring out such incomparabilities.

Supposing now that the decision-maker requests a total preorder, we then can use PROMETHEE II. According to (5.6) we calculate the net flows:

$$\begin{aligned} \phi(a_1) &= -0.728, & \phi(a_4) &= -0.102, \\ \phi(a_2) &= +0.085, & \phi(a_5) &= +1.466, \\ \phi(a_3) &= -0.447, & \phi(a_6) &= -0.274; \end{aligned} \tag{6.7}$$

so that the total preorder is shown in Figure 8.

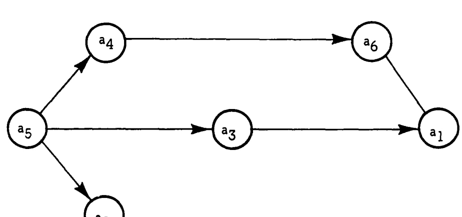

FIGURE 7. Partial PROMETHEE I Relation.

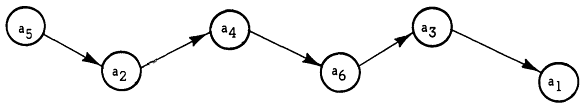

FIGURE 8. Total PROMETHEE II Relation.

It is of course interesting to compare the results obtained with PROMETHEE I and II. PROMTHEE II provides a complete ranking which is "agreeable" to the decision-maker, but some useful information about incomparabilities gets lost.

In case of a problematic choice, the actions a_5 and a_2, having both a positive net flow, may be considered as a set of good actions.

7. Practical Applications

The PROMETHEE methods were used successfully by J. M. Dujardin (1984) and G. D'Avignon (1983).

J. M. Dujardin has used the ELECTRE and the PROMETHEE methods in order to compare different teaching projects, the purpose of which is to avoid failures in high schools.

G. D'Avignon et al. extensively used the PROMETHEE methods to analyze the efficiency of different services in some Canadian hospitals. The purpose of this study was to provide more support only to the most efficient services of each hospital. Through this application, it was clearly shown that the PROMETHEE methods were very easily accepted and understood by the practitioners. These methods seem to be the easiest approach for solving a multicriteria problem by considering simultaneously extended criteria and outranking relations.

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