Outranking Methods As Tools in Strategic Natural Resources Planning

Annika Kangas, Jyrki Kangas and Jouni Pykäläinen

Kangas, A., Kangas, J. & Pykäläinen, J. 2001. Outranking methods as tools in strategic natural resources planning. Silva Fennica 35(2): 215–227.

Two outranking methods, ELECTRE III and PROMETHEE II, commonly used as decision-aid in various environmental problems, and their applications to decision support for natural resources management are presented. These methods represent 'the European school' of multi-criteria decision making (MCDM), as opposed to 'the American school', represented by, for instance, the AHP method. On the basis of a case study, outranking methods are compared to so far more usually applied techniques based on the ideas of multi attribute utility theory (MAUT). The outranking methods have been recommended for situations, where there is a finite number of discrete alternatives to be chosen among. The number of decision criteria and decision makers may be large. An important advantage of outranking methods, when compared to decision support techniques most often applied in today's natural resources management, is the ability to deal with ordinal and more or less descriptive information on the alternative plans to be evaluated. Furthermore, the uncertainty concerning the values of the criterion variables can be taken into account using fuzzy relations, determined by indifference and preference thresholds. The difficult interpretation of the results, on the other hand, is the main drawback of the outranking methods.

Keywords fuzzy relations, multicriteria decision support, multiple-use planning, uncertainty
Authors' addresses *Kangas* and *Kangas*, Finnish Forest Research Institute, Kannus Research Station, P.O. Box 44, FIN-69101 Kannus, Finland; *Pykäläinen*, University of Joensuu, Faculty of Forestry, P.O. Box 111, FIN-80101 Joensuu, Finland
E-mail annika.kangas@metla.fi
Received 24 January 2000 **Accepted** 23 January 2001

1 Introduction

Nowadays, natural resources are more and more often managed for multiple uses. Decision-makers have not only economic objectives but also those of amenity and non-market values of recreation and nature conservation, for instance. Generally, both economic, ecological and socio-cultural sustainability are required. Multi-functionality calls for multi-objective natural resources management planning and decision support. In addition, there is more and more often a need to take into account aims of multiple decision makers or participants in natural resources decision-making. This, in turn, calls for group decision support and participatory planning.

Research on natural resources planning has answered these challenges by applying and developing decision support methods and techniques for multiple criteria and participatory planning. Attempts have been made to solve planning problems on one hand by quantitatively and on the other hand by qualitatively oriented approaches. Both of them have their benefits and disadvantages (e.g. Kangas et al. 2000). In practical planning processes, all the information available should be able to be dealt with – no matter were the information descriptive or numerical. Consequently, participatory and multiple use natural resources planning call for analytical decision support methods by which the various kinds of information can be dealt with in a versatile way.

Recently, methods based on the very ideas of multi-attribute utility theory (MAUT) have been developed for purposes of natural resources planning. Many applications and extensions of the Analytic Hierarchy Process (AHP), developed by T.L. Saaty (1980), are examples of such efforts (see, e.g., Kangas 1999). From the viewpoints of multiple use and participatory planning, the AHP has several advantages. Both objective value information, expert knowledge and subjective preferences can be utilised by using it. Also, qualitative criteria can be applied in the evaluation of alternative plans when the AHP is applied. The AHP is based on a theory of ratio scale estimation (Saaty 1977), and by using it pairwise comparisons of qualitatively expressed measures can be transferred into a ratio scale. Other MAUT and MAUT-related methods usually require values of the criteria to be measured straightly in ratio scale and quantitatively.

Crucial problems with most MAUT and MAUT-related methods include handling of uncertain or fuzzy information, and coping with information expressed in other than ratio or interval scale. In natural resources management, descriptive expressions instead of quantitative measures, and qualitative or ordinal information are frequently faced. Furthermore, in natural resources management, a great share of information gathered or produced during any planning process is typically uncertain. The AHP method, for instance, has been further developed in order to meet the needs of analysing uncertainties (e.g. Alho and Kangas 1997). The same holds with approaches based on mathematical programming (e.g. Mendoza and Sprouse 1989). These lines of development work are still continuing, and many advances are still required for elaborating the methods.

Outranking methods serve as one alternative for approaching complex choice problems with multiple criteria and multiple participants. Outranking indicates the degree of dominance of one alternative over another (e.g. Rogers and Bruen 1998b). The outranking methods enable the utilisation of incomplete value information and, for example, judgments on ordinal measurement scale (e.g. Rogers and Bruen 1998b). They provide the (partial) preference ranking of the alternatives, not a cardinal measure of the preference relations. The outranking methods have been used, for example, for choosing the solid waste management system (Hokkanen and Salminen 1997a,c), for locating the waste treatment facility (Hokkanen and Salminen 1997b), for nuclear waste management (Briggs et al. 1990), for irrigation system evaluation (Raju and Pillai 1999) and other Environmental Impact Analysis (EIA) projects.

In outranking methods, strong assumptions concerning the 'true' preference structure of the decision maker are avoided. It is not necessary to assume that a utility function exists, or that it can be described with a certain functional form. The question is, whether there is enough information to state that one alternative is at least as good as another. In voting theory, the alternative *a* is deemed better than alternative *b* if the number of votes (or criteria) indicating that alternative *a* is better than alternative *b* is larger than the number of votes indicating the opposite. The voting theory can be seen as an ancestor of the outranking methods (Vincke 1992).

Because the very nature of outranking methods is different to that of mathematical programming and of most MAUT methods, it could be useful to examine them in natural resources management. This article is a report of such an examination, concerning especially the methods PROMETHEE II (Brans et al. 1986) and

ELECTRE III (Roy 1991). These two outranking methods were applied in a case study based on a real-life strategic planning process of State owned natural resources in Finland. In the initial planning process, an interactive decision analysis method making use of MAUT was adopted by the Finnish Forest and Park Service, which governs the case study area. The planning case is reanalyzed in this study using the outranking methods. The original application is also briefly presented below for the sake of comparison and as background information on the case examined.

2 The Outranking Methods

2.1 The Pseudo-Criteria

In PROMETHEE II and ELECTRE III outranking methods, the criteria are treated as so-called pseudo-criteria (Brans et al. 1986, see e.g. Hokkanen and Salminen 1997). This means that a threshold model is applied to the original criteria value. If the criteria values are sufficiently close to each other, they are indifferent to the decision maker, and if the difference between the criteria values is sufficiently large, there is no doubt which alternative is better according to that criterion. In between there is an area, in which the decision maker is assumed to hesitate between indifference and strict preference.

The ELECTRE methods have originally been developed by Bernard Roy (1968). Several versions of the ELECTRE method have been presented for different situations: ELECTRE I and IS are designed for selection problems, ELECTRE TRI for sorting problems and ELECTRE II, III and IV for ranking problems (see Roy 1991, Yu 1992). ELECTRE II is an older version, where an abrupt change from indifference to strict preference is assumed instead of pseudo-criteria. The main difference between III and IV is that the relative importance indices for the different criteria are not applied in the latter. The ELECTRE III method that is utilised in this study, can be considered as a non-compensatory model (Rogers and Bruen 1998a). It means that a really bad score of any alternative with respect to any one criterion cannot necessarily be compensated for by good scores in other criteria. The PROMETHEE methods were developed in the 1980's (see Brans et al. 1986).

In each case, the problem is formulated with a set of distinct alternatives a_i, $i=1,...,n$ and a set of decision criteria g_j, $j=1,...,p$ so that $g_j(a_i)$ represents the performance of alternative i with respect to criterion j. These criteria may be ordinal or even descriptive, on the contrary to most decision-aid methods. The values of these criteria may also contain uncertainty, which can be described either by probability distributions (random variation) or fuzzy zones (uncertainty due to ignorance etc.) (Miettinen and Salminen 1999).

The uncertainty is dealt using pseudo-criteria (e.g. Vincke 1992). This means that two thresholds, namely indifference and preference thresholds, are defined. The indifference threshold for criterion j, q_j, is a difference beneath which the decision maker is indifferent between two management alternatives a_k and a_l, i.e.

$$a_k \mathbf{I} a_l \Leftrightarrow \left| g_j(a_k) - g_j(a_l) \right| \leq q_j \tag{1}$$

The preference threshold for criterion j, p_j, is a difference above which the decision maker strongly prefers management alternative a_k over a_l, i.e.

$$a_k \mathbf{P} a_l \Leftrightarrow g_j(a_k) - g_j(a_l) > p_j \tag{2}$$

Between these two thresholds there is a zone where the decision maker hesitates between indifference and strong preference, i.e. the zone of weak preference.

$$a_k \mathbf{Q} a_l \Leftrightarrow q_j < g_j(a_k) - g_j(a_l) \leq p_j \tag{3}$$

However, the zone of weak preference does not make sense if the criteria are ordinal or descriptive. In such a case, the preference and indifference thresholds could be set to zero. This means that if one alternative is considered better in ordinal scale, this alternative is strictly preferred, as in ELECTRE II. If some of the criteria are ordinal, this should also be taken into account when the outranking results are calculated: some of the procedures that can be used are based on ordinal, some on cardinal properties of the criteria.

The indifference threshold can be defined either with respect to the uncertainty of the criteria values or as a threshold at which the differences become perceptible to decision makers (Rogers and Bruen 1998b). Maystre et al. (1994) defined the indifference threshold as the minimum margin of uncertainty and the preference threshold as the maximum margin of uncertainty with respect to different criteria. Thus, the preference threshold implies that there is no doubt that a certain alternative is better than the other. However, there are no right values for the thresholds, or even a right way to define them.

2.2 The PROMETHEE Method

In PROMETHEE I and II, the outranking degree $\Pi(a_k,a_l)$, describing the credibility of the outranking relation that 'alternative a_k is better than alternative a_l', for each pair of alternatives (a_k,a_l) is calculated as

$$\Pi(a_k,a_l) = \sum_{j=1}^{p} w_j F_j(a_k,a_l) \tag{4}$$

where $F_j(a_k,a_l)$ is the preference function and w_j are the relative importance of the different criteria (scaled to add up to one in the formula). The weights can be obtained, for example, by giving scores from 1 to 7 to the criteria, with 1 given to the least important criterion (Hokkanen and Salminen 1994). However, the weights could also be obtained from pairwise comparisons as in the AHP method.

In PROMETHEE outranking method, the threshold values are assumed to be constant (see Salminen et al. 1998). The value of preference function $F_j(a_k,a_l)$ for a pair of alternatives a_k and a_l with respect to criteria j are calculated using thresholds p_j and q_j as

$$F_j(a_k,a_l) = \begin{cases} 1, \text{ if } g_j(a_k) - g_j(a_l) \geq p_j \\ 0, \text{ if } g_j(a_k) - g_j(a_l) \leq q_j \\ \dfrac{g_j(a_k) - g_j(a_l) - q_j}{p_j - q_j}, \text{ otherwise} \end{cases} \tag{5}$$

In this formula, the linear threshold function is utilised (Fig. 1a). However, six different forms of the threshold function can be applied, which can be either linear, nonlinear, or a step function (see Brans et al. 1986). The criteria and threshold values together constitute the pseudo-criteria.

The outranking degrees Π are used to calculate for each alternative the leaving flow,

$$\Phi^+(a_k) = \sum_{l \neq k} \Pi(a_k,a_l) / (n-1) \tag{6}$$

the entering flow

$$\Phi^-(a_k) = \sum_{l \neq k} \Pi(a_l,a_k) / (n-1) \tag{7}$$

and the net flow

$$\Phi(a_k) = \Phi^+(a_k) - \Phi^-(a_k) \tag{8}$$

In PROMETHEE I the alternatives are ranked based on both the leaving and entering flows.

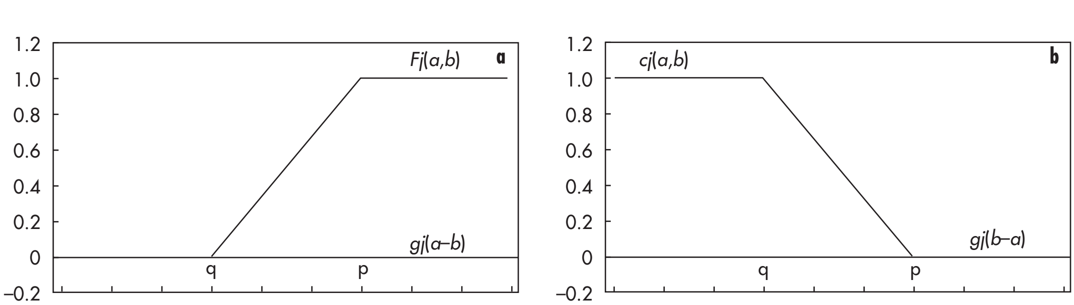

Fig. 1. The preference function F_j (a) and the local concordance index c_j (b). Note the different x-axis.

These rankings are then used to calculate a partial preorder, where certain alternatives may remain incomparable. In PROMETHEE II the net flow is used, which leads to complete ranking (Hokkanen and Salminen 1997a,b). This ranking method utilises the 'cardinal' properties of the valuations, PROMETHEE I the 'ordinal' properties (Bouyssou and Perny 1992, Bouyssou 1992).

2.3 The ELECTRE Method

In ELECTRE III method, a concordance index $C(a_k,a_l)$ for each pair of alternatives is computed, describing the strength of a claim that alternative a_k is at least as good as alternative a_l, utilising pseudo-criteria in a similar fashion as in PROMETHEE method. The concordance index is calculated as

$$C(a_k,a_l) = \sum_{j=1}^{p} w_j c_j(a_k,a_l) \tag{9}$$

where w_j are the relative importance of the different criteria (scaled to add up to one in the formula) and $c_j(a_k,a_l)$ is the local concordance index, defined as (Fig. 1b)

$$c_j(a_k,a_l) = \begin{cases} 0, \text{ if } g_j(a_l) - g_j(a_k) \geq p_\mathrm{j} \\ 1, \text{ if } g_j(a_l) - g_j(a_k) \leq q_\mathrm{j} \\ \dfrac{p_j - (g_j(a_l) - g_j(a_k))}{p_j - q_j}, \text{ otherwise} \end{cases} \tag{10}$$

In formula (10), constant threshold values are applied. However, in ELECTRE III, the thresholds may be either constant, proportional to the criterion value or they could be expressed with a linear model as a function of the criterion value (e.g. Rogers and Bruen 1998b).

If the decision were based on the concordance indices of alternatives, weighted with the importance of different criteria, the approach would basically be based on an additive utility function similarly as in PROMETHEE method (see Salminen et al. 1998). Then, the weights of different criteria would represent the substitution rates between the different criteria.

However, in ELECTRE III there is also a so-called veto threshold v_j, which is used to compute the discordance index for the alternatives. The discordance index is used to model the degree of incompensation between the criteria. This means that an alternative with a very poor value of any one criterion cannot be chosen irrespective of the values of the other criteria. It also means that the weights of the criteria cannot be interpreted as substitution rates, but they represent votes for the criteria (Miettinen and Salminen 1999). The discordance index is defined for each criterion as

$$d_j(a_k,a_l) = \begin{cases} 0, \text{ if } g_j(a_l) - g_j(a_k) \leq p_\mathrm{j} \\ 1, \text{ if } g_j(a_l) - g_j(a_k) \geq v_\mathrm{j} \\ \dfrac{(g_j(a_l) - g_j(a_k)) - p_j}{v_j - p_j}, \text{ otherwise} \end{cases} \tag{11}$$

The discordance indices of different criteria are not aggregated using the weights, since one discordant criterion is sufficient to discard outranking. In environmental planning the veto threshold is appropriate in a sense that some alternatives are not found acceptable at all (Rogers and Bruen 1998b). The closer the veto threshold v_j is to the preference threshold p_j, the more important the criterion j can be considered (Roy 1991).

Finally, the degree of outranking is defined by $S(a_k,a_l)$ as

$$S(a_k,a_l) = \begin{cases} C(a_k,a_l), \text{ if } J(a_k,a_l) = \varnothing \\ C(a_k,a_l) \displaystyle\prod_{j \in J(a_k,a_l)} \frac{1 - d_j(a_k,a_l)}{1 - C(a_k,a_l)}, \text{ otherwise} \end{cases} \tag{12}$$

where $J(a_k,a_l)$ is a set of criteria for which $d_j(a_k,a_l) > C(a_k,a_l)$ (Miettinen and Salminen 1999).

In basic ELECTRE III method, a descending (Z_1) and ascending (Z_2) preorder is constructed using the outranking degrees S. The final partial order $Z = Z_1 \cap Z_2$ is constructed based on these two complete orders. The preorders Z_1 and Z_2 are constructed using a descending and ascending distillation. In distillation procedure, the ranking is based on the number of alternatives outranked by each alternative minus the number of alternatives which outrank it (for details, see Maystre et al. 1994).

In the obtained partial preorder some alternatives may be incomparable, i.e. their performance order cannot be determined. A complete ranking may be obtained using, for example, the 'min' procedure (see Pirlot 1995). In the 'min' procedure, the alternatives are ranked according to the minimum outranking degree of each alternative. The alternative having the highest minimum is ranked first, and so on (see Miettinen and Salminen 1999). The 'min' procedure utilises the ordinal properties of the valuations (Pirlot 1995). In this study, the 'min' procedure is used for ranking the alternatives.

The PROMETHEE II method includes an indifference threshold and a preference threshold, but not a veto threshold as ELECTRE III. Also the method by which the alternatives are ranked differs, and thus, these methods may not always produce similar results. However, given similar thresholds, and veto threshold high enough in ELECTRE III, the outranking degrees produced with these methods are identical (Salminen et al. 1998).

The outranking methods are typically used for group decision making situations. In group decision making, the analyst typically chooses the values for the thresholds, and the decision makers only choose the weight of the criteria. Usually, each decision maker gives his/her own weights, and in the analysis the median or mean values for the weights are used (Roy 1991). However, it is also important to study the effect of the extreme values to the weights in a sensitivity analysis.

3 Outranking and MAUT in Forest Management Planning – a Case Study

3.1 An Application of HIPRE Program

Pykäläinen et al. (1999) used ideas of multi attribute utility theory – more closely the HIPRE program developed by Hämäläinen and Lauri (1995) – in their application of interactive decision analysis (IDA) on strategic planning of State-owned natural resources. HIPRE allows the use of a modified MAUT-version of the AHP, which utilises sub-utility functions in the evaluation of choice alternatives, as is shown below. HIPRE program was chosen to be used by the Finnish Forest and Park Service (FPS) governing the case study area. Other MAUT-based methods could also be applied to similar natural resources management problems. In Finland, applications of the standard AHP (Kangas 1994) and HERO heuristic optimization (Kangas et al. 1996) in participatory forestry decision support have been presented.

The IDA application was part of a wider participatory planning project initiated by the FPS in Kainuu, eastern Finland. The function of the IDA was to produce comprehensive decision support for the formulation and selection of a forest strategy. The reader is referred to Pykäläinen et al. (1999) for more detailed information.

Initially, four strategies following different scenarios were formulated in the planning project of Kainuu. The feasibility of land use allocations in general and their implications on producing forest outputs was mapped out by doing this. The impacts of the strategies were measured by numeric criterion variables and they were estimated through planning calculations. So called 'Basic strategy' included the current principles of land use allocation. The 'Business strategy' emphasized economical goals of the FPS in Kainuu. The 'Forest recreation' and 'Nature conservation' strategies emphasized the related goals, respectively.

The IDA was started with a decision hierarchy formulation (Fig. 2). The hierarchy consisted of six levels: the total utility, the parties, the four main criteria for forest management, the subcriteria, the criterion variables, and the alternative forest strategies. The preferences of the parties involved (FPS, one regional and four local working groups including 10–12 interest groups each, and the public) were defined and included into planning in a form of an additive utility function:

$$U_{tot} = \sum_{j=1}^{n} w_j U_j \tag{13}$$

where, U_{tot} is the total utility, w_j is the weight of party j, U_j is the utility of party j, and n is the

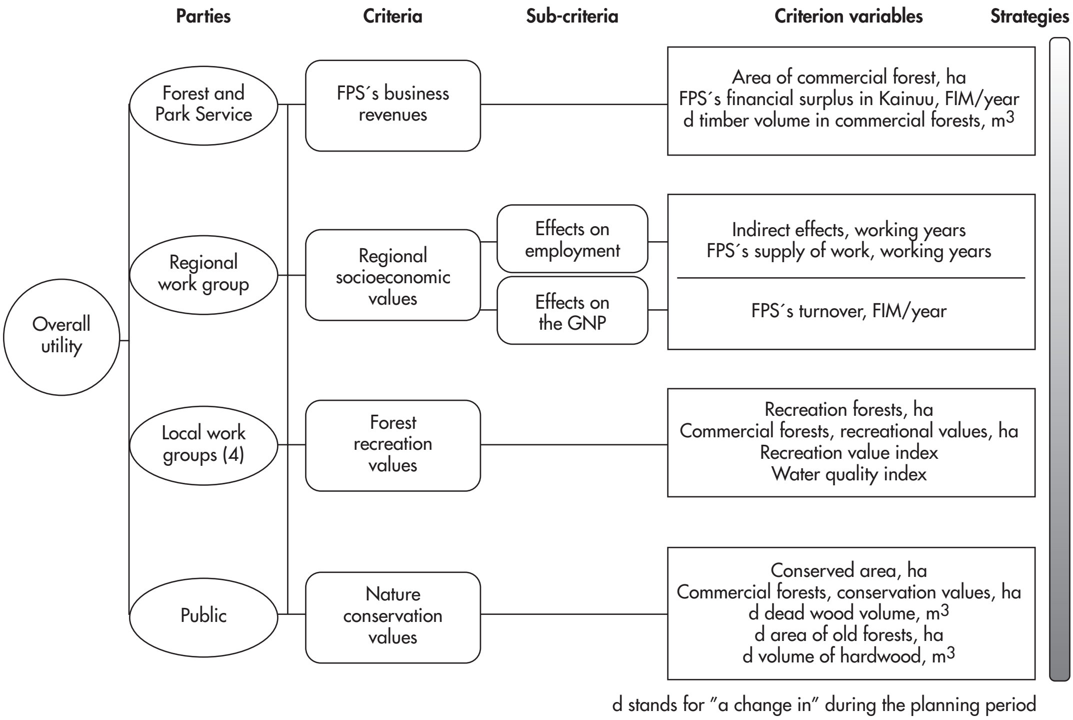

Fig. 2. Decision hierarchy applied by the FPS in Kainuu region.

number of parties involved.

The utility of an individual party was calculated as follows:

$$U_j = \sum_{i=1}^{m_j} a_{ij} u_{ij}(q_{ij}) \quad (14)$$

where m_j is the number of criteria of party j, a_{ij} is the relative importance of criterion i, u_{ij} is the sub-utility function of criterion i, and q_{ij} is the quantity that the plan produces or consumes the criterion variable i of party j.

So called sub-utility functions (Fig. 3) defined the utilities attained through producing different criterion variables. Each sub-utility function was defined with respect to one upper level criterion or sub-criterion. By using the sub-utility functions, the values of criterion variables – measured in their own units (m^3, monetary units, working years and hectares etc.) – were converted to relative sub-utilities which were scaled on a fixed interval between 0 and 1 (100%). The production possibilities of the planning area were assumed to be fully explained and transitions from the worst to best values of different criterion variables were assumed to have equal effects on the total utility if the variables were weighted equally.

The sub-utilities were made comparable by counting them with weights a_{ij} which described the mutual importance of the criterion variables when striving for the criteria i. The differences between the worst and the best values of the variables were taken into account when defining the weights. The sub-utility functions and the weights of the criterion variables were defined by experts.

The weights of the main criteria, instead, were defined interactively by the parties. With the interactive computer interface, the participants saw immediately how the current set of weights affected the strategy selection. For example, more weight could be given to the criterion not meeting the requirements of the party, and the consequences of this change could be seen immediately. Interactive defining of the weights was continued until the participant accepted the plan.

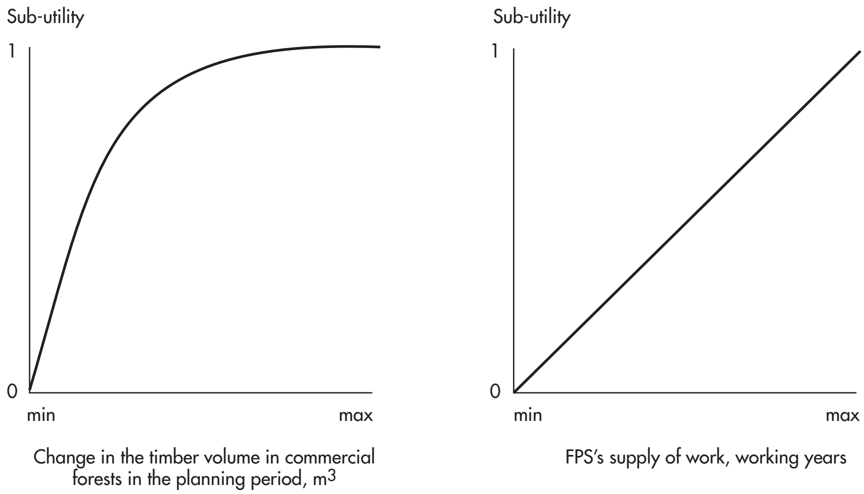

Fig. 3. Examples of sub-utility functions.

Using tactics in this process was reduced by asking the participants justify their utility functions to the other participants involved.

The weights of the parties were defined by the FPS (weights in brackets): FPS (0.5), regional work group (0.250), local work groups (0.125) and the public (0.125). By using these weights, the global weights (priorities) were calculated for the other decision elements in respect to the upper level elements related to them. The global weights of the criteria were: FPS's business revenues (0.310), regional socioeconomical values (0.239), forest recreation values (0.244) and nature conservation values (0.206).

Benefits related to FPS's business revenues were measured by using the area of commercial forests, FPS's financial surplus in Kainuu and the change in timber volume in commercial forests. The regional socioeconomical values were measured by the effect on employment (direct and indirect) and FPS's turnover. Forest recreation values were measured by the area of recreational forests, the area of commercial forests with recreational values, the recreation value index and the water quality index. The water quality index, in turn, was measured by the area of clearcut forest stands, the area of fertilised forests and the area of ditch network maintenance. The fourth main criterion was the nature conservation value, measured by the conserved area, the area of commercial forests with conservation values, the change in dead wood volume, the change in the area of old forests and the change in the volume of hardwood. The global priorities of these criteria are presented in Table 1.

Table 1. The criterion variables and their global priorities.

Criterion variable	Global priority
Area of commercial forests	0.076
FPS's financial surplus in Kainuu	0.186
Change in timber volume in commercial forests	0.048
Effect on employment (direct)	0.084
Effect on employment (indirect)	0.084
FPS's turnover	0.072
Area of recreational forests	0.100
Area of commercial forests with recreational values	0.076
Recreation value index	0.043
Area of clearcut forest stands	0.014
Area of fertilised forests	0.003
Area of ditch network maintenance	0.008
Conserved area	0.103
Area of commercial forests with conservation values	0.031
Change in dead wood volume	0.010
Change in the area of old forests	0.052
Change in the volume of hardwood	0.010

Table 2. The original HIPRE results.

Strategy	Priority
Business	0.520
Basic	0.462
Forest recreation	0.440
Mixed 2	0.417
Mixed 1	0.376
Nature conservation	0.331

Table 3. The results of PROMETHEE II calculations with two sets of indifference and preference threshold values.

Strategy	Net flow 1	Net flow 2
Business	0.124	0.126
Forest recreation	0.071	0.084
Basic	0.009	0.057
Mixed 2	–0.022	–0.018
Mixed 1	–0.066	–0.070
Nature conservation	–0.116	–0.179

1 $q_j = 0$ and $p_j = \max(g_j(a_k) - g_j(a_l))$ and
2 $q_j = 0.1\max(g_j(a_k) - g_j(a_l))$ and $p_j = 0.5\max(g_j(a_k) - g_j(a_l))$

Each strategy was considered to be a feasible one in the beginning of the planning process. However, the Finnish conservation program of old forests was constructed simultaneously with the natural resources strategy of Kainuu. In the conservation program of old forests, the area of conserved forests was to be increased from 28 000 ha to 62 000 ha. Also the landscape ecological planning in the FPS called for restrictions in wood production on certain areas (92 000 ha). As a consequence of this, all the initial strategies were not feasible any more. That is why two new strategies were constructed: 'Mixed 1' strategy and 'Mixed 2' strategy. 'Mixed 1' was the 'Basic' strategy including the new nature conservation criteria. The 'Mixed 2' strategy was a modified version of the 'Business' strategy. The priorities of the initial and the mixed strategies are presented in Table 2.

In the sensitivity analysis, the utility function was changed according to the possible changes of the parties' criteria or of the weights between the parties. A non-sensitive solution was assessed to be the best one with a higher degree of certainty compared with a very sensitive solution due to the uncertainty involved in planning. In general, the priorities of the strategies were not sensitive to individual changes in the utility function.

3.2 Results Obtained with Outranking Methods

The multi-criteria decision making (MCDM) results were calculated with the two presented outranking methods, PROMETHEE II and ELECTRE III (based on 'min' procedure). Because of the differencies in the formulation and preference estimation principles between different methods, it was not possible to formulate exactly the same choice situation with them. Thus, there was no guarantee of calculations reflecting the same preference information, and the results obtained using different methods were not directly comparable. In order to produce a problem formulation as close as possible to the original HIPRE formulation, the weights for the 17 criteria considered in the outranking process were those obtained with HIPRE analysis. Also, the used threshold values were related to the range of variation in the alternatives, to resemble the scaling in HIPRE.

Using PROMETHEE II, the indifference threshold was first set to zero and the preference threshold was set to be the difference between the best and the worst alternative for each criterion. This means that only alternatives with the same criteria values were considered indifferent, and all the comparisons were in the hesitation zone except for the comparison of the best and the worst alternative with respect to each criterion. In the second case, the indifference threshold was one tenth of the range of variation and the preference threshold was set to half of it. This means that differences less than 10% of the range of variation were considered indifferent and the differences more than 50% of the range of variation were not considered to have a greater effect on the decision than the differences which were 50% of the range of variation.

The best alternative in the analysis proved to be the business strategy. The only difference between the two rankings with different threshold values

Table 4. The results of ELECTRE III calculations using 'min' procedure in ranking with three sets of indifference, preference and veto threshold values.

Rank 1	Rank 2	Rank 3
Basic	Basic	Forest recreation
Business	Mixed 1	Nature conservation
Forest recreation	Forest recreation	Mixed 1
Mixed 2	Mixed 2	Mixed 2
Mixed 1	Nature conservation	Basic
Nature conservation	Business	Business

1 $q_j = 0$, $p_j = \max(g_j(a_k) - g_j(a_l))$ and $v_j = 10\max(g_j(a_k) - g_j(a_l))$;
2 $q_j = 0.1\max(g_j(a_k) - g_j(a_l))$, $p_j = 0.5\max(g_j(a_k) - g_j(a_l))$ and $v_j = \max(g_j(a_k) - g_j(a_l))$ and
3 $q_j = 0.1\max(g_j(a_k) - g_j(a_l))$, $p_j = 0.5\max(g_j(a_k) - g_j(a_l))$ and $v_j = 0.75 \max(g_j(a_k) - g_j(a_l))$

was that the net flows were not exactly the same (Table 3). Compared to the MAUT analysis using HIPRE, the only difference was that the forest recreation and basic strategies changed places.

In ELECTRE method, three different threshold combinations were tested. In the first, the indifference threshold was zero and the preference threshold the range of variation, i.e. the same values as in the first PROMETHEE test. The veto threshold was given a value ten times the range of variation, so that it had no effect on the analysis. In the second test, the indifference threshold was 10%, the preference threshold 50% and the veto threshold 100% of the range of variation. This means that in the comparison of the best and the worst alternative the worst was vetoed with respect to each criterion, otherwise the thresholds were similar to the second PROMETHEE test. In the last test, the veto threshold was set to the 75% of the range of variation with respect to each criterion.

In the first ranking, the order was quite similar to the initial analysis, only the basic and business strategies changed order. This may be explained by the use of 'min' procedure – the performance of business strategy was worse in the worst case, for example with respect to the criterion 'change in the timber volume in commercial forests'. When veto threshold was applied, the rank of the business strategy falled to the last place, and the compromise strategies, e.g. the mixed 1 strategy, rose. When the veto threshold was further lowered, both the basic and the business strategies performed lousy and the nature conservation strategy rose (Table 4).

Using the veto threshold only to the economical criteria, excluding the change in the timber volume, retained the rank obtained also with high veto thresholds. Using the range of variation as the veto threshold for nature conservation criteria raised the mixed and nature conservation as best strategies. The similar veto threshold for recreation criteria raised the basic and forest recreation strategies the best. Consequently, the veto threshold is very powerful tool, by which the importance of the considered criteria can be greatly emphasized.

4 Discussion

All the methods gave somewhat different results with respect to the rank of the alternatives (see also Zanakis et al. 1998). Especially the results concerning the ELECTRE III method differed from the others. The differences were partly due to the 'min' procedure used, which favours compromise alternatives, partly they were due to the use of veto thresholds. However, the calculations of this study should be taken more as illustrative examples of the use of the methods, and, as mentioned above, the results are not directly comparable as such. The inconsistencies in the results of different methods are due to differencies both in the preference estimation process and in the calculation techniques. Not only the fact that the choice problem formulations did not reflect the same preference structures caused the differencies in the results, but also the differencies in the manners how preference information is processed in different methods. Also, the interpretation of the criteria weights is different in the methods.

In any MCDM situation there is uncertainty concerning not only the values of the criterion variables but also concerning, for example, the weights of the criteria. A sensitivity analysis with respect to the uncertain parameters used in the calculations is thus essential. If the obtained solutions are not sensitive to the parameter values, the analyst may be satisfied. In other case it may be that not enough information is available (Vincke 1999). However, taking the uncertainty explicitly into account in the calculations would be even more useful (see e.g. d'Avignon and Vincke 1988).

In most situations it might be useful to utilise several decision-aid methods to the same problem. No single method can be expected to tell the one-and-the-only truth of any natural resource planning problem. If the methods do not agree, the decision makers could be given the solutions from different methods with an explanation why they differ. Then, the decision makers can make the final choice among these alternative solutions (Salminen et al. 1998). In practise, however, this may be difficult: each method may require different input and the decision makers may not want to spend that much time pondering the problem.

Outranking methods can be applied to decision problems with a finite number of choice alternatives. Thus, the outranking methods are at their best in strategic level decision support. For example, in tactical forest management planning typically with huge number of production programme alternatives, more efficient optimization procedures are needed. The same basic limitation of the small number of decision alternatives to be compared holds with many MAUT and MAUT-related methods, too. For purposes of tactical planning, HERO heuristic optimization method (Pukkala and Kangas 1993, Kangas et al. 2000) making use of numerical optimization and MAUT techniques, for example, could be applied.

Ability to deal with uncertain and fuzzy information is an indisputable advantage of outranking methods. Same holds with the ability to deal with ordinal and other informal preference statements. A further advantage is that preference estimation procedures of outranking methods are versatile and diverse. For example, veto option gives possibilities to express constraints pragmatically and in an intuitively reasonable way. In usual MAUT methods, multiplicative partial utility functions can serve similar purposes.

Generally taken, outranking methods do not require as much preference information as MAUT-based methods. Furthermore, theoretical assumptions for the information usable in calculations (existence of an a priori utility function, additivity, etc.) are not so demanding as is usual with MAUT methods (Vincke 1992). However, the techniques by which the preference information is dealt with in calculations are rather complicated and hard to explain to non-specialists.

Easiness to use and understand the method, and interpretability of the results, are important qualities of planning methods applied particularly in participatory planning. When compared to applications of MAUT, difficulties in understanding and interpreting the calculations and their results are, perhaps, the most crucial deficiencies of most outranking methods. This problem, especially concerning the veto threshold, has been noted also by the developers of the methods (Vincke 1992).

When applying any decision support method it is crucial to understand the technical roles of each part of the evaluation model, and to take these roles into consideration in all the steps of the planning process. More important than what is the choice of the method applied is to fully understand the method and, in addition, to apply it correctly. For example, in outranking methods the analyst may choose the values of threshold values. Especially when considering the veto threshold, this may give the analyst too much influence on the decision problem if he/she does not adhere to the role of adviser.

One interesting topic of future studies is to clarify the interpretations of the parameters used in the choice models applied by different MCDM methods, as well as those of the other parts of the choice models. This knowledge is necessary in the estimation of the models in line with the preferences of the decision-makers, so that the calculations produce priorities or rankings that really reflect the preferences. A further important topic of future studies is the utilisation of different kind of advisory tools in the estimation of the choice models, such as thematic interviews and techniques of interactive preference modelling.

One problem with many MCDM methods is that rank reversal may occur (e.g. Salminen et al. 1998). It also happens with MAUT-related methods if the priority of one alternative depends on other alternatives. In HIPRE, rank reversal may occur because of the scaling used. This means that adding a new (non-optimal) alternative may change the ranks of the initial alternatives. Rank reversal problem is faced also when outranking methods are applied. Possibility of rank reversal together with the other above mentioned deficiencies emphasizes the need for sensitivity analysis and interactivity in applying the methods. Interactive approach enables the preferences evolving as new information becomes available through calculations or otherwise. In an interactive approach, any decision model is primarily a technical tool helping the search for the optimal solutions; the aim is not to fully describe the preferences but to find good solutions to complex choice problems.

As a conclusion, outranking methods are worth studying further in natural resources management. They serve alleviation to some tasks which have been observed to be bottlenecks of other decision support methods used in multiple use and participatory natural resources planning. In the method development work, it would be important to pay special attention to the interpretability and understandability of the results as well as of the use of the methods, in order to produce applications more useful in practical natural resources planning. It would also be interesting to try to develop hybrid approaches for the integrated use of different decision support methods, not only hybrids of different outranking methods but also hybrids of outranking, MAUT and numerical optimization. Perhaps that kind of hybrid methods would be applicable in tactical planning, too.

References

Alho, J. & Kangas, J. 1997. Analysing uncertainties in experts' opinions of forest plan performance. Forest Science 43: 521–528.

Bouyssou, D. 1992. Ranking methods based on valued preference relations: a characterization of the net flow method. European Journal of Operational Research 60: 61–67.

— & Perny, P. 1992. Ranking methods for valued preference relations: a characterization of a method based on leaving and entering flows. European Journal of Operational Research 61: 186–194.

Brans, J.P., Vincke, Ph. & Mareschal, B. 1986. How to select and how to rank projects: the PROMETHEE method. European Journal of Operational Research 24: 228–238.

Briggs, Th., Kunsch, P.L. & Mareschal, B. 1990. Nuclear waste management: an application of the multicriteria PROMETHEE methods. European Journal of Operational Research 44: 1–10.

d'Avignon, G.R. & Vincke, Ph. 1988. An outranking method under uncertainty. European Journal of Operational Research 36: 311–321.

Hämäläinen, R. & Lauri, H. 1995. Hipre3+ users guide. Helsinki University of Technology, Systems Analysis Laboratory.

Hokkanen, J. & Salminen, P. 1997a. Choosing a solid waste management system using multicriteria decision analysis. European Journal of Operational Research 98: 19–36.

— & Salminen, P. 1997b. Locating a waste treatment facility by multicriteria analysis. Journal of Multi-Criteria Decision Analysis 6: 175–184.

— & Salminen, P. 1997c. ELECTRE III and IV decision aids in an environmental problem. Journal of Multi-Criteria Decision Analysis 6: 215–226.

Kangas, J. 1994. An approach to public participation in strategic forest management planning. Forest Ecology and Management 70: 75–88.

— 1999. The analytic hierarchy process (AHP): standard version, forestry application and advances. In: Helles, F., Holten-Andersen, P. & Wichmann, L. (eds.). Multiple use of forests and other natural resources. Kluwer Academic Publishers, Forestry Sciences 61. p. 96–105.

— , Hytönen, L. & Loikkanen, T. 2000. Integrating the AHP and HERO into the process of participative natural resources planning. To appear in Schmoldt, D., Kangas, J., Mendoza, G.M. & Pesonen, M.

(eds.). The Analytic Hierarchy Process in natural resources and environmental decision making.
— , Loikkanen, T., Pukkala, T. & Pykäläinen, J. 1996. A participatory approach to tactical forest planning. Acta Forestalia Fennica 251. 24 p.
Maystre, L.Y., Pictet, J. & Simos, J. 1994. Méthodes multicritères ELECTRE, Lausanne. Presses Polytechniques et Universitaires Romandes.
Mendoza, G.A. & Sprouse, W. 1989. Forest planning and decision making under fuzzy environments: An overview and illustration. Forest Science 33: 458–468.
Miettinen, K. & Salminen, P. 1999. Decision-aid for discrete multiple criteria decision making problems with imprecise data. European Journal of Operational Research 119: 50–60.
Pirlot, M. 1995. A characterization of 'Min' as a procedure for exploiting valued preference relations and related results. Journal of Multi-Criteria Decision Analysis 4: 37–56.
Pykäläinen, J., Kangas, J. & Loikkanen, T. 1999. Interactive decision analysis in participatory strategic forest planning: experiences from State owned boreal forests. Journal of Forest Economics 5: 341–364.
Raju, K.S. & Pillai, C.R.S. 1999. Multicriteria decision making in performance evaluation of an irrigation system. European Journal of Operational Research 112: 479–488.
Rogers, M. & Bruen, M. 1998a. A new system for weighting environmental criteria for use within ELECTRE III. European Journal of Operational Research 107: 552–563.
— & Bruen, M. 1998b. Choosing realistic values of indifference, preference and veto thresholds for use with environmental criteria within ELECTRE. European Journal of Operational Research 107: 542–551.
Roy, B. 1968. Classement et choix en présence de points de vue multiples (la méthode ELECTRE). Revue Française d'Informatique et de Recherche Opérationnelle 8: 57–75.
— 1991. The outranking approach and the foundations of Electre methods. Theory and Decision 31:49–73.
Saaty, T.L. 1977. A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology 15: 234–281.
— 1980. The Analytic Hierarchy Process. McGraw-Hill, New York. 287 p.
Salminen, P., Hokkanen, J. & Lahdelma, R. 1998. Comparing multicriteria methods in the context of environmental problems. European Journal of Operational Research 104: 485–496.
Vincke, Ph. 1992. Multi-criteria decision aid. John Wiley & Sons. 154 p.
Vincke, Ph. 1999. Robust and neutral methods for aggregating preferences into an outranking relation. European Journal of Operational Research 112: 405–412.
Zanakis, S.H., Solomon, A., Wishart, N. & Dublish, S. 1998. Multi-attribute decision making: a simulation comparison of select methods. European Journal of Operational Research 107: 507–529.
Yu, W. 1992. Aide multicritère à la décision dans le cadre de la problématique du tri: méthodes et applications. PhD thesis, LAMSADE, Université Paris-Dauphine, Paris.

Total of 31 references