Appendix S1 A list of the assumptions, advantages, disadvantages, applications to CAN design, and available software packages for each of the 26 MCDM methods discussed in this review.

Notation Used:

A	:	a set, $\{\alpha_1,\alpha_2,...,\alpha_m\}$ consisting of *m* alternatives
K	:	a set, $\{\kappa_1,\kappa_2,...,\kappa_n\}$ consisting of *n* criteria
α_j	:	an arbitrary element of A
κ_i	:	an arbitrary element of K
$\succ$	:	a binary relation meaning “is preferred to”
$\sim$	:	a binary relation meaning “is equally preferred to”
ν_{ij}	:	a quantitative measure of the performance of α_j on the basis of κ_i
ν'_{ij}	:	ν_{ij} when normalized
μ_{ij}	:	a qualitative measure of the performance of α_j on the basis of κ_i
ω_i	:	a quantitative weight assigned to κ_i
λ_i	:	a qualitative weight assigned to κ_i
$\upsilon(\nu_{ij})$	:	a measure of the value of the performance of ν_{ij}
$\upsilon(\alpha_j)$	:	a measure of the overall value of α_j
γ_i	:	a measure of the minimum acceptable level of ν_{ij} for κ_i

S1.1. The Analytic Hierarchy Process (AHP)

Assumptions:

1. Pairwise comparisons can be made between each of the criteria with the difference in the importance of the criteria capable of being evaluated on a ratio scale.
2. For each criterion, pairwise comparisons can be made between each of the alternatives with the difference in preference of the alternatives with respect to the criterion capable of being evaluated on a ratio scale.
3. The performance of each alternative relative to each criterion can be evaluated on the basis of a common ratio scale.
4. The criteria are mutually difference independent.

Use of the Method:

For each criterion, κ_i, in K a comparison is made between each pair of alternatives in A on the basis of their performance with regard to the given κ_i. The extent to which one alternative outperforms the other alternative is measured on a scale from $1/9$ to 9, and this information is recorded in an (*n* x *n*)-matrix M_i, in which m_{ef} represents the extent to which α_e outperforms α_f with respect to κ_i. Thus, if $m_{ef} = 9$, α_e performs 9 times as well as α_f with respect to κ_i, whereas if $m_{ef} = 1/9$, α_f instead performs 9 times as well as α_e. Integer values between 1 and 8, and their reciprocals, are used to represent intermediate values. A matrix, M_i, of this type is constructed for each κ_i. For each M_i, the eigenvector associated with its largest eigenvalue is calculated and the value,

ν_{ij}, representing the performance of α_j relative to κ_i is set equal to the *j*-th entry of this eigenvector. The ν_{ij} are normalized by setting each $\nu_{ij} = \nu'_{ij}$, where

$$\nu'_{ij} = \frac{\nu_{ij}}{\sum_{j=1}^{m} \nu_{ij}} . \qquad \text{(S1.1.1)}$$

with $\sum_{j=1}^{m} \nu'_{ij} = 1$ for each κ_i. To determine the overall value, $\upsilon(\alpha_j)$, of each α_j, each κ_i is assigned a value, ω_i, representing its importance, with $\sum_{i=1}^{n} \omega_i = 1$.

The ω_i are calculated as follows. An (*m* x *m*)-matrix, P, of pairwise comparisons is constructed, with p_{gh} equal to the importance of κ_g relative to κ_h, and these comparisons are again quantified on a scale from $1/9$ to 9. The eigenvector, $\vec{\rho}$, corresponding to the greatest eigenvalue associated with P is then calculated and normalized, yielding $\vec{\rho}'$, where

$$\vec{\rho}'_i = \frac{\vec{\rho}_i}{\sum_{i=1}^{n} \vec{\rho}_i} \qquad \text{(S1.1.2)}$$

such that $\sum_{i=1}^{n} \vec{\rho}'_i = 1$. The consistency of the comparisons represented in P is then evaluated, and if it is within the prescribed limit, each ω_i is set equal to $\vec{\rho}'_i$. With the ω_i thus determined, the overall values, $\upsilon(\alpha_j)$, of the alternatives are calculated using:

$$\upsilon(\alpha_j) = \sum_{i=1}^{n} \omega_i \nu'_{ij} \,. \tag{S1.1.3}$$

The alternatives are ranked on the basis of their assigned priorities so that, for any two alternatives, α_e and α_f, $\alpha_e \succ \alpha_f$ if and only if $\upsilon(\alpha_e) > \upsilon(\alpha_f)$, with the difference in value between α_e and α_f equal to $\upsilon(\alpha_e) - \upsilon(\alpha_f)$.

Advantages:

1. The AHP produces a weak linear ordering of the alternatives.
2. The AHP allows for the difference in value between any two alternatives to be quantified.
3. The methodology by which the AHP assigns weights to criteria is simpler than that used by most of the other MCDM methods that rely upon an aggregate value function.
4. Unlike MAVT, the AHP does not assume the complete transitivity of the decision maker’s preferences. A certain degree of inconsistency is allowed, which in most decision scenarios is realistic.
5. The methodology of the AHP is similar to that used in common sense decision making. Consequently, this methodology is quite easy for most decision makers to understand.

Disadvantages:

1. The AHP requires that comparisons between both alternatives and criteria can be quantified.
2. The values of the ν'_{ij} calculated by the AHP are dependent upon the cardinality of A. If $\nu_{i(m+1)} > 0$, the addition of a new alternative, α_{m+1}, to

A will result in a change in the value of each ν_{ij}' from $\frac{\nu_{ij}}{\sum_{j=1}^{m}\nu_{ij}}$ to $\frac{\nu_{ij}}{\sum_{j=1}^{m+1}\nu_{ij}}$,

where $\frac{\nu_{ij}}{\sum_{j=1}^{m}\nu_{ij}} > \frac{\nu_{ij}}{\sum_{j=1}^{m+1}\nu_{ij}}$. As a result, if $\nu_{i(m+1)} > 0$, the inclusion of α_{m+1} will alter the $\upsilon(\alpha_j)$. This change can be great enough such that what had been the optimal α_j in $\{\alpha_j : j = 1,2,...,m\}$ is no longer optimal in $\{\alpha_j : j = 1,2,...,m+1\}$. This alteration of the rank ordering of the alternatives is referred to as rank reversal. The susceptibility of the AHP to rank reversal demonstrates that the results produced by the method are in a sense arbitrary; in certain situations, the structure of the AHP itself dictates the assignment of certain rankings to the alternatives independently of the of the decision maker's expressed preferences.

3. The use of the AHP requires the assumption that the performance of the alternatives with respect to each of the criteria can be evaluated on the basis of a common ratio scale.

Remarks:

If the performance of the alternatives with respect to the criteria can be quantitatively measured and the values of these performances can be represented by a linear value function, then the mAHP (S1.14) is clearly superior to the AHP in that: (i) pairwise comparisons need not be used in the determination of the ν_{ij}; and (ii) the results produced by the mAHP are not subject to rank reversal.

Applications to CAN Design:

Anselin, A., Miere, P., & Anselin, M. (1989) Multicriteria techniques in ecological evaluation: an example using the Analytic Hierarchy Process. *Biological Conservation*, **49**, 215 -229.

Mendoza G. & Sprouse, W. (1989) Forest planning and decision making under fuzzy environments: an overview and illustration. *Forest Science*, **35**, 481 -502.

Kuusipalo, J. & Kangas. J. (1994) Managing biodiversity in a forestry environment. *Conservation Biology*, **8**, 450 -460.

Malczewski, J., Moreno-Sánchez, R., Bojórquez-Tapia, L., & Ongay-Delhumeau, E. (1997) Multicriteria group decision-making model for environmental conflict analysis in the Cape Region, Mexico. *Journal of Environmental Planning and Management*, **40,** 349 -374.

Li, W., Wang, Z., & Tang, H. (1999) Designing the buffer zone of a nature reserve: a case study in Yancheng Biosphere Reserve, China. *Biological Conservation*, **90,** 159 -165.

Huang, W., Luukkanen, O., Johanson, S., Kaarakka, V., Räisänen, S., & Vihemäki, H. (2002) Agroforestry for biodiversity conservation of nature reserves: functional group identification and analysis. *Agroforestry Systems*, **55,** 65 -72.

Laukkanen, S., Kangas, A., & Kangas, J. (2002) Applying voting theory in natural resource management: a case of multiple-criteria group decision support. *Journal of Environmental Management*, **64,** 127 -137.

Villa, F., Tunesi, L., & Agardy, T. (2002) Zoning marine protected areas through spatial multiple-criteria analysis: the case of the Asinara Island National Marine Reserve of Italy. *Conservation Biology*, **16,** 515 -526.

Ananda, J. & Herath, G. (2003) The use of the Analytic Hierarchy Process to incorporate stakeholder preferences into regional forest planning. *Forest Policy and Economics*, **5**, 13 -26.

Bojórquez-Tapia, L., Brower, L., Castilleja, G., Sánchez-Colón, S., Hernández, M., Calvert, W., Díaz, S., Gómez-Priego, P., Alcantar, G., Melgarejo, D., José Solars, M., Gutiérrez, L., & Juárez, M. (2003) Mapping expert knowledge: redesigning the Monarch Butterfly biosphere reserve. *Conservation Biology*, **17**, 367 -379.

Bojórquez-Tapia, L., de la Cueva, H., Díaz, S., Melgarejo, D., Alcantar, G., José Solares, M., Grobet, G., & Cruz-Bello, G. (2004) Environmental conflicts and nature reserves: redesigning Sierra San Pedro Mártir national park, Mexico. *Biological Conservation*, **117**, 111 -126.

Herath, G. (2004) Incorporating community objectives in improved wetland management: the use of the Analytic Hierarchy Process. *Journal of Environmental Management*, **70**, 263 -273.

Sources for the Method:

Saaty, T. (1980) *The Analytic Hierarchy Process: planning, priority setting, resource allocation*. McGraw Hill Inc., New York.

Saaty, T. (2005) The Analytic Hierarchy and Analytic Network Processes for the measurement of intangible criteria and for decision-making. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueira, J., Greco, S., & Ehrgott, M.), pp. 345 -406. Springer, Berlin.

Software:

Criterium Decision Plus; Expert Choice; Logical Decisions; MultCSync; Web-

HIPRE.

Sources for the Software:

Expert Choice, (2000) *Expert Choice 2000 2nd edition for groups*. <*http://www.expertchoice.com*> [accessed July 2005].

InfoHarvest, (1998) *Criterium Decision Plus 3.0*. <*http://www.inforharvest.com*> [accessed July 2005].

Logical Decisions, (2003) *Logical Decisions for Windows version 5.1*. <*http://www.logicaldecisions.com*> [accessed July 2005].

Moffett, A., Garson, J., & Sarkar, S. (2005) MultCSync: a software package for incorporating multiple criteria in conservation planning. *Environmental Modelling and Software*, **20**, 1315 -1322.

Mustajoki, J., Hämälälainen, R., & Marttunen, M. (2004) Participatory multicriteria decision support with Web-HIPRE: a case of lake regulation policy. *Environmental Modelling and Software*, **19**, 537 -547.

S1.2. ARGUS

Assumptions:

1. For each criterion, κ_i, and each pair of alternatives, α_e and α_f, the difference, $\delta_i(\alpha_e,\alpha_f)$, in preference between α_e and α_f with respect to κ_i can be measured on an ordinal scale.
2. A qualitative value, λ_i, can be assigned to each κ_i representing its importance.

Use of the Method:

Pairwise comparisons are made between each of the alternatives on the basis of each criterion with the difference, $\delta_i(\alpha_e,\alpha_f)$, in preference between α_e and α_f with respect to κ_i equal to: 1 if there is a small preference for α_e over α_f; 2 if there is a moderate preference for α_e over α_f; 3 if there is a strong preference for α_e over α_f; 4 if there is a very strong preference for α_e over α_f; 5 if there is no preference for α_e over α_f; 6 if there is a small preference for α_f over α_e; 7 if there is a moderate preference for α_f over α_e; 8 if there is a strong preference for α_f over α_e; and 9 if there is a very strong preference for α_f over α_e. The importance of each criterion is evaluated and a qualitative value, λ_i, is assigned to each criterion with λ_i equal to: 0 if the criterion is not important; 1 if the criterion has a small importance; 2 if the criterion is moderately important; 3 if the criterion is very important; and 4 if the criterion is extremely important. For each pair α_e and α_f, let $\nu_{ef}(g,h)$ equal the number of criteria for which $\delta_i(\alpha_e,\alpha_f)=g$ and $\lambda_i=h$.

For each of the two possibilities, $\alpha_e \succ \alpha_f$ and $\alpha_f \succ \alpha_e$, eight different ordinal rankings are defined with $\upsilon_k(\alpha_e,\alpha_f)$ equal to the k-th ranking associated with $\alpha_e \succ \alpha_f$ and $\upsilon_k(\alpha_e,\alpha_f) \succ \upsilon_{k+1}(\alpha_e,\alpha_f)$. The values of the $\upsilon_k(\alpha_e,\alpha_f)$ are defined by sums of the $\nu_{ef}(g,h)$, as determined by the decision maker. Then $\alpha_e \succ \alpha_f$ if and only if

$$\sum_{k=1}^{h}\upsilon_k(\alpha_e,\alpha_f) > \sum_{k=1}^{h}\upsilon_k(\alpha_f,\alpha_e) \text{ for h = 1, 2, 3,…, 8,} \quad \text{(S1.2.1)}$$

$\alpha_e \sim \alpha_f$ if and only if

$$\sum_{k=1}^{h}\upsilon_k(\alpha_e,\alpha_f) = \sum_{k=1}^{h}\upsilon_k(\alpha_f,\alpha_e) \text{ for h = 1, 2, 3,…, 8,} \quad \text{(S1.2.2)}$$

with α_e and α_f incomparable otherwise. A weak linear ordering of A is then produced.

Advantages:

1. ARGUS produces a weak linear ordering of the alternatives.
2. This method does not require either the qualitative or quantitative evaluation of the criteria.
3. Unlike many other MCDM methods, it is not assumed that the performances of the alternatives with respect to different criteria can be evaluated on the basis of a common scale.

Disadvantages:

1. The qualitative scale used to assign values to the $\delta_i(\alpha_e,\alpha_f)$ is ambiguous.
2. It is unclear exactly how the sums of the $\nu_{ef}(g,h)$ are to be chosen in the calculation of the $\upsilon_k(\alpha_e,\alpha_f)$; it is questionable whether or not these values can be meaningfully added.
3. Because the comparisons required by this method are not employed in common sense decision making, it is difficult both to determine the appropriate values of these comparisons and to justify these values once they have been chosen.
4. There is a substantial probability that a given pair of alternatives will prove incomparable; consequently, the ranking of alternatives produced by this method is unlikely to be total.
5. ARGUS requires the compounding of rankings of alternatives and criteria by a method that is open to the charge of being *ad hoc*.

Remarks:

Like REGIME, ARGUS occupies a niche between Dominance and ELECTRE. Its use may be reasonable if the cardinality of Ω, as produced by Dominance, is intractably large and a qualitative evaluation of the criteria is feasible, while a quantitative evaluation of the criteria, of the type required by ELECTRE I, is unavailable.

Applications to CAN Design:

None.

Sources for the Method:

De Keyser, W. & Peters, P. (1994) ARGUS – a new multiple criteria method based on the general idea of outranking. *Applying multiple criteria aid for decision to environmental management* (ed. by Paruccini, M.), pp. 263 - 278. Kluwer Academic Publishers, Dordrecht.

Martel, M. & Matarazzo, B. (2005) Other outranking approaches. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueria, J., Greco, S., & Ehrgott, M.), pp. 197 -260. Springer, Berlin.

Software:

None.

S1.3. ELECTRE I

Assumptions:

1. Each criterion, κ_i, induces a weak linear ordering on A.
2. Each κ_i can be assigned a quantitative value, ω_i, representing its importance.
3. Discordance and concordance thresholds, as defined below, can be determined, representing the extent to which one alternative must outperform another alternative to count as outranking it.

Use of the Method:

Each alternative, α_j, is ranked on the basis of each κ_i, with μ_{ij} equal to the rank of α_j on the basis of κ_i. Each κ_i is then assigned a weight, ω_i, representing the importance of the criterion. For each pair of alternatives, α_e and α_f, let $R(\alpha_e,\alpha_f) = \{\omega_i : \mu_{ie} \geq \mu_{if}\}$. The concordance index $C(\alpha_e,\alpha_f)$ associated with the comparison of α_e and α_f is defined by:

$$C(\alpha_e,\alpha_f) = \frac{\sum_{i \in R(\alpha_e,\alpha_f)} \omega_i}{\sum_{i=1}^{n} \omega_i}. \qquad \text{(S1.3.1)}$$

Let $S(\alpha_e,\alpha_f) = \{k_i : \mu_{ie} \leq \mu_{if}\}$. The discordance index of $D(\alpha_e,\alpha_f)$ associated with the comparison of α_e and α_f is defined by:

$$D(\alpha_e, \alpha_f) = \frac{\sum_{i \in S(\alpha_e, \alpha_f)} \omega_i}{\sum_{i=1}^{n} \omega_i}. \tag{S1.3.2}$$

As with NDS computation (S1.16), ELECTRE I calculates the set of alternatives that are not dominated by any other alternative. However, ELECTRE I utilizes a different concept of dominance than that defined by (S1.16.1). Let T_c represent a concordance threshold with $0 \le T_c \le 1$, where the value of T_c is selected by the decision maker. Let T_d represent a discordance threshold with $0 \le T_d \le 1$ and the value of T_d selected by the decision maker. In ELECTRE I one alternative, α_e, dominates another alternative, α_f, if and only if the concordance and discordance thresholds are satisfied for this pair. That is, under ELECTRE I, $\alpha_e \succ \alpha_f$ if and only if

$$C(\alpha_e, \alpha_f) \ge T_c \wedge D(\alpha_e, \alpha_f) \le T_d. \tag{S1.3.3}$$

A given alternative α_e is non-dominated if and only if $(\forall i)\neg(\alpha_i \succ \alpha_e)$. As thus defined, non-dominated alternatives are clearly superior to their outranked counterparts, with the set of optimal alternatives equal to $\{\alpha_j : (\forall i)\neg(\alpha_i \succ \alpha_j)\}$.

Advantages:

1. ELECTRE I assumes relatively little of the decision maker. In particular, it assumes neither that the criteria under consideration are commensurable, nor that each criterion does anything more than provide a weak linear ordering of A.
2. ELECTRE I does not assume that the performances of the alternatives, relative to the criteria, can be quantified.

3. Unlike many other MCDM methods, it is not assumed that the criteria are mutually difference independent.
4. Unlike many other MCDM methods, it is not assumed that the performances of the alternatives with respect to different criteria can be evaluated on the basis of a common scale.

Disadvantages:

1. ELECTRE I cannot produce a weak linear ordering of the alternatives.
2. ELECTRE I requires the assignment of a numerical weight to each criterion in addition to the valuation of the T_c and T_d; however, no clear method is provided with which to make these assignments.
3. Because the roles played by the discordance and concordance thresholds have no clear corollary in common sense decision making it is difficult for a decision maker to provide any justification for the values chosen for these parameters.

Remarks:

The probability that one alternative will dominate another alternative is greater when the dominance relation is interpreted using (S1.3.3) than it is when using (S1.16.1). Therefore, the cardinality of Ω when calculated using (S1.3.3) is likely to be significantly smaller than when calculated using (S1.16.1). At the expense of requiring an evaluation of the importance of the criteria, ELECTRE I thus allows for a more precise evaluation of A than that provided by NDS computation. ELECTRE I can thus be thought of as providing a middle path between those methods that use an aggregate value function to calculate the set of acceptable alternatives and the calculation of this set on the basis of (S1.16.1).

Applications to CAN Design:

None.

Sources for the Method:

Roy, B. (1968) Classement et choix en présence de points de vue multiples: la méthode ELECTRE. *Revue Francaise d'Informatique et de Recherche Opérationnelle*, **8**, 57 -75.

Vincke, P. (1992) *Multicriteria decision aid*. John Wiley and Sons, Chichester.

Belton, V. & Stewart, B. (2002) *Multiple criteria decision analysis: an integrated approach*. Kluwer, Dordrecht.

Collete, Y. & Siarry, P. (2003) *Multiobjective optimization: principles and case studies*. Springer, Berlin.

Figueira, J., Mousseau, V., & Roy, B. (2005) ELECTRE methods. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueira, J., Greco, S., & Ehrgott, M.), pp. 133 -162. Springer, New York.

Software:

ELECTRE IS; SANNA.

Sources for the Software:

Jablonsky, J. (2000) *SANNA*: *<http://nb.vse.dz/~jablon/sanna.htm>* [accessed July 2005].

LAMSADE (2005) *ELECTRE IS:* <*http://www.lamsade.dauphine.fr/english/software.html#el1s>* [accessed July 2005].

S1.4. ELECTRE II

Assumptions:

1. Each criterion, κ_i, induces a weak linear ordering on A.
2. Each κ_i can be assigned a quantitative value, ω_i, representing its importance.
3. Both strong and weak concordance thresholds and strong and weak discordance thresholds, as defined below, can be determined, representing the extent to which one alternative must outperform another alternative to count as either strongly or weakly outranking it.

Use of the Method:

Each alternative, α_j, is ranked on the basis of each κ_i, with λ_{ij} equal to the rank of α_j on the basis of κ_i. Each κ_i is assigned a weight, ω_i, representing the importance of the criterion. For each pair of alternatives, α_e and α_f, let $R(\alpha_e,\alpha_f) = \{\omega_i;\lambda_{ie} \geq \lambda_{if}\}$. The concordance index $C(\alpha_e,\alpha_f)$ associated with the comparison of α_e and α_f is defined by:

$$C(\alpha_e,\alpha_f) = \frac{\sum_{i \in R(\alpha_e,\alpha_f)} \omega_i}{\sum_{i=1}^{n} \omega_i}. \tag{S1.4.1}$$

Let $S(\alpha_e,\alpha_f) = \{k_i;\lambda_{ie} \leq \lambda_{if}\}$. The discordance index of $D(\alpha_e,\alpha_f)$ associated with the comparison of α_e and α_f is defined by:

$$D(\alpha_e, \alpha_f) = \frac{\sum_{i \in S(\alpha_e, \alpha_f)} \omega_i}{\sum_{i=1}^{n} \omega_i}. \qquad \text{(S1.4.2)}$$

In ELECTRE II, a number of different concordance and discordance thresholds are used to refine the initial set of pairwise comparisons on the basis of the above concordance and discordance indices. Let T_c^- and T_c^+ be such that $0 \le T_c^- \le T_c^+ \le 1$, where T_c^- represents the weak concordance threshold, and T_c^+ represents the strong concordance threshold. Let T_d^- and T_d^+ such that $0 \le T_d^- \le T_d^+ \le 1$, where T_d^- represents the weak discordance threshold while T_d^+ represents the strong discordance threshold. Two different outranking relationships are then defined on the basis of the above thresholds. An alternative α_e is said to strongly outrank an alternative α_f if and only if

$$C(\alpha_e, \alpha_f) \ge T_c^+ \wedge D(\alpha_e, \alpha_f) \le T_d^+, \qquad \text{(S1.4.3)}$$

while α_e is said to weakly outrank an alternative α_f if and only if

$$C(\alpha_e, \alpha_f) \ge T_c^- \wedge D(\alpha_e, \alpha_f) \le T_d^-. \qquad \text{(S1.4.4)}$$

These two outranking relations are used to produce a weak linear ordering of A on the basis of two different weak linear orderings of the alternatives, one made by working down from the best alternative to the worst, and other made by working up from the worst alternative to the best. The outranking relation working down is defined by first specifying the set, A_1', of elements in A that are not strongly outranked by any other alternatives. This set A_1' is further refined to yield the set, A_1'', consisting of those elements of A_1' that are not weakly outranked by any other element in A_1'. The elements in A_1'' are set aside to constitute the optimal set of alternatives and the process is repeated, this time on $A \setminus A_1''$, yielding A_2' and A_2'', with the elements in A_2'' constituting the second best set of alternatives. This process is repeated until each element in A has been classified. The other outranking relation, this time working up from the worst alternatives to the best, is produced in a similar manner. The set A_1' is again defined as a subset of A, though with A_1' this time consisting of those alternatives that fail to strongly outrank any other alternative in A. The set A_1'' then consists of those members of A_1' that do not weakly outrank any element of A_1'. As above, the elements in A_1'' are set aside, this time to define the set of the least optimal alternatives. This process is repeated until each element in A has been classified. The ascending and descending rankings are then combined to yield a weak linear ordering of A.

Advantages:

1. ELECTRE II produces a weak linear ordering of the alternatives in A.
2. ELECTRE II does not assume that the performances of the alternatives, relative to the criteria, can be quantified.
3. Unlike many other MCDM methods, it is not assumed that the performances of the alternatives with respect to different criteria can be evaluated on the basis of a common scale.

Disadvantages:

1. ELECTRE II requires the assignment of a numerical weight to each criterion in addition to the valuation of T_c^+, T_c^-, T_d^-, and T_d^-; however, no clear method is provided with which to make these assignments.
2. Because the roles played by the discordance and concordance thresholds have no clear corollary in typical decision making processes, it is difficult for a decision maker to justify the values chosen for these parameters.

Remarks:

At the cost of requiring the valuation of two additional thresholds, ELECTRE II provides a more precise evaluation of A than ELECTRE I.

Applications to CAN Design:

None.

Sources for the Method:

Roy, B. & Bertier, P. (1973) La méthode ELECTRE II: une application au média-planning. *OR'72* (ed. by Ross, M.), pp. 291 -302. North Holland, Amsterdam.

Belton, V. & Stewart, B. (2002) *Multiple criteria decision analysis: an integrated approach*. Kluwer, Dordrecht.

Collete, Y. & Siarry, P. (2003) *Multiobjective optimization: principles and case studies*. Springer, Berlin.

Figueira, J., Mousseau, V., & Roy, B. (2005) ELECTRE methods. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueira, J., Greco, S., & Ehrgott, M.), pp. 133 -162. Springer, Berlin.

Software:

None.

S1.5. ELECTRE III

Assumptions:

1. A quantitative value, ω_i, can be assigned to each criterion, κ_i representing its importance.
2. A quantitative value, ν_{ij}, can be assigned to each alternative, α_j, on the basis of each κ_i representing the performance of α_j on the basis of κ_i.
3. Preference, indifference, and veto thresholds, as defined below, can be assigned to each κ_i.

Use of the Method:

For each κ_i, a quantitative value, ν_{ij}, is assigned to each α_j representing the value of α_j on the basis of κ_i. Each κ_i is assigned a weight, ω_i, representing the importance of κ_i, with $0 \leq \omega_i \leq 1$. An indifference threshold, ι_{ij}, is assigned to each α_j relative to each κ_i, with ι_{ij} a constant whose value is such that an alternative, α_e, is considered to be weakly preferred to an alternative, α_f, if

$$\nu_{ie} > \nu_{if} + \iota_{if} . \tag{S1.5.1}$$

Let ρ_{ij} be a constant assigned to each α_j relative to each κ_i such that α_e is strictly preferred to α_f if

$$\nu_{ie} > \nu_{if} + \rho_{if} . \tag{S1.5.2}$$

A concordance index, $C_i(\alpha_e,\alpha_f)$, is defined relative to each κ_i for each pair of alternatives, α_e and α_f, with

$$\begin{cases} C_i(\alpha_e,\alpha_f) = \dfrac{\nu_{ie} + \rho_{if} - \nu_{if}}{\rho_{if} - \iota_{if}} & \textit{if } \iota_{if} < \nu_{if} - \nu_{ie} \le p_{if} \\ C_i(\alpha_e,\alpha_f) = 1 & \textit{if } \nu_{if} - \nu_{ie} \le \iota_{if} \\ C_i(\alpha_e,\alpha_f) = 0 & \textit{if } \rho_{if} < \nu_{if} - \nu_{ie} \end{cases} \tag{S1.5.3}$$

and a global concordance index for each α_e and α_f is defined by

$$C(\alpha_e,\alpha_f) = \frac{\sum_{i=1}^{n} \omega_i C_i(\alpha_e,\alpha_f)}{\sum_{i=1}^{n} \omega_i}. \tag{S1.5.4}$$

A veto threshold, τ_{if}, is assigned to each α_j relative to each κ_i with the value of this constant such that the outranking of an alternative α_f by alternative α_e is prevented if for some κ_i

$$\nu_{if} \le \nu_{ie} + \tau_{if}. \tag{S1.5.5}$$

A discordance index $D_i(\alpha_e,\alpha_f)$ can then be defined, relative to each criterion κ_i, for each pair of alternatives α_e and α_f, with

$$\begin{cases} D_i(\alpha_e,\alpha_f) = \dfrac{\nu_{if} - \rho_{if} - \nu_{ie}}{\tau_{if} - \rho_{if}} & \textit{if } \rho_{if} < \nu_{if} - \nu_{ie} \le \tau_{if} \\ D_i(\alpha_e,\alpha_f) = 1 & \textit{if } \tau_{if} < \nu_{if} - \nu_{ie} \\ D_i(\alpha_e,\alpha_f) = 0 & \textit{if } \nu_{if} - \nu_{ie} \le \rho_{if} \end{cases}, \tag{S1.5.6}$$

and a global discordance index for a pair of alternatives α_e and α_f, defined by

$$D(\alpha_e,\alpha_f) = \frac{\sum_{i=1}^{n} \omega_i D_i(\alpha_e,\alpha_f)}{\sum_{i=1}^{n} \omega_i}. \tag{S1.5.7}$$

Finally, the credibility, χ_{ef}, that $\alpha_e \prec \alpha_f$ is defined by

$$\chi_{ef} = \begin{cases} C(\alpha_e,\alpha_f) & \text{if } (\forall i)(D_i(\alpha_e,\alpha_f) \le C(\alpha_e,\alpha_f)) \\ C(\alpha_e,\alpha_f) \prod_{\{\kappa_i : D_i(\alpha_e,\alpha_f)\}} \frac{(1-D_i(\alpha_e,\alpha_f))}{(1-C(\alpha_e,\alpha_f))} & \text{otherwise} \end{cases} \quad \text{(S1.5.8)}$$

which is then used to define a concept of $\lambda-$preference under which one alternative, α_e is $\lambda-$preferred to another if and only if

$$((1-s)\chi_{ef} > \chi_{fe}) \wedge (\chi_{ef} > \lambda) \quad \text{(S1.5.9)}$$

where $s = 0.3 - .15\lambda$, where λ is described below. The credibility of each pair of alternatives is calculated and then used to create a weak linear ordering of A. As with ELECTRE II, this ordering is produced by defining two different outranking relations, one working "down" from the best alternative to the worst, and one working "up" from the worst alternative to the best. Working down, one begins by identifying λ_{max}, the maximum value of χ_{ef} across all pairs of alternatives. Letting $\lambda^* = \lambda_{max} - (0.3 - 0.15\lambda_{max})$, the lambda strength of each alternative is calculated, with the lambda strength of an alternative equal to the number of alternatives in A to which α_j is $\lambda-$preferred when (S1.5.9) is calculated using $\lambda = \lambda^*$. The lambda weakness of each alternative is then calculated, with the lambda weakness of an alternative α_j equal to the number of alternatives in A that are $\lambda-$preferred to it, again using $\lambda = \lambda^*$ in (S1.5.9). Let the qualification of an alternative equal its lambda strength minus its lambda weakness. The qualification of each alternative is calculated and the set of alternatives with the greatest qualification is defined as A_1. If the cardinality of A_1 is greater than 1, then the above procedure is repeated, this time on A_1 instead of A, with alternatives removed until A_1 consists of only a single alternative. The above procedure is then repeated until a linear order of A has been produced. The other outranking relation, this time produced by working up, is constructed in exactly the same fashion except that, at each step, rather than choosing alternatives with the greatest qualification, the alternatives with the least qualification are chosen. Finally, as with ELECTRE II, a weak linear order of A is produced through the reconciliation of the two different outranking relations.

Advantages:

1. ELECTRE III produces a weak linear order of the alternatives in A.
2. Unlike many other MCDM methods, it is not assumed that the performances of the alternatives with respect to different criteria can be evaluated on the basis of a common scale.

Disadvantages:

1. ELECTRE III requires the attribution of a quantitative value to each alternative relative to each criterion along with the valuation of a number of different thresholds; however, no clear method is provided with which to make these assignments.
2. Because the roles played by the indifference, preference, and veto thresholds have no clear corollary in the typical decision making process, it is difficult both to determine the appropriate values of these parameters and to justify these values once they have been chosen.

Remarks:

ELECTRE III differs from both ELECTRE I and ELECTRE II in its use of pseudo-criteria to define notions of strict and weak preference. The use of pseudo-criteria allows for a more precise evaluation of A at the cost of stronger assumptions and increased methodological complexity.

Applications to CAN Design:

None.

Sources for the Method:

Roy, B. (1978) ELECTRE III: un algorithme de classment fondé sur une représentation floue des préférences en présence de critéres multiples. *Cahiers Centre d'Études de Recheche Operationelle*, **20**, 3 -24.

Belton, V. & Stewart, B. (2002) *Multiple criteria decision analysis: an integrated approach*. Kluwer, Dordrecht.

Collete, Y. & Siarry, P. (2003) *Multiobjective optimization: principles and case studies*. Berlin: Springer.

Figueira, J., Mousseau, V., & Roy, B. (2005) ELECTRE methods. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueira, J., Greco, S., & Ehrgott, M.), pp. 133 -162. Springer, Berlin.

Software:

ELECTRE III – IV.

Sources for the Software:

LAMSADE (2005) *ELECTRE III-IV:* <*http://www.lamsade.dauphine.fr/english/software.html#e34*> [accessed July 2005].

S1.6. ELECTRE IV

Assumptions:

1. For each κ_i and each pair of alternatives, α_e and α_f exhibit one of seven possible relations, as described below.
2. The κ_i are more or less equally important.

Use of the Method:

For a given pair of alternatives, α_e and α_f: (i) let $\mu_v(\alpha_e,\alpha_f)$ equal the number of criteria under which α_e vetoes α_f; (ii) let $\mu_p(\alpha_e,\alpha_f)$ equal the number of criteria under which is α_e is strictly preferred to α_f; (iii) let $\mu_q(\alpha_e,\alpha_f)$ equal the number of criteria under which α_e is weakly preferred to α_f; (iv) let $\mu_i(\alpha_e,\alpha_f)$ equal the number of criteria under which α_e and α_f are considered equivalent; (v) let $\mu_q(\alpha_f,\alpha_e)$ equal the number of criteria under which α_f is weakly preferred to α_e; (vi) let $\mu_p(\alpha_f,\alpha_e)$ equal the number of criteria under which α_f is strictly preferred to α_e; and (vii) let $\mu_v(\alpha_f,\alpha_e)$ equal the number of criteria under which α_f vetoes α_e. Thus

$$\mu_v(\alpha_e,\alpha_f)+\mu_p(\alpha_e,\alpha_f)+\mu_q(\alpha_e,\alpha_f)+ \mu_i(\alpha_e,\alpha_f)+\mu_q(\alpha_f,\alpha_e)+\mu_p(\alpha_f,\alpha_e)+\mu_v(\alpha_f,\alpha_e)=m. \tag{S1.6.1}$$

An alternative, α_e strongly outranks an alternative α_f if and only if

$$\mu_p(\alpha_f,\alpha_e)=0 \wedge \mu_q(\alpha_f,\alpha_e)<\mu_p(\alpha_e,\alpha_f), \tag{S1.6.2}$$

while α_e weakly outranks α_f if and only if

$$(\mu_p(\alpha_f,\alpha_e)=0 \wedge \mu_q(\alpha_f,\alpha_e)=0) \vee$$
$$(\mu_p(\alpha_f,\alpha_e)+\mu_q(\alpha_f,\alpha_e)=1 \wedge$$
$$\mu_p(\alpha_e,\alpha_f)+\mu_q(\alpha_e,\alpha_f) \geq \frac{m}{2} \wedge \mu_v(\alpha_f,\alpha_e)=0) \tag{S1.6.3}$$

A weak linear ordering of A can be defined, as with ELECTRE II and ELECTRE III, by constructing two different outranking relations, one working down from the best alternative to the worst, and one working up from the worst alternative to the best. As with ELECTRE II, the outranking relation working down is defined by first specifying the set, A_1', of elements in A that are not strongly outranked by any other alternative. This set A_1' is further refined to yield the set, A_1'', consisting of those elements of A_1' that are not weakly outranked by any other element in A_1'. The elements in A_1'' are then set aside and interpreted as constituting the set of optimal alternatives. This process is repeated on $\mathrm{A} \setminus \mathrm{A}_1''$, yielding A_2' initially and subsequently A_2'', with the elements in A_2'' interpreted as constituting the set of next to optimal alternatives. This process is further repeated until each element in A has been classified. The other outranking relation, this time working up from the worst alternatives to the best, is produced in a similar manner. The set A_1' is again defined as a subset of A, though with A_1' this time consisting of those alternatives that fail to strongly outrank any other alternative in A. The set A_1'' consists of those members of A_1' that do not weakly outrank any element of A_1'. As above, the elements in A_1'' are then set aside, this time comprising the set of the worst alternatives. This process is further repeated until each element in A has been classified. Finally, as with

ELECTRE II and ELECTRE III, a weak linear order of A is produced through the reconciliation of the two different outranking relations.

Advantages:

1. ELECTRE IV produces a weak linear ordering of the alternatives
2. Unlike the other ELECTRE methods, ELECTRE IV does not assume that quantitative values can be assigned to the criteria. As such, ELECTRE IV can be applied in a wider range of scenarios than ELECTRE II and ELECTRE III.
3. The performances of the alternatives, relative to the criteria, can be quantified by ELECTRE IV.
4. Unlike many other MCDM methods, it is not assumed that the criteria are mutually difference independent.
5. Unlike many other MCDM methods, it is not assumed that the performances of the alternatives with respect to different criteria can be evaluated on the basis of a common scale.

Disadvantages:

1. ELECTRE IV assumes that the decision maker can classify each pair of alternatives, relative to each criterion, as exhibiting one of seven possible relationships.
2. The possible relationships between criteria employed by ELECTRE IV are not clearly defined.
3. ELECTRE IV assumes that the number of criteria by which a given alternatives outperforms another alternative is sufficient to determine the relative value of the two alternatives; this method is thus applicable only in

those decision scenarios in which the criteria are of more or less equal import.

Remarks:

Assuming that the criteria are more or less equally important, ELECTRE IV provides a way in which to rank order the alternatives without evaluating either the importance or the performance of the criteria or the alternatives on a quantitative scale. However, because the method requires the assumption that the criteria are more or less equally important, it can only be applied to a limited number of decision scenarios.

Applications to CAN Design:

None.

Sources for the Method:

Roy, B. and Hugonnard, J. (1982) Ranking of suburban line extension projects on the Paris Metro System by a multicriteria method. *Transportation Research* **16A**: 301 -312.

Belton, V. and Stewart, B. (2002) *Multiple criteria decision analysis: an integrated approach*. Kluwer, Boston.

Collete, Y. and Siarry, P. (2003) *Multiobjective optimization: principles and case studies*. Springer, Berlin.

Figueira, J., Mousseau, V., and Roy, B. (2005) ELECTRE methods. *Multiple criteria decision analysis: state of the art surveys*, (ed. by Figueira, J., Greco, S., & Ehrgott, M.), pp. 133 -162. Springer, Berlin.

Software:

ELECTRE III – IV.

Sources for the Software:

LAMSADE (2005) *ELECTRE III-IV:* <*http://www.lamsade.dauphine.fr/english/software.html#e34*> [accessed July 2005].

S1.7. Goal Programming

Assumptions:

1. For each criterion κ_i, a quantitative value, ν_{ij}, can be assigned to each alternative α_j, representing the performance of α_j on the basis of κ_i.
2. A quantitative value, γ_i, can be assigned to each κ_i representing the minimum acceptable level of performance of an alternative on the basis of κ_i.

Use of Method:

In its simplest form, goal programming works as follows. The quantitative value, ν_{ij}, of each α_j relative to each κ_i is determined. For each κ_i, a quantitative value, γ_i, is specified such that a given alternative, α_j, is considered acceptable only if $\nu_{ij} \geq \gamma_i$. Once γ_i has been defined for each κ_i the ν_{ij} of each α_j are evaluated on the basis of the γ_i. The set of acceptable alternatives is defined by

$$\{\alpha_j : (\forall i)(\nu_{ij} \geq \gamma_i)\}. \qquad \text{(S1.7.1)}$$

Advantages:

1. This method assumes relatively little of the decision maker, and can be used in any decision scenario in which the decision maker is capable of (i) assigning quantitative values to the alternatives on the basis of the criteria and (ii) assigning a minimal performance level to each criterion under consideration.

Disadvantages:

1. Goal programming cannot produce a weak linear ordering of the alternatives.
2. The likely subjectivity of the γ_i means that the set of acceptable alternatives defined by this method will in most scenarios be arbitrary.
3. Given the often contradictory demands placed upon the alternatives by the criteria in K, it is unlikely that an alternative will perform well with respect to all criteria. As such, the set of acceptable alternatives defined by this method will often be either empty or unmanageably large.

Remarks:

If a meaningful target exists for each of the criteria, then goal programming can be a useful way to evaluate A on the basis of a relatively small set of assumptions.

Applications to CAN Design:

Berbel, J. & Zamora, R. (1995) An application of MOP and GP to wildlife management (deer). *Journal of Environmental Management*, **44**, 29 -38.

Malczewski, J., Moreno-Sánchez, R., Bojórquez-Tapia, L., & Ongay-Delhumeau, E. (1997) Multicriteria group decision-making model for environmental conflict analysis in the Cape Region, Mexico. *Journal of Environmental Planning and Management*, **40**, 349 -374.

Rothley, K. D. (1999) Designing bioreserve networks to satisfy multiple, conflicting demands. *Ecological Applications*, **9**, 741 –750.

Sources for the Method:

Hwang, C. a& Masud, A. (1979) *Multiple objective decision making methods and applications: a state-of-the-art survey*. Springer, Berlin.

Chankong, V. & Haimes, Y. (1983) *Multobjective decision making: theory and methodology*. North Holland, Amsterdam.

Steuer, R. (1986) *Multiple criteria optimization: theory, computation, and application*. Wiley, New York.

Software:

ADBASE; FGM; MultiGen; SOLVEX; VIG.

Sources for the Software:

Korhonen, P. (1987) VIG – A visual interactive support system for multiple criteria decision making. *Belgian Journal of Operations Research, Statistics, and Computer Science*, **27**, 3 -15.

Lotov, A., Bushenkov, V., & Kamenev, G. (2001) *Feasible goals method: search for smart decisions*. Computing Center RAS, Moscow.

Mirrazavi, S., Jones, D., & Tamiz, M. (2003) MultiGen: an integrated multiple-objective solution system. *Decision Support Systems*, **36**, 177 -187.

Potapov, M. & Kabanov, P. (1994) SOLVES – system for solving nonlinear, global, and Multicriteria problems. *Proceedings of the 3rd IFIP WG-7.6 Working Conference on Optimization-Based Computer-Aided Modelling and Design* (ed. by Dolézal, J. & Fidler, J.), pp. 343 -347. Institute for Information Theory and Automation, Academy of Sciences of the Czech Republic, Prague.

Steuer, R. (2003) *ADBASE: A multiple objective linear programming solver for efficient extreme points and unbounded efficient edges part 1: ADBASE users manual: <http://www.terry.uga.edu/~rsteuer/install/MPart1x18Aug03.pdf>* [accessed July 2005].

S1.8. IDRA

Assumptions:

1. For each criterion, κ_i, a quantitative value, ν_{ij} can be assigned to each alternative, α_j, representing the performance of α_j with respect to κ_i.
2. A quantitative value, ω_i, can be assigned to each κ_i representing its importance.
3. The value, $\upsilon(\nu_{ij})$, of each ν_{ij} can be quantified on a common interval scale.
4. The criteria are mutually difference independent.

Use of the Method:

For each κ_i, a value, ν_{ij}, is assigned to each α_j representing the performance of α_j on the basis of κ_i. For each κ_i, a value function is produced and used to assign a value, $\upsilon(\nu_{ij})$, to each ν_{ij}, with

$$\upsilon(\nu_{ij}) = \frac{\nu_{ij} - \min[\nu_{ij}]}{\max[\nu_{ij}] - \min[\nu_{ij}]}, \tag{S1.8.1}$$

where "$\min[\nu_{ij}]$" and "$\max[\nu_{ij}]$" are the minimum and maximum possible values of the ν_{ij} relative to κ_i. A quantitative value, δ_{gh}, is assigned to each pair of criteria, κ_g and κ_h, representing the units of κ_g that need to be added to an alternative to compensate for a loss of one unit of κ_h, with the δ_{gh} normalized such that $0 \le \delta_{gh} \le 1$. A second quantitative value, λ_{gh}, is assigned to each pair of criteria κ_g and κ_h, representing the extent to which κ_g is more important than κ_h, with $\omega_{gh} + \omega_{hg} = 1$. Let $\pi_{gh}(\alpha_e, \alpha_f)$ represent the probability that, in a mixed value function, with weighs randomly chosen, α_e will be assigned a greater value than α_f. For each pair of alternatives, α_e and α_f, let

$$\pi(\alpha_e, \alpha_f) = \sum_{g \neq h} (\delta_{gh} + \lambda_{gh}) \pi_{gh}(\alpha_e, \alpha_f) . \qquad \text{(S1.8.2)}$$

Preference relations are then defined such that

$$\alpha_e \succ \alpha_f \text{ if and only if } 0 \leq \pi(\alpha_f, \alpha_e) < 0.5 < \pi(\alpha_e, \alpha_f) \leq 1. \qquad \text{(S1.8.3)}$$

While

$$\alpha_e \sim \alpha_f \text{ if and only if } \pi(\alpha_e, \alpha_f) = 0.5 = \pi(\alpha_e, \alpha_f) . \qquad \text{(S1.8.3)}$$

Advantages:

1. IDRA produces a weak linear ordering of the alternatives.

Disadvantages:

1. IDRA requires the calculation of a value function for each criterion. As such, the method assumes substantially more of a decision maker than do most other outranking methods. Likewise, in relying upon such functions, IDRA proves to be a less objective method than these alternatives.
2. IDRA requires the assignment of values to the ν_{ij}; however, it does not provide a clear method by which to assign these values.

Remarks:

It is unclear why two different forms of weights, one based on trade-off calculations and the other based on importance, should be incorporated into a single aggregate value function.

Applications to CAN Design:

None.

Sources for the Method:

Greco, S. (1997) A new PCCA method: IDRA. *European Journal of Operational Research*, **98**, 587 -601.

Martel, M. & Matarazzo, B. (2005) Other outranking approaches. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueria, J., Greco, S., & Ehrgott, M.), pp. 197 -260. Springer, Berlin.

Software:

None.

S1.9. MACBETH

Assumptions:

1. A quantitative value, ν_{ij}, can be assigned to each alternative, α_j, on the basis of each criterion, κ_i.
2. Each pair of alternatives can be compared with respect to each criterion and, if there is a perceived difference in the performance of the alternatives, the strength of this difference can be assigned one of six values, as described below.
3. A set of *n*+2 alternatives, described below, can be evaluated and, if there is a perceived difference in the performance of the alternatives, the strength of this difference can be assigned to one of six values, likewise described below.
4. The criteria are mutually difference independent.

Use of the Method:

For each criterion, κ_i, pairwise comparisons are made between each of the alternatives, α_e and α_f, on the basis of the performance of the alternatives with respect to κ_i. Let $\delta_i(\alpha_e,\alpha_f)$ represent the difference between the performance of α_e and α_f on the basis of κ_i. If there is no difference, let $\delta_i(\alpha_e,\alpha_f)=0$. If there is a difference, then let $\delta_i(\alpha_e,\alpha_f)$ equal: 1 if the difference is between null and weak; 2 if the difference is weak; 3 if the difference is between weak and strong; 4 if the difference is strong; five if the difference is between strong and extreme; and 6 if the difference is extreme. Let $\upsilon(\nu_{ij})$ equal the value of α_j with respect to κ_i. In order to calculate the $\upsilon(\nu_{ij})$, a system of linear inequalities is produced whereby for any three alternatives, α_e, α_f, and α_g, $\upsilon(\nu_{ie}) > \upsilon(\nu_{if})$ if and only if $\delta_i(\alpha_e,\alpha_g) > \delta_i(\alpha_f,\alpha_g)$. The $\upsilon(\nu_{ij})$ are thus assigned in a manner compatible with the $\delta_i(\alpha_e,\alpha_f)$. If the $\delta_i(\alpha_e,\alpha_f)$ are such that the $\upsilon(\nu_{ij})$ cannot be assigned in a way that satisfies this requirement, then the decision maker must modify the $\delta_i(\alpha_e,\alpha_f)$.

A similar process is used to assign a scaling constant, ω_i, to each κ_i. Pairwise comparisons are made between *m*+2 hypothetical alternatives where *m* of these alternatives perform optimally with respect to one of the *m* criteria and least optimally with respect to all other criteria (with each of the *m* hypothetical alternatives performing optimally with respect to a difference criterion), one alternative performs optimally with respect to each criterion, and the final alternative performs least optimally with respect to each criterion. Again, if a difference is identified between the overall performance of a given pair of hypothetical alternatives, the degree of this difference is assigned one of the six different values defined above. On the basis of these comparisons, a system of linear inequalities is produced with the values of the ω_i calculated as above. If the pairwise comparisons are such that the ω_i cannot be assigned in a consistent manner then the decision maker must modify the comparisons.

The overall value, $\upsilon(\alpha_j)$, of each alternative is defined by

$$\upsilon(\alpha_j) = \sum_{i=1}^{n} \omega_i \nu_{ij} \ . \tag{S1.9.1}$$

The alternatives are then ranked on the basis of their assigned priorities so that, for any two alternatives, α_e and α_f, $\alpha_e \succ \alpha_f$ if and only if $\upsilon(\alpha_e) > \upsilon(\alpha_f)$, with the difference in value between α_e and α_f equal to $\upsilon(\alpha_e) - \upsilon(\alpha_f)$.

Advantages:

1. MACBETH produces a weak linear ordering of the alternatives.
2. MACBETH allows for the difference in value between any two alternatives to be quantified.
3. This method does not assume that quantitative values can be directly assigned either to the criteria or to the alternatives.

Disadvantages:

1. This method assumes that the decision maker can evaluate the differences between the criteria and the differences between the alternatives using a six point scale.
2. The qualitative scale used to assign a value to each pair of alternatives is ambiguous.

Remarks:

MACBETH provides a way in which to construct an aggregate value function on the basis of an easily produced set of pairwise comparisons.

Applications to CAN Design:

None.

Sources for the Method:

Bana e Costa, C. & Vansnick, J. (1994) "MACBETH – an interactive path toward the construction of cardinal value functions." *International Transactions in Operational Research* **1**: 489 -500.

Bana e Costa, C., De Corte, J., & Vansnick, J. (2005) On the mathematical foundation of MACBETH. *Multiple criteria decision analysis: state of the* *art survey* (ed. by Figueira, J., Greco, S., & Ehrgott, M.), pp. 409 -442. Springer, Berlin.

Bouyssou, D. & Pirlot, M. (2005) Conjoint measurement tools for MCDM: a brief introduction. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueira, J., Greco, S., & Ehrgott, M.), pp. 73 -130. Springer, Berlin.

Software:

MACBETH.

Sources for the Software:

Bana e Coasta, C., De Corte, J., & Vansnick, J. (2005) *M-Macbeth*

<*http://www.m-macbeth.com/Msite.html*> [accessed July 2005].

S1.10. MAPPAC

Assumptions:

1. For each κ_i, a quantitative value, ν_{ij} can be assigned to each alternative, α_j, representing the performance of α_j with respect to κ_i.
2. A quantitative value, ν_{ij}, can be assigned to each alternative, α_j, on the basis of each criterion, κ_i.
3. The value, $\upsilon(\nu_{ij})$, of each ν_{ij} can be quantified on the interval $[0,1]$.
4. The criteria are mutually difference independent.

Use of the Method:

For each κ_i, a value, ν_{ij}, is assigned to each α_j representing the performance of α_j on the basis of κ_i. A numerical weight, ω_i, is assigned to each κ_i representing the importance of κ_i, with $\sum_{i=1}^{n}\omega_i = 1$. For each κ_i, a value function is produced and used to assign a value, $\upsilon(\nu_{ij})$, to each ν_{ij}, with $0 \le \upsilon(\nu_{ij}) \le 1$. Basic preference indices, $\pi_{gh}(\alpha_e,\alpha_f)$, are then calculated between each pair of alternatives, α_e and α_f, on the basis of each pair of criteria, κ_g and κ_h, with

$$\pi_{gh}(\alpha_e,\alpha_f) = 1 \quad \text{if} \quad \upsilon(\nu_{ge}) > \upsilon(\nu_{gf}) \wedge \upsilon(\nu_{he}) > \upsilon(\nu_{hf}) \qquad \text{(S1.10.1)}$$

$$\pi_{gh}(\alpha_e,\alpha_f) = 0 \quad \text{if} \quad \upsilon(\nu_{ge}) < \upsilon(\nu_{gf}) \wedge \upsilon(\nu_{he}) < \upsilon(\nu_{hf})$$

$$\pi_{gh}(\alpha_e,\alpha_f) = \tfrac{1}{2} \quad \text{if} \quad \upsilon(\nu_{ge}) = \upsilon(\nu_{gf}) \wedge \upsilon(\nu_{he}) = \upsilon(\nu_{hf})$$

$$\pi_{gh}(\alpha_e,\alpha_f)=\frac{\omega_g(\upsilon(\nu_{ge})-\upsilon(\nu_{gf}))}{\omega_g(\upsilon(\nu_{ge})-\upsilon(\nu_{gf}))+\omega_h(\upsilon(\nu_{hf})-\upsilon(\nu_{he}))} \quad \text{if} \quad \begin{array}{l}(\upsilon(\nu_{ge})>\upsilon(\nu_{gf})\wedge\upsilon(\nu_{he})\le\upsilon(\nu_{hf}))\vee\\(\upsilon(\nu_{ge})=\upsilon(\nu_{gf})\wedge\upsilon(\nu_{he})<\upsilon(\nu_{hf}))\end{array}$$

$$\pi_{gh}(\alpha_e,\alpha_f)=\frac{\omega_h(\upsilon(\nu_{he})-\upsilon(\nu_{hf}))}{\omega_g(\upsilon(\nu_{gf})-\upsilon(\nu_{ge}))+\omega_h(\upsilon(\nu_{he})-\upsilon(\nu_{hf}))} \quad \text{if} \quad \begin{array}{l}(\upsilon(\nu_{ge})\le\upsilon(\nu_{gf})\wedge\upsilon(\nu_{he})>\upsilon(\nu_{hf}))\vee\\(\upsilon(\nu_{ge})<\upsilon(\nu_{gf})\wedge\upsilon(\nu_{he})\ge\upsilon(\nu_{hf})).\end{array}$$

Let $\pi_{ef}=\sum_{i<j}\pi_{ij}(\alpha_e,\alpha_f)\frac{\omega_i+\omega_j}{m-1}$. An overall value, π_e, is assigned to each alternative, α_e, with $\pi_e=\sum_{\alpha_f\in \mathrm{A}\setminus\alpha_e}\pi_{ef}$. Then the α_e with the greatest associated π_e is selected and set aside as the optimal alternative. The π_e are recalculated, excluding the optimal alternative from A, and the remaining α_e with the greatest associated π_e is selected as the second best alternative. This process is repeated until each of the alternatives have been ranked. A similar process is then performed, beginning with the selection of the least optimal alternative from A. This alternative is then removed from A, the π_e are recalculated, and the remaining α_e with the lowest π_e is selected as the second worst alternative. This process is continued until each of the alternatives has been ranked. These ascending and descending rankings are then combined to arrive at a weak linear ordering of A.

Advantages:

1. MAPPAC produces a weak linear ordering of the alternatives in A.
2. MAPPAC does not assume that the performances of the alternatives, relative to the criteria, can be quantified.

Disadvantages:

1. This method assumes that the performances of the alternatives can be aggregated across criteria, but produces only a ranking of the alternatives. If an assumption of this magnitude is to be made, there is no reason not use it to employ a method that produces a more precise evaluation of the alternatives.
2. MAPPAC requires the calculation of a value function for each criterion. As such, the method assumes substantially more of a decision maker than do most other outranking methods. Likewise, in relying upon such functions, MAPPAC proves to be a less objective method than these alternatives.
3. MAPPAC requires the attribution of quantitative weights to the criteria; however, it does not provide a clear method by which to assign these weights.
4. MAPPAC requires the assignment of values to the ν_{ij}; however, it does not provide a clear method by which to assign these values.

Remarks:

It is unclear whether there exist decision scenarios in which this method would not be clearly inferior to existing alternatives.

Applications to CAN Design:

None.

Sources for the Method:

Matarazzo, B. (1990) A Pairwise criterion comparison approach: the MAPPAC and PRAGMA methods. *Readings in multiple criteria decision aid* (ed. by Bana e Costa, C.), pp. 253 -273. Springer, Berlin.

Matarazzo, B. (1991) MAPPAC as a compromise between outranking methods and MAUT. *European Journal of Operational Research*, **54**, 48 -65.

Martel, M. & Matarazzo, B. (2005) Other outranking approaches. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueria, J., Greco, S., &

Ehrgott, M.), pp. 197 -260. Springer, Berlin.

Software:

SANNA.

Sources for the Software:

Jablonsky, J. (2000) *SANNA*: <*http://nb.vse.dz/~jablon/sanna.htm*> [accessed July 2005].

S1.11. Maximax

Assumptions:

1. Each criterion, κ_i, induces a weak linear ordering on A.

Use of the Method:

For each κ_i an ordinal value, ν_{ij}, is assigned to each alternative, α_j, representing the rank value of α_j with respect to κ_i. For each α_j let its value, $\upsilon(\alpha_j)$, equal the minimum of its ν_{ij}. The α_j are then ranked on the basis of their assigned $\upsilon(\alpha_j)$ so that, for any two alternatives, α_e and α_f, $\alpha_e \succ \alpha_f$ if and only if $\upsilon(\alpha_e) > \upsilon(\alpha_f)$.

Advantages:

1. Maximax produces a weak linear ordering of the alternatives in A.
2. Maximax requires no subjective assumptions other than those required to rank order the alternatives relative to the criteria.

Disadvantages:

1. Maximax fails to consider the aggregate performance of the alternatives with respect to the criteria. As a result, one can easily construct decision scenarios in which Maximax will fail to select what is, at least intuitively, an optimal alternative.

Remarks:

None.

Applications to CAN Design:

None.

Sources for the Method:

Yoon, K., & Hwang, C. (1995) *Multiattribute decision making: an introduction*. Sage Publications, London.

Software:

None.

S1.12. Maximin

Assumptions:

1. Each criterion, κ_i induces a weak linear ordering on A.

Use of the Method:

For each criterion an ordinal value, ν_{ij}, is assigned to each alternative, α_j, representing the rank value of α_j on the basis of κ_i. For each α_j let its value, $\upsilon(\alpha_j)$ equal the maximum of its ν_{ij}. The $\upsilon(\alpha_j)$ are used to rank the α_j, so that for any two alternatives, α_e and α_f, $\alpha_e \succ \alpha_f$ if and only if $\upsilon(\alpha_e) > \upsilon(\alpha_f)$.

Advantages:

1. Maximin produces a weak linear ordering of the alternatives in A.
2. Maximin requires not subjective assumptions other than those required to rank order the alternatives relative to the criteria.

Disadvantages:

1. Maximin fails to consider the aggregate performance of the alternatives with respect to the criteria. As a result, one can easily construct decision scenarios in which Maximin will fail to select what is, at least intuitively, an optimal alternative.

Remarks:

None.

Applications to CAN Design:

None.

Sources for the Method:

Yoon, K., & Hwang, C. (1995) *Multiattribute decision making: an introduction*. Sage Publications, London.

Software:

None.

S1.13. MELCHIOR

Assumptions:

1. A quantitative value, ν_{ij}, can be assigned to each alternative, α_j, on the basis of each κ_i.
2. A qualitative value can be assigned to each κ_i representing its importance.
3. Preference and indifference thresholds, as defined below, can be assigned to each alternative on the basis of each criterion.
4. The criteria are mutually difference independent.

Use of the Method:

For each κ_i, a value, ν_{ij}, is assigned to each α_j, representing the performance of α_j relative to κ_i. For each α_j, preference and indifference thresholds, Φ_{ij} and I_{ij}, are assigned to each κ_i, with $0 \le \mathrm{I}_{ij} \le \Phi_{ij}$. Comparisons are made between each pair of alternatives, α_e and α_f, on the basis of each of the criteria with: (i) α_e strictly preferred to α_f on the basis of κ_i ($\alpha_e \succ_i^s \alpha_f$) if and only if $\nu_{ie} > \nu_{if} + \Phi_{if}$; (ii) α_e weakly preferred to α_f on the basis of κ_i ($\alpha_e \succ_i^w \alpha_f$) if and only if $\nu_{if} + \Phi_{if} \ge \nu_{ie} > \nu_{if} + \mathrm{I}_{ij}$; and (iii) α_e indifferent to α_f on the basis of κ_i ($\alpha_e \sim \alpha_f$) otherwise. Each κ_i is assigned an ordinal value, ρ_i, representing the rank value of its importance compared to that of the other criteria in K.

Comparisons are made between each pair α_e and α_f on the basis of each κ_i and a value, υ_{ief} defined such that $\upsilon_{ief} = 1$ if and only if either $\alpha_e \succ_i^s \alpha_f$, $\alpha_e \succ_i^w \alpha_f$, or $\nu_{ie} > \nu_{if}$, while $\upsilon_{ief} = -1$ if and only if either $\alpha_f \succ_i^s \alpha_e$, $\alpha_f \succ_i^w \alpha_e$, or $\nu_{if} > \nu_{ie}$. A strong preference relation, $\succ^s$, is defined between each pair α_e and α_f such that $\alpha_e \succ^s \alpha_f$ if and only if, for each κ_i for which $\upsilon_{ief} = -1$, there exists a unique criterion κ_h, with $h \neq i$, for which $\upsilon_{hef} = 1$ and $\rho_h < \rho_i$. A weak preference relation, $\succ^w$, is defined between each pair α_e and α_f such that $\alpha_e \succ^w \alpha_f$ if and only if, for each κ_i for which $\upsilon_{ief} = -1$, there exists a unique criterion κ_h, with $h \neq i$, for which $\upsilon_{hef} = 1$ and $\rho_h \leq \rho_i$.

These two relations are used to produce a weak linear ordering of A on the basis of two different weak linear orderings of the alternatives, one made by working "down" from the best alternative to the worst, and other made by working "up" from the worst alternative to the best. The outranking relation working down is defined by first specifying the set, A_1', of elements in A to which no other alternatives are strongly preferred. This set A_1' is further refined to yield the set, A_1'', consisting of those elements of A_1' to which no other alternatives in A_1' are weakly preferred. The elements in A_1'' are set aside to constitute the optimal set of alternatives and the process is repeated, this time on $\mathrm{A} \setminus \mathrm{A}_1''$, yielding A_2' and A_2'', with the elements in A_2'' constituting the second best set of alternatives. This process is repeated until each element in A has been classified. The other ordering, this time working up from the worst alternatives to the best, is produced in a similar manner. The set A_1' is again defined as a subset of A, though with A_1' this time consisting of those alternatives that are not strongly preferred to any other alternative in A, with the set A_1'' consisting of those members of A_1' that are not weakly preferred to any other element in A_1'. As above, the elements in A_1'' are set aside, this time to define the set of the worst alternatives. This process is repeated until each element in A has been classified. The ascending and descending rankings are then combined to arrive at a weak linear ordering of A.

Advantages:

1. MELCHIOR produces a weak linear ordering of the alternatives in A.

Disadvantages:

1. MELCHIOR requires the attribution of a quantitative value to each alternative relative to each criterion along with the valuation of preference and indifference thresholds; however, no clear method is provided with which to make these assignments.
2. The use of pseudocriteria requires the attribution of a quantitative value to each alternative relative to each alternative; however, it is unclear whether the cost of this requirement is outweighed by the advantage associated with the use of pseudocriteria.

Applications to CAN Design:

None.

Sources for the Method:

Leclercq, J. (1984) Propositions d'extensions de al notion de dominance en presence de relations d'ordre sur le pseudo-critéres: MELCHIOR. *Revue Belge de Recherche Operationnelle, de Statistique et d'Informatique*, **24**, 32 -46.

Martel, M. & Matarazzo, B. (2005) Other outranking approaches. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueria, J., Greco, S., & Ehrgott, M.), pp. 197 -260. Springer, Berlin.

Software:

None.

S1.14. The Modified AHP

Assumptions:

1. Pairwise comparisons can be made between each of the criteria with the difference in importance of the criteria evaluated on a ratio scale.
2. A quantitative value, ν_{ij}, can be assigned to each alternative, α_j, on the basis of each κ_i.
3. For each κ_i, a linear function can be used to calculate the value, $\upsilon(\nu_{ij})$, of each ν_{ij}.
4. The same interval scale can be used to used to calculate each $\upsilon(\nu_{ij})$ for each κ_i.
5. The criteria are mutually difference independent.

Use of the Method:

For each κ_i, a value, ν_{ij}, is assigned to each α_j, representing the performance of α_j relative to κ_i. The values of these performances are calculated using

$$\upsilon(\nu_{ij}) = \frac{\nu_{ij} - \min[\nu_{ij}]}{\max[\nu_{ij}] - \min[\nu_{ij}]}, \qquad \text{(S1.14.1)}$$

where "$\min[\nu_{ij}]$" and "$\max[\nu_{ij}]$" are the minimum and maximum possible values, respectively, of the ν_{ij} relative to κ_i. Once, the $\upsilon(\nu_{ij})$ have been calculated, the weight, ω_i, assigned to each κ_i is determined according to the methodology employed by the AHP (S1.1). That is, an (*m* x *m*)-matrix, P, of pairwise comparisons is constructed, with p_{ij} equal to the importance of κ_i relative to κ_j, with this comparison quantified on a scale from $1/9$ to 9. The eigenvector, $\vec{\rho}$, corresponding to the greatest eigenvalue associated with P is then calculated and normalized, yielding $\vec{\rho}'$, where

$$\vec{\rho}_i' = \frac{\vec{\rho}_i}{\sum_{i=1}^{n} \vec{\rho}_i}, \qquad \text{(S1.14.2)}$$

with $\sum_{i=1}^{n} \vec{\rho}_i' = 1$. Each ω_i is then set equal to $\vec{\rho}_i'$ and an overall value, $\upsilon(\alpha_j)$, is assigned to each α_j, where

$$\upsilon(\alpha_j) = \sum_{i=1}^{n} \omega_i \upsilon(\nu_{ij}). \qquad \text{(S1.14.3)}$$

The alternatives are ranked on the basis of their assigned priorities so that, for any two alternatives, α_e and α_f, $\alpha_e \succ \alpha_f$ if and only if $\upsilon(\alpha_e) > \upsilon(\alpha_f)$, with the difference in value between α_e and α_f equal to $\upsilon(\alpha_e) - \upsilon(\alpha_f)$.

Advantages:

1. The modified AHP produces a weak linear ordering of the alternatives.
2. The modified AHP allows for the difference in value between any two alternatives to be quantified.
3. The methodology by which the modified AHP assigns weights to criteria is relatively simple and transparent. The methodology of the AHP is similar to that used in common sense decision making. Consequently, this methodology is quite easy for most decision makers to understand.

4. Unlike MAVT, the modified AHP does not assume the complete transitivity of the decision maker's preferences. A certain degree of inconsistency is allowed, which in most decision scenarios is realistic.
5. Because the modified AHP uses value functions to calculate the $\upsilon(\nu_{ij})$, its results are independent of the number of alternatives in A. As such, unlike the AHP, this method is not susceptible to rank reversal.

Disadvantages:

1. The use of the modified AHP requires the assumption that the performance of the alternatives with respect to each of the criteria can be evaluated on the basis of a common scale.
2. In the modified AHP, the functions used to define the $\upsilon(\nu_{ij})$ are assumed to be linear. As such, the $\upsilon(\nu_{ij})$ determined using this method are less likely to reflect the precise preferences of the decision maker than the $\upsilon(\nu_{ij})$ calculated under MAVT, in which the precise form of each value function is specified by the decision maker. The cost associated with the simplicity of the value functions used to calculate the $\upsilon(\nu_{ij})$ is a likely decrease in their accuracy.
3. The modified AHP requires that comparisons between the importance of pairs of criteria can be quantified.

Remarks:

If the performance of the alternatives with respect to the criteria can be quantitatively measured and the values of these performances can be represented by a linear value function, then the mAHP is clearly superior to the

AHP in that: (i) pairwise comparisons need not be used in the assignment of the v_{ij}; and (ii) the results produced by the mAHP are not subject to rank reversal. If, additionally, it can be assumed that the value function defined for each criterion is linear, then the mAHP is likely to prove superior to MAVT.

Applications to CAN Design:

Sarkar, S., Moffett, A., Sierra, R., Fuller, T., Cameron, S., & Garson, J. (2004) Incorporating multiple criteria into the design of conservation area networks. *Endangered Species Update*, **21**, 100 -107.

Moffett, A., Garson, J., & Sarkar, S. (2005) MultCSync: a software package for incorporating multiple criteria in conservation planning. *Environmental Modelling and Software*, **20**, 1315 -1322.

Phua M. & Minowa, M. (2005) A GIS-based multi-criteria decision making approach to forest conservation planning at a landscape scale: a case study in the Kinabalu area, Sabah, Malaysia. *Landscape and Urban Planning*, **71**, 207 -222.

Sources for the Method:

Belton, V. & Gear, T. (1983) On a short-coming of Saaty's method of the Analytic Hierarchies. *Omega*, **11**, 228 -230.

Dyer, J. (1990) Remarks on the Analytic Hierarchy Process. *Management Science*, **36**, 249 -258.

Software:

Expert Choice; Logical Decisions; MultCSync; Web-HIPRE.

Sources for the Software:

Expert Choice, (2000) *Expert Choice 2000 2nd edition for groups*. <*http://www.expertchoice.com*> [accessed July 2005].

InfoHarvest, (1998) *Criterium Decision Plus 3.0*. <*http://www.inforharvest.com*> [accessed July 2005].

Logical Decisions, (2003) *Logical Decisions for Windows version 5.1*. <*http://www.logicaldecisions.com*> [accessed July 2005].

Moffett, A., Garson, J., & Sarkar, S. (2005) MultCSync: a software package for incorporating multiple criteria in conservation planning. *Environmental Modelling and Software*, **20**, 1315 -1322.

Mustajoki, J., Hämälälainen, R., & Marttunen, M. (2004) Participatory multicriteria decision support with Web-HIPRE: a case of lake regulation policy. *Environmental Modelling and Software*, **19**, 537 -547.

S1.15. Multiattribute Value Theory (MAVT)

Assumptions:

1. A numerical weight, ω_i, can be assigned to each criterion, κ_i, on the basis of a pairwise comparison between two alternatives.
2. A quantitative value, ν_{ij}, can be assigned to each alternative, α_j, on the basis of each κ_i.
3. A value, $\upsilon(\nu_{ij})$, of the performance of each α_j with respect to each κ_i, can be quantified on the interval $[0,1]$.
4. The performance of each alternative relative to each criterion can be evaluated on the basis of a common interval scale.
5. The criteria are mutually difference independent.

Use of the Method:

For each κ_i, a value, ν_{ij}, is assigned to each α_j, representing the performance of α_j relative to κ_i. For each κ_i, a single criterion value function is defined which takes a ν_{ij} as its input and outputs the utility, $\upsilon(\nu_{ij})$, of the value, with $0 \leq \upsilon(\nu_{ij}) \leq 1$. For a given κ_i, this function is defined by assigning a utility of 1.0 to the α_j with the highest ν_{ij} and a utility of 0.0 to the α_j with the lowest ν_{ij}. The ν_{ij} for which the differences between it and the highest and lowest ν_{ij} are equal is then assigned a utility of 0.5. This process is then repeated to determine the ν_{ij} associated with utilities of 0.25 and 0.75, with the $\upsilon(\nu_{ij})$ associated with further ν_{ij} calculated in the same way. After a sufficient number of these calculations have been made, the value function associated with criterion κ_i is defined by fitting the points resulting from the above calculations, with the accuracy of the value function increasing with the number of calculations.

The weight, ω_i, associated with each κ_i is determined in a similar manner. Two equally preferable alternatives, α_e and α_f, are identified with $\upsilon(\nu_{1e}) \neq \upsilon(\nu_{1f})$, $\upsilon(\nu_{2e}) \neq \upsilon(\nu_{2f})$, and $\upsilon(\nu_{ie}) = \upsilon(\nu_{if})$ for $i = 3,4,...,n$. (If A fails to contain two alternatives that meet these requirements, then hypothetical α_e and α_f are be defined by varying the above values until the requirements are met.) For each α_j let $\upsilon(\alpha_j)$ equal its overall value, with

$$\upsilon(\alpha_j) = \sum_{i=1}^{n} \omega_i \upsilon(\nu_{ij}). \tag{S1.15.1}$$

Because α_e and α_f are equally preferable, it follows that $\upsilon(\alpha_e) = \upsilon(\alpha_f)$. By (S1.15.1), it thus follows that

$$\omega_1\upsilon(\nu_{1e}) + \omega_2\upsilon(\nu_{2e}) + ... + \omega_n\upsilon(\nu_{ne}) = \omega_1\upsilon(\nu_{1f}) + \omega_2\upsilon(\nu_{2f}) + ... + \omega_n\upsilon(\nu_{nf}) \tag{S1.15.2}$$

Given that $\nu_{ie} = \nu_{if}$ for $i = 3,4,...,n$, $\omega_1\upsilon(\nu_{1e}) + \omega_2\upsilon(\nu_{2e}) = \omega_1\upsilon(\nu_{1f}) + \omega_2\upsilon(\nu_{2f})$. Then

$$\frac{\omega_1}{\omega_2} = \frac{\upsilon(\nu_{2e}) - \upsilon(\nu_{2f})}{\upsilon(\nu_{1f}) - \upsilon(\nu_{1e})}. \tag{S1.15.3}$$

Repeating the above process n – 2 times allows for the calculation of $\omega_2, \omega_3, ..., \omega_n$ in terms of ω_1. These values are then normalized such that $\sum_{i=1}^{n} \omega_i = 1$. Using (S1.15.1), the alternatives are ranked on the basis of their assigned values so that, for any two alternatives, α_e and α_f, $\alpha_e \succ \alpha_f$ if and only if $\upsilon(\alpha_e) > \upsilon(\alpha_f)$, with the difference in value between α_e and α_f equal to $\upsilon(\alpha_e) - \upsilon(\alpha_f)$.

Advantages:

1. MAVT produces a weak linear ordering of the alternatives.
2. MAVT allows for the difference in value between any two alternatives to be quantified.
3. No assumptions are made by MAVT with respect to the form of the single criterion value functions used to calculate the $\upsilon(\nu_{ij})$. The $\upsilon(\nu_{ij})$ calculated by MAVT are thus more likely to reflect the decision maker's actual preferences than $\upsilon(\nu_{ij})$ calculated using value functions more restricted in form.
4. The methodology of MAVT is similar to that used in common sense decision making. Consequently, this method is quite easy for most decision makers to understand.
5. Because MAVT uses value functions to calculate the $\upsilon(\nu_{ij})$, its results are independent of the number of alternatives in A. Therefore, unlike the AHP, the method is not susceptible to rank reversal.

Disadvantages:

1. As is the case with any method employing an aggregate value function, the use of MAVT requires the assumption that the performance of the alternatives with respect to each of the criteria can be evaluated on the basis of a common scale. This is a strong assumption and in many

decision scenarios it will prove to be unfounded. As such, the applicability of this method is somewhat limited.

2. The decision maker must be able to assign a scaling constant to each criterion. This requirement can be difficult to fulfill and serves also to increase the subjectivity of the method.
3. The requirement that a numerical value, ν_{ij}, be assigned to each α_j on the basis of each κ_i limits the applicability of this method to those decision scenarios in which the performances of the alternatives can be readily quantified.
4. The construction of the aggregate value function using MAVT can be quite involved.

Remarks:

This method is more complex than either the AHP or mAHP. What is acquired at the cost of this complexity is immunity to rank reversal in conjunction with the freedom to construct a unique value function for each criterion. Neither the AHP nor the mAHP has both of these attributes.

Applications to CAN Design:

Rothley, K. D. (1999) Designing bioreserve networks to satisfy multiple, conflicting demands. *Ecological Applications*, **9**, 741 –750.

Noss, R., Carroll, C., Vance-Borland, K., & Wuerthner, G. (2002) A multicriteria assessment of the irreplaceability and vulnerability of sites in the Greater Yellowstone Ecosystem. *Conservation Biology*, **16**, 895 -908.

Sierra, R., Campos, F., & Chamberlin, J. (2002) Assessing biodiversity conservation priorities: ecosystem risk and representativeness in Continental Ecuador. *Landscape and Urban Planning*, **59**, 95 -110.

Memtsas, D. (2003) Multiobjective programming methods in the reserve selection problem. *European Journal of Operational Research*, **150**, 640 -652.

Bojórquez-Tapia, L., de la Cueva, H., Díaz, S., Melgarejo, D., Alcantar, G., Solares, M., Grobet, G., & Cruz-Bello, B. (2004) Environmental conflicts and nature reserves: redesigning Sierra San Pedro Mártir National Park, Mexico. *Biological Conservation*, **117**, 111 -126.

Geneletti, D. (2004) A GIS-based decision support system to identify nature conservation priorities in an alpine valley. *Land Use Policy*, **21**, 149 -160.

Huth, A., Drechsler, M., & Köhler, P. (2004) Multicriteria evaluation of simulated logging scenarios in a tropical rain forest. *Journal of Environmental Management*, **71**, 321 -333.

Redpath, S., Arroyo, B., Leckie, F., Bacon, P., Bayfield, N., Gutiérrez, R., & Thirgood, S. (2004) Using decision modeling with stakeholders to reduce human-wildlife conflict: a raptor-grouse case study. *Conservation Biology*, **18**, 350 -359.

Janssen, R., Goosen, H., Verhoeven, M., Verhoeven, J., Omtzigt, A., & Maltby, E. (2005) Decision support for integrated wetland management. *Environmental Modelling and Software*, **20**, 215 -229.

Sources for the Method:

Keeney, R. L. & Raiffa, H. (1993) *Decisions with multiple objectives: preferences and value tradeoffs*. Cambridge University Press, Cambridge.

Dyer, J. & Sarin, R. (1979) Measurable multiattribute value functions. *Operations Research*, **27**, 810 -822.

Dyer, J. (2005) MAUT – multiattribute utility theory. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueira, J., Greco, S., & Ehrgott, M.), pp. 265 -294. Springer, Berlin.

Software:

Criterium Decision Plus; DataScope; DEFINITE; Expert Choice; High Priority;

HIVIEW; Logical Decisions; V.I.S.A.; Web-HIPRE.

Sources for the Software:

Catalyze, (2005) *HiView3* <*http://www.catalyze.co.uk/hiview/hiview.html*> [accessed July 2005].

Expert Choice, (2000) *Expert Choice 2000 2nd edition for groups*. <*http://www.expertchoice.com*> [accessed July 2005].

InfoHarvest, (1998) *Criterium Decision Plus 3.0*. <*http://www.inforharvest.com*> [accessed July 2005].

Logical Decisions, (2003) *Logical Decisions for Windows version 5.1*. <*http://www.logicaldecisions.com*> [accessed July 2005].

Moffett, A., Garson, J., & Sarkar, S. (2005) MultCSync: a software package for incorporating multiple criteria in conservation planning. *Environmental Modelling and Software*, **20**, 1315 -1322.

Mustajoki, J., Hämälälainen, R., & Marttunen, M. (2004) Participatory multicriteria decision support with Web-HIPRE: a case of lake regulation policy. *Environmental Modelling and Software*, **19**, 537 -547.

Simul8 Corporation, (2005) *V.I.S.A. <http:www.simul8.com/products/visa.htm>* [accessed July 2005].

S1.16. NDS Computation

Assumptions:

1. Each criterion, κ_i, induces a weak linear ordering on A.

Use of the Method:

For each κ_i an ordinal value, μ_{ij}, is assigned to each alternative, α_j, representing the rank value of α_j relative to κ_i. On the basis of these rankings, a dominance relation, $\succ$, is defined such that, for each pair of alternatives, α_e and α_f, where $e \neq f$, $\alpha_e \succ \alpha_f$ if and only if

$$(\exists i)(\mu_{ie} < \mu_{if}) \wedge (\forall k)(\mu_{ke} \leq \mu_{kf}). \qquad \text{(S1.16.1)}$$

It follows that, for all alternatives α_e and α_f, $e \neq f$, α_e does not dominate α_f if and only if

$$(\forall i)(\mu_{ie} \geq \mu_{if}) \vee (\exists k)(\mu_{ke} > \mu_{kf}). \qquad \text{(S1.16.2)}$$

A given alternative α_e is non-dominated if and only if $(\forall i)\neg(\alpha_i \succ \alpha_e)$. As thus defined, non-dominated alternatives are clearly superior to their outranked counterparts. Consequently, the set of optimal alternatives is equal to the set of non-dominated alternatives, $\{\alpha_j : (\forall i)\neg(\alpha_i \succ \alpha_j)\}$.

Advantages:

1. This method assumes only that the alternatives can be ranked by the criteria.
2. This method does not require either the qualitative or quantitative evaluation of the criteria.

3. Unlike many other MCDM methods, it is not assumed that the performances of the alternatives with respect to different criteria can be evaluated on the basis of a common scale.
4. Unlike many other MCDM methods, it is not assumed that the criteria are mutually difference independent.
5. This method can be applied in all decision scenarios and its results are compatible with those of all other rational decision procedures.

Disadvantages:

1. The decision maker cannot specify the cardinality of the set of non-dominated alternatives. Moreover, the cardinality of the this set generally increases with the size of both A and K. As a result, in decision scenarios involving large numbers of alternatives evaluated on the basis of several criteria, is it unlikely that the set of non-dominated alternatives will be sufficiently small. In such scenarios, further information is required to refine this set to a manageable size.

Remarks:

This method assumes as little as is possible about the abilities of the decision maker and can thus be thought to provide a maximally objective evaluation of A. Moreover, because of its minimal assumptions, this method can be used in any decision scenario. Finally, this method is compatible with the results produced by any other rational decision making procedure. As a result, this method should be used as a first step in the analysis of any decision scenario. It is only if the set of non-dominated alternatives thereby produced is insufficiently small that other methods should be used.

Applications to CAN Design:

Berbel, J. & Zamora, R. (1995) An application of MOP and GP to wildlife management (deer). *Journal of Environmental Management*, **44**, 29 -38.

Rothley, K. D. (1999) Designing bioreserve networks to satisfy multiple, conflicting demands. *Ecological Applications*, **9**, 741 –750.

Sarkar, S., Parker, N., Garson, J., Aggarwal, A., & Haskell, S. (2000) Place prioritization for Texas using GAP data: the use of biodiversity and economic surrogates within socioeconomic constraints. *Gap Analysis Bulletin*, **9**, 48 -51.

Memtsas, D. (2003) Multiobjective programming methods in the reserve selection problem. *European Journal of Operational Research*, **150**, 640 -652.

Sarkar, S. & Garson, J. (2004) Multiple criterion synchronization (MCS) for conservation area network design: the use of non-dominated alternative sets. *Conservation and Society*, **2**, 433 -448.

Sarkar, S., Moffett, A., Sierra, R., Fuller, T., Cameron, S., & Garson, J. (2004) Incorporating multiple criteria into the design of conservation area networks. *Endangered Species Update*, **21**, 100 -107.

Moffett, A., Garson, J., & Sarkar, S. (2005) MultCSync: a software package for incorporating multiple criteria in conservation planning. *Environmental Modelling and Software*, **20**, 1315 -1322.

Sources for the Method:

Arrow, K. & Raynaud, H. (1986) *Social choice and multicriterion decision-making*. The MIT Press, Cambridge.

Sarkar, S., & Garson, J. (2004) Multiple criterion synchronization (MCS) for conservation area network design: the use of non-dominated alternative sets. *Conservation and Society*, **2**, 433 -448.

Software:

MultCSync.

Sources for the Software:

Moffett, A., Garson, J., & Sarkar, S. (2005) MultCSync: a software package for incorporating multiple criteria in conservation planning. *Environmental Modelling and Software*, **20**, 1315 -1322.

S1.17. ORESTE

Assumptions:

1. Each criterion, κ_i, induces a weak linear ordering on A.
2. The κ_i can be ordered according to their importance.
3. Incomparability and indifference measures, as defined below, can be selected.

Use of the Method:

Each alternative α_j is assigned a qualitative value, ν_{ij}, relative to each κ_i representing the rank value of its performance relative to κ_i. A qualitative value, ω_i, is assigned to each κ_i representing the rank value of its importance relative to the other κ_i. On the basis of these values, the distance, $\delta(0,\nu_{ij})$, between an arbitrary origin, 0, and ν_{ij} is defined such that such that for any two alternatives, α_e and α_f, and for each κ_i

$$\delta(0,\nu_{ie}) < \delta(0,\nu_{if}) \text{ if and only if } \nu_{ie} > \nu_{if}. \tag{S1.17.1}$$

Distances are thus assigned to each alternative relative to each criterion on the basis of which a rank, $\rho(\nu_{ij})$ is assigned to each of the m x n ν_{ij} with

$$1 \le \rho(\nu_{ij}) \le mn, \tag{S1.17.2}$$

where, for any two alternatives, α_e and α_f, and for any two criteria, κ_e and κ_f,

$$\rho(\nu_{ee}) \le \rho(\nu_{ff}) \text{ if and only if } \delta(0,\nu_{ee}) \le \delta(0,\nu_{ff}). \tag{S1.17.3}$$

A concordance index, $C(\alpha_e,\alpha_f)$ is defined for each pair of alternatives α_e and α_f such that

$$C(\alpha_e, \alpha_f) = \sum_{i:\delta(0,\nu_{ie}) > \delta(0,\nu_{if})} \nu_{if} - \nu_{ie} \ . \tag{S1.17.4}$$

The rank, $\rho(\alpha_j)$, of an alternative α_j is defined by

$$\rho(\alpha_j) = \sum_{i=1}^{n} \nu_{ij} \ . \tag{S1.17.5}$$

Quantitative values, γ and β, are defined where γ represents the maximal level of indifference and β represents the minimal level of incomparability between two alternatives. A preference relation, $\prec$, is defined such that, given any two alternatives, α_e and α_f, $\alpha_e \prec \alpha_f$ if and only if

$$\neg\left(\frac{R(\alpha_f) - R(\alpha_e)}{n^2(m-1)} \leq \beta\right) \wedge \frac{C(\alpha_f, \alpha_e)}{R(\alpha_f) - R(\alpha_e)} \leq \gamma_{ef} \ . \tag{S1.17.6}$$

Advantages:

1. ORESTE produces a weak linear ordering of the alternatives.
2. ORESTE does not assume that the criteria under consideration are commensurable.
3. ORESTE requires neither the attribution of quantitative weights to the criteria nor the attribution of quantitative values to the alternatives relative to the criteria.

Disadvantages:

1. ORESTE requires the pairwise comparison of each ν_{ij}; however it is questionable whether or not such comparisons are even meaningful.
2. ORESTE requires the use of incommensurability and indifference measures though the method fails to specify just how such measures are to be determined. This is at least somewhat problematic in that the role

played by these measures has no clear corollary in the typical decision making scenarios and is thus likely to be arbitrarily chosen by the decision maker.

Remarks:

Because it is unclear on what grounds the ν_{ij} are to be compared, ORESTE should likely be avoided in favor of methods like PROMETHEE I which likewise allows the decision maker to specify the cardinality of Ω while avoiding the assumption that the criteria are commensurable. Though PROMETHEE I requires the attribution of weights to the criteria, is nonetheless structured upon a well founded set of evaluations.

Applications to CAN Design:

None.

Sources for the Method:

Roubens, M. (1982) Preference relations on actions and criteria in multicriteria decision making. *European Journal of Operational Research*, **10**, 51-55.

Martel, M. & Matarazzo, B. (2005) Other outranking approaches. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueria, J., Greco, S., & Ehrgott, M.), pp. 197 -260. Springer, Berlin.

Software:

None.

S1.18. PACMAN

Assumptions:

1. For each κ_i, a quantitative value, ν_{ij} can be assigned to each alternative, α_j, representing the performance of α_j with respect to κ_i.
2. The value, $\upsilon(\nu_{ij})$, of each ν_{ij} can be quantified on the interval $[0,1]$.
3. The criteria are mutually difference independent.

Use of the Method:

For each κ_i, a value, ν_{ij}, is assigned to each α_j representing the performance of α_j on the basis of κ_i. For each κ_i and each pair of alternatives, α_e and α_f, the difference, $\delta_i(\alpha_e,\alpha_f)$, between α_e and α_f with respect to κ_i, is calculated, with

$$\delta_i(\alpha_e,\alpha_f) = \frac{\nu_{ie} - \nu_{if}}{\max[\nu_{ij}] - \min[\nu_{ij}]}, \tag{S1.18.1}$$

where "$\min[\nu_{ij}]$" and "$\max[\nu_{ij}]$" are the minimum and maximum possible values of the ν_{ij} relative to κ_i and $-1 \le \delta_i(\alpha_e,\alpha_f) \le 1$. Each pair of criteria, κ_g and κ_h, is compared and the extent to which positive differences in the performances of alternatives associated with κ_g compensate for negative differences associated with κ_h is quantified on the interval $[0,1]$ with a value of 1 representing the inability of differences in κ_h to compensate for differences in κ_g and a value of 0 representing the opposite. These values are used to construct a compensatory function $CF_{\triangleright gh}$ defined on each pair κ_g and κ_h of criteria in K with the function both weakly monotonic and continuous. This function is then considered in the assignment of indices, $\Pi^{+}(\alpha_e,\alpha_f)$ and $\Pi^{-}(\alpha_e,\alpha_f)$, to each pair of alternatives, α_e and α_f, where $\Pi^{+}(\alpha_e,\alpha_f)$ represents the extent to which α_e compensates for α_f and $\Pi^{-}(\alpha_e,\alpha_f)$ represents the extent to which α_f resists such compensation. The compensated preference of α_e over α_f is said to be accepted, $\Gamma^{+}(\alpha_e,\alpha_f)$ if and only if $\Pi^{+}(\alpha_e,\alpha_f) > \Pi^{-}(\alpha_e,\alpha_f)$, doubtful, $\Gamma^{=}(\alpha_e,\alpha_f)$, if and only if $\Pi^{+}(\alpha_e,\alpha_f) = \Pi^{-}(\alpha_e,\alpha_f)$, and rejected, $\Gamma^{-}(\alpha_e,\alpha_f)$, if and only if $\Pi^{+}(\alpha_e,\alpha_f) < \Pi^{-}(\alpha_e,\alpha_f)$. Preference relations are then defined such that

$$\alpha_e \succ \alpha_f \text{ if and only if}$$
$$(\Gamma^{+}(\alpha_e,\alpha_f) \wedge \Gamma^{-}(\alpha_f,\alpha_e)) \vee (\Gamma^{+}(\alpha_e,\alpha_f) \wedge \Gamma^{=}(\alpha_f,\alpha_e)) \vee (\Gamma^{=}(\alpha_e,\alpha_f) \wedge \Gamma^{-}(\alpha_f,\alpha_e)) \tag{S1.18.2}$$

while

$$\alpha_e \sim \alpha_f \text{ if and only if}$$
$$(\Gamma^{=}(\alpha_e,\alpha_f) \wedge \Gamma^{=}(\alpha_f,\alpha_e)) \vee (\Gamma^{+}(\alpha_e,\alpha_f) \wedge \Gamma^{+}(\alpha_f,\alpha_e)). \tag{S1.18.3}$$

Advantages:

1. PACMAN produces a weak linear ordering of the alternatives.

Disadvantages:

1. PACMAN requires the calculation of a value function for each criterion. As such, the method assumes substantially more of a decision maker than do most other outranking methods. Likewise, in relying upon such functions, PACMAN proves to be a less objective method than these alternatives.

2. PACMAN requires the assignment of values to the ν_{ij}; however, it does not provide a clear method by which to assign these values.
3. This method is quite complex and requires a large amount of information from the decision maker.

Remarks:

It is unclear whether there exist decision scenarios in which this method would not be clearly inferior to existing alternatives.

Applications to CAN Design:

None.

Sources for the Method:

Giarlotta, A. (1998) Passive and active compensability multicriteria analysis (PACMAN). *Journal of Multi-Criteria Decision Analysis*, **7**, 204 -216.

Martel, M. & Matarazzo, B. (2005) Other outranking approaches. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueria, J., Greco, S., & Ehrgott, M.), pp. 197 -260. Springer, Berlin.

Software:

None.

S1.19. PRAGMA

Assumptions:

1. For each κ_i, a quantitative value, ν_{ij} can be assigned to each alternative, α_j, representing the performance of α_j with respect to κ_i.
2. The value, $\upsilon(\nu_{ij})$, of each ν_{ij} can be quantified on the interval $[0,1]$.
3. The criteria are mutually difference independent.

Use of the Method:

For each κ_i, a value, ν_{ij}, is assigned to each α_j representing the performance of α_j on the basis of κ_i. A numerical weight, ω_i, is assigned to each κ_i representing the importance of κ_i, with $\sum_{i=1}^{n}\omega_i = 1$. For each κ_i, a value function is produced and used to assign a value, $\upsilon(\nu_{ij})$, to each ν_{ij}, with $0 \le \upsilon(\nu_{ij}) \le 1$. For each pair of criteria, κ_g and κ_h, a partial profile of the criteria is produced by representing κ_g and κ_h as two parallel line segments of length 1 that are located 1 unit apart. In this profile, the value, $\upsilon(\nu_{ij})$, of each alternative is plotted along the lines representing κ_g and κ_h. These points are then connected and the intersections are used to construct, for each pair of criteria, an (*m* x *m*)-matrix M_{gh} in which *m* values are assigned to each of the *m* alternatives on the basis of κ_g and κ_h. These values are then aggregated to produce an (*m* x *m*)-matrix M in which *m* values are assigned to the *m* alternatives. This matrix is then used to produce a weak linear ordering of the alternatives.

Advantages:

1. PRAGMA produces a weak linear ordering of the alternatives.

Disadvantages:

1. PRAGMA requires the calculation of a value function for each criterion. As such, the method assumes substantially more of a decision maker than do most other outranking methods. Likewise, in relying upon such functions, PRAGMA proves to be a less objective method than these alternatives.
2. PRAGMA requires the assignment of values to the ν_{ij}; however, it does not provide a clear method by which to assign these values.
3. This method is quite complex and requires a large amount of information from the decision maker.

Remarks:

It is unclear whether there exist decision scenarios in which this method would not be clearly inferior to existing alternatives.

Applications to CAN Design:

None.

Sources for the Method:

Matarazzo, B. (1988) Preference global frequencies in multicriterion analysis (PRAGMA). *European Journal of Operational Research*, **36**, 36 -49.

Martel, M. & Matarazzo, B. (2005) Other outranking approaches. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueria, J., Greco, S., & Ehrgott, M.), pp. 197 -260. Springer, Berlin.

S1.20. PROMETHEE I

Assumptions:

1. A quantitative value, ω_i, can be assigned to each κ_i representing its importance.
2. For each κ_i, a quantitative value, ν_{ij} can be assigned to each alternative, α_j, representing the performance of α_j with respect to κ_i.
3. The value, $\upsilon(\nu_{ij})$, of each ν_{ij} can be quantified on the interval $[0,1]$.
4. The criteria are mutually difference independent.

Use of Method:

For each κ_i, a value, ν_{ij}, is assigned to each α_j representing the performance of α_j on the basis of κ_i. A numerical weight, ω_i, is assigned to each κ_i representing the importance of κ_i, with $\sum_{i=1}^{n} \omega_i = 1$. For each κ_i, a value function is produced and used to assign a value, $\upsilon(\nu_{ij})$, to each ν_{ij}, with $0 \le \upsilon(\nu_{ij}) \le 1$. For each pair of alternatives, α_e and α_f, the preference index of α_e over α_f with respect to κ_i, is defined by

$$\pi_i(\alpha_e, \alpha_f) = \upsilon(\nu_{ie}) - \upsilon(\nu_{if}) . \qquad \text{(S1.20.1)}$$

The overall preference index of α_e and α_f, taking into account each κ_i, is subsequently defined by

$$\pi(\alpha_e, \alpha_f) = \sum_{i=1}^{n} \omega_i \pi_i(\alpha_e, \alpha_f). \qquad \text{(S1.20.2)}$$

For each α_j, the outgoing flow is defined by

$$\varphi_j^+ = \sum_{\alpha_k \in \mathrm{A}} \pi(\alpha_j, \alpha_k), \qquad \text{(S1.20.3)}$$

while the incoming flow is defined by

$$\varphi_j^- = \sum_{\alpha_k \in \mathrm{A}} \pi(\alpha_k, \alpha_j). \qquad \text{(S1.20.4)}$$

Thus, the greater the value of φ_j^+, the more α_j dominates the other alternatives in A, while the greater the value of φ_j^+, the more α_j is dominated by the other alternatives in A. The outgoing and incoming flows are calculated for each α_j and, for each pair of alternatives, α_e and α_f, $\alpha_e \succ \alpha_f$ if and only if

$$(\varphi_e^+ > \varphi_f^+ \wedge \varphi_e^- < \varphi_f^-) \vee (\varphi_e^+ > \varphi_f^+ \wedge \varphi_e^- = \varphi_f^-) \vee (\varphi_e^+ = \varphi_f^+ \wedge \varphi_e^- < \varphi_f^-). \qquad \text{(S1.20.5)}$$

Advantages:

1. PROMETHEE I produces a weak linear ordering of the alternatives in A.
2. The use of PROMETHEE I does not require the assumption that the set of criteria under consideration are commensurable.

Disadvantages:

1. PROMETHEE I requires the calculation of a value function for each criterion. As such, the method assumes substantially more of a decision maker than do most other outranking methods. Likewise, in relying upon such functions, PROMETHEE I proves to be a less objective method than these alternatives.

2. PROMETHEE I requires the attribution of quantitative weights to the criteria; however, it does not provide a clear method by which to assign these weights.
3. PROMETHEE I requires the assignment of values to the ν_{ij}; however, it does not provide a clear method by which to assign these values.

Remarks:

PROMETHEE I occupies a niche between the ELECTRE methods and methods like the AHP and MAVT that rely upon the construction of an aggregate value function. PROMETHEE I, in producing a value function for each criterion, allows for a more precise evaluation of A than do the ELECTRE methods while the assumption, made by the AHP and MAVT, that these value functions are commensurable, is avoided.

Applications to CAN Design:

Drechsler, M. (2004) “Model-based conservation decision aiding in the presence of goal conflicts and uncertainty.” *Biodiversity and Conservation*, **13**, 141 - 164.

Sources for the Method:

Brans, J. & Vincke, P. (1985) A preference ranking organization method: the PROMETHEE method for multiple criteria decision making. *Management Science*, **31**, 647 -656.

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

Brans, J. & Mareshcal, B. (2005) PROMETHEE methods. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueira, J., Greco, S., & Ehrgott, M.), pp. 163 -195. Springer, Berlin.

Software:

Decision Lab 2000.

Sources for the Software:

Visual Decision (2003) *Decision Lab 2000* *<http://www.visualdecision.com>* [accessed July 2005].

S1.21. PROMETHEE II

Assumptions:

1. A quantitative value, ν_{ij}, can be assigned to each alternative, α_j, on the basis of each κ_i.
2. A quantitative value, ω_i, can be assigned to each κ_i representing its importance.
3. The value, $\upsilon(\nu_{ij})$, of the performance of each ν_{ij} can be quantified on the interval $[0,1]$.
4. The criteria are mutually difference independent.

Use of Method:

For each κ_i, a value, ν_{ij}, is assigned to each α_j representing the performance of α_j on the basis of κ_i. A numerical weight, ω_i, is assigned to each κ_i representing the importance of κ_i, with $\sum_{i=1}^{n} \omega_i = 1$. For each κ_i, a value function is produced and used to assign a value, $\upsilon(\nu_{ij})$, to each ν_{ij}, with $0 \le \upsilon(\nu_{ij}) \le 1$. For each pair of alternatives, α_e and α_f, the preference index of α_e over α_f with respect to κ_i, is defined as

$$\pi_i(\alpha_e, \alpha_f) = \upsilon(\nu_{ie}) - \upsilon(\nu_{if}) . \qquad \text{(S1.21.1)}$$

The overall preference index of α_e and α_f, taking into account each κ_i, is subsequently defined by

$$\pi(\alpha_e, \alpha_f) = \sum_{i=1}^{n} \omega_i \pi_i(\alpha_e, \alpha_f) . \qquad \text{(S1.21.2)}$$

For each α_j, the outgoing flow is defined as

$$\varphi_j^+ = \sum_{\alpha_k \in \mathrm{A}} \pi(\alpha_j, \alpha_k) , \qquad \text{(S1.21.3)}$$

while the incoming flow is defined as

$$\varphi_j^- = \sum_{\alpha_k \in \mathrm{A}} \pi(\alpha_k, \alpha_j) . \qquad \text{(S1.21.4)}$$

Consequently, as with PROMETHEE I, the greater the value of φ_j^+, the more α_j dominates the other alternatives in A, while the greater the value of φ_j^+, the more α_j is dominated by the other alternatives in A. Ultimately, the only difference between PROMETHEE I and PROMETHEE II is found in the definition of outranking employed by the two methods. Whereas, on the basis of the above definitions, PROMETHEE I defines outranking with condition (S1.20.5), under PROMETHEE II, for each pair of alternatives, α_e and α_f, $\alpha_e \succ \alpha_f$ if and only if

$$\varphi^+(\alpha_e) - \varphi^-(\alpha_e) > \varphi^+(\alpha_f) - \varphi^-(\alpha_f) . \qquad \text{(S1.21.5)}$$

Advantages:

1. PROMETHEE II produces a weak linear ordering of the alternatives in A.
2. The use of PROMETHEE II does not require the assumption that the set of criteria under consideration are commensurable.
3. Unlike PROMETHEE I, PROMETHEE II is guaranteed to produce an ordering of A.

Disadvantages:

1. PROMETHEE II, in assigning a single quantitative value to each alternative, requires the assumption that the criteria are commensurable.
2. PROMETHEE I requires the attribution of quantitative weights to the criteria; however, it does not provide a clear method by which to assign these weights.
3. PROMETHEE I requires the assignment of values to the ν_{ij}; however, it does not provide a clear method by which to assign these values.

Remarks:

Though PROMETHEE II requires the assumption that the criteria are commensurable, the method only uses this information to construct an outranking relation. If the decision maker is willing to make this assumption, there is no reason to employ PROMETHEE II instead of an MCDM method that makes use of an aggregate value function. Though the assumptions will be identical, the later method will provide a more precise ranking of the alternatives than the former.

Applications to CAN Design:

Laukkanen, S., Kangas, A., & Kangas, J. (2002) "Applying voting theory in natural resource management: a case of multiple-criteria group decision support." *Journal of Environmental Management*, **64**, 127 -137.

Sources for the Method:

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

Brans, J. & Mareshcal, B. (2005) PROMETHEE methods. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueira, J., Greco, S., & Ehrgott, M.), pp. 163 -195. Springer, Berlin.

Software:

Decision Lab 2000; SANNA.

Sources for the Software:

Jablonsky, J. (2000) *SANNA*: <*http://nb.vse.dz/~jablon/sanna.htm*> [accessed July 2005].

Visual Decision (2003) *Decision Lab 2000* <*http://www.visualdecision.com*> [accessed July 2005].

S1.22. QUALIFLEX

Assumptions:

1. Each criterion, κ_i, induces a weak linear ordering on A.
2. The κ_i can be ranked according to their importance.

Use of the Method:

For each κ_i an ordinal value, λ_{ij}, is assigned to each alternative, α_j, representing the rank value of α_j relative to κ_i. For each criterion, the set of *m*! possible rankings of alternatives is produced with μ_{jk} equal to the position of α_j in the *k*-th such ranking. For each ranking, pairwise comparisons are made between each of the alternatives. Let $C_{ik}(\alpha_e,\alpha_f)$ be the concordance index associated with the comparison of α_e and α_f with respect to κ_i and the *k*-th ranking, with

$$C_{ik}(\alpha_e,\alpha_f)=\begin{cases}1 & \text{if} \quad (\lambda_{ie}>\lambda_{if}\wedge\mu_{ek}>\mu_{fk})\vee(\lambda_{ie}<\lambda_{if}\wedge\mu_{ek}<\mu_{fk}) \\ 0 & \text{if} \quad \lambda_{ie}=\lambda_{if}\wedge\mu_{ek}=\mu_{fk} \\ -1 & \text{otherwise}\end{cases} \qquad \text{(S1.22.1)}$$

The $C_{ik}(\alpha_e,\alpha_f)$ are calculated for each pair of alternatives on the basis of each of the $n\times m!$ pairs of possible rankings and criteria. Let C_{ik} represent the overall concordance index associated with κ_i and the *k*-th ranking, with

$$C_{ik}=\sum_{\alpha_e,\alpha_f\in\mathrm{A}}C_{ik}(\alpha_e,\alpha_f). \qquad \text{(S1.22.2)}$$

The C_{ik} are calculated for each pair of possible ranking and criteria. The κ_i are ranked on the basis of their importance. Let C_k represent the overall concordance index associated with the k-th possible ranking, with

$$C_k = \sum_i \omega_i C_{ik}(\alpha_e, \alpha_f), \tag{S1.22.3}$$

where ω_i is equal to the weight of κ_i and the ω_i are selected such that they maximize the value of C_k. The α_j are then ranked using the ranking, k, with the greatest associated C_k, with the rank value assigned to α_j equal to the rank value assigned to it in k.

Advantages:

1. QUALIFLEX has the potential to yield a weak linear ordering of A.
2. QUALIFLEX requires only the assumptions that the criteria can be ranked on the basis of their importance and the that each criterion induces a weak linear ordering of the alternatives. These assumptions are relatively weak.

Disadvantages:

1. QUALIFLEX requires the compounding of rankings of alternatives and criteria by a method that is open to the charge of being *ad hoc*.

Remarks:

It is unclear whether there exist decision scenarios in which this method would not be clearly inferior to existing alternatives.

Applications to CAN Design:

None.

Sources for the Method:

Paelink, J. (1976) Qualitative multiple criteria analysis, environmental protection and multiregional development. *Papers of the Regional Science*

Association, **36**, 59 -74.

Martel, M. & Matarazzo, B. (2005) Other outranking approaches. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueria, J., Greco, S., & Ehrgott, M.), pp. 197 -260. Springer, Berlin.

Software:

MICRO-QUALIFLEX.

Sources for the Software:

Ancot, J. (1988) *Micro-Qualiflex an interactive software package for the determination and analysis of the optimal solution to decision problems*. Kluwer, Dordrecht.

S1.23. Regime

Assumptions:

1. Each criterion, κ_i, induces a weak linear ordering on A.
2. The κ_i can be ranked according to their importance.

Use of the Method:

Each κ_i is assigned an ordinal value representing its rank compared to that of the other criteria in K. Pairwise comparisons of each of the alternatives are made relative to each criterion resulting in the assignment of a binary value, ν_{ijk}, to each pair of alternatives relative to each criterion, where $\nu_{ijk} = -1$ if α_k outperforms α_j with respect to κ_i and $\nu_{ijk} = 1$ if α_j outperforms α_k with respect to κ_i. A regime is defined as the set of values, ν_{ijk}, associated with the comparison of α_j and α_k relative to each criterion. On the basis of each regime, an outranking relationship, $\prec$, is defined as follows. For each pair of alternatives, α_j and α_k, let K^+ equal the set of criteria in K under which $\nu_{ijk} = 1$ and let K^- equal the set of criteria in K under which $\nu_{ijk} = -1$. Then $\alpha_j \succ \alpha_k$ if and only if there exists an injective mapping from K^- to K^+ under which each criterion in K^- is mapped to a more important criterion in K^+ and $\mathrm{K}^+ \neq \varnothing$. The set of optimal alternatives is then $\{\alpha_j : (\forall k)\neg(\alpha_k \succ' \alpha_j)\}$

Advantages:

1. Regime produces a weak linear ordering of the alternatives.

2. The use of Regime requires only the assumptions that the alternatives can be ordered relative to the criteria, that the criteria themselves can be ordered, and that the criteria are mutually difference independent. These assumptions are relatively weak; consequently, Regime can be applied in a wide variety of decision making scenarios.

Disadvantages:

1. In many decision scenarios, the outranking relation defined by Regime will be insufficiently precise.

Remarks:

REGIME occupies a niche between Dominance and ELECTRE and should be used when the cardinality of the set of optimal alternatives, as produced by Dominance, is intractably large and a qualitative evaluation of the criteria is feasible, while a quantitative evaluation of the criteria, of the type required by ELECTRE I, is unavailable.

Applications to CAN Design:

None.

Sources for the Method:

Hinloopen, E., Nijkamp, P., & Rietveld, P. (1983a) The regime method: a new multicriteria method. *Essays and surveys on multiple criteria decision making* (ed. by Henson, P), pp. 146 -155. Springer, Berlin.

Hinloopen, E., Nijkamp, P., & Rietveld, P. (1983b) Qualitative discrete multiple criteria choice models in regional planning. *Regional Science and Urban Economics*, **13**, 77 -102.

Hinloopen, E., & Nijmkamp, P. (1990) Qualitative multiple choice analysis: the dominant regime method. *Quality and Quantity*, **24**, 37 -56.

Nijkamp, P., Rietveld, P., & Voogd, H. (1990) *Multicriteria evaluation in physical planning*. North-Holland, Amsterdam.

Martel, M. & Matarazzo, B. (2005) Other outranking approaches. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueria, J., Greco, S., &

Ehrgott, M.), pp. 197 -260. Springer, Berlin.

Software:

None.

S1.24. Tactic

Assumptions:

1. A quantitative value, ν_{ij}, can be assigned to each alternative, α_j, on the basis of each κ_i.
2. A quantitative value, ω_i, can be assigned to each κ_i representing its importance.

Use of the Method:

For each κ_i, a value, ν_{ij}, is assigned to each α_j representing the performance of α_j on the basis of κ_i. A numerical weight, ω_i, is assigned to each κ_i representing the importance of κ_i, with $\sum_{i=1}^{n}\omega_i = 1$. For each criterion, and each pair of alternatives, α_e and α_f, the difference between ν_{ie} and ν_{if} is calculated and δ_{ef} set equal to the minimum such difference. For each pair, α_e and α_f, the set, B, is defined such that

$$\mathrm{B}_{ef} = \{\kappa_i : \nu_{ie} > \nu_{if} + \delta_{ef}\}. \qquad \text{(S1.24.1)}$$

Using this set, an outranking relation, $\succ$, is defined such that $\alpha_e \succ \alpha_f$ if and only if

$$\sum_{\kappa_i \in \mathrm{B}_{ef}} \omega_i > \rho \sum_{\kappa_i \in \mathrm{B}_{fe}} \omega_i , \qquad \text{(S1.24.2)}$$

where ρ represents the concordance threshold selected by the decision maker, with $1 \le \rho$.

Advantages:

1. Unlike many other MCDM methods, Tactic does not assume that the criteria are mutually difference independent.
2. It is not assumed that the performances of the alternatives with respect to different criteria can be evaluated on the basis of a common scale.

Disadvantages:

1. Tactic requires the assignment of a difference threshold to each pair of alternatives; however, no clear method is provided with which to do this.
2. Because the role played by the difference threshold has no clear corollary in the typical decision making process, it is difficult both to determine the appropriate values of these parameters and to justify these values once they have been chosen.

Remarks:

Tactic requires a stronger set of assumptions than ELECTRE I and yet does not provide a more detailed evaluation of the alternatives. As such, it is unclear whether there exist decision scenarios in which Tactic should be chosen instead of ELECTRE I.

Applications to CAN Design:

None.

Sources for the Method:

Vansnick, J. (1986) On the problem of weights in multiple criteria decision making (the non-compensatory approach). *European Journal of Operational Research*, **24**, 288 -294.

Martel, M. & Matarazzo, B. (2005) Other outranking approaches. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueria, J., Greco, S., & Ehrgott, M.), pp. 197 -260. Springer, Berlin.

Software:

None.

S1.25. TOPSIS

Assumptions:

1. A quantitative value, ω_i, can be assigned to each criterion, κ_i, representing its importance.
2. For each κ_i, a quantitative value, ν_{ij}, can be assigned to each alternative, α_j, representing the performance of α_j on the basis of κ_i.
3. The performance of each alternative relative to each criterion can be evaluated on the basis of a common scale.
4. The criteria are mutually difference independent.

Use of the Method:

Each α_j is assigned a quantitative value, ν_{ij}, with respect to each κ_i representing the performance of α_j with respect to κ_i. Each ν_{ij} is normalized with

$$\nu'_{ij} = \frac{\nu_{ij}}{\sqrt{\sum_{i=1}^{n} \nu_{ij}^2}}. \qquad \text{(S1.25.1)}$$

Each κ_i is assigned a weight, ω_i, representing its importance, with $\sum_{i=1}^{n} \omega_i = 1$.

Let $\alpha^+ = (\nu_1^+, \nu_2^+, ..., \nu_n^+)$, where ν_i^+ denotes the optimal value of any α_j with respect to κ_i. Let $\alpha^- = (\nu_1^-, \nu_2^-, ..., \nu_n^-)$, where ν_i^- denotes the least optimal performance of any α_j with respect to κ_i. α^+ is the positive-ideal solution, while

α^- is the negative-ideal solution. The weighted value, $\upsilon(\nu_{ij})$, of each α_j relative to each κ_i is calculated with

$$\upsilon(\nu_{ij}) = \omega_i \nu'_{ij}. \tag{S1.25.2}$$

The Euclidian distance, δ_j^+ between each α_j and α^+ in *n*-dimensional space is calculated using

$$\delta_j^+ = \sqrt{\sum_{i=1}^{n}(\upsilon(\nu_{ij}) - \upsilon_i^+)^2}, \tag{S1.25.3}$$

where υ_i^+ is equal to the $\upsilon(\nu_{ij})$ of the α_j that performs optimally with respect to κ_i.

The distance, δ_j^- between each α_j and α^- is calculated in the same manner, using

$$\delta_j^- = \sqrt{\sum_{i=1}^{n}(\upsilon(\nu_{ij}) - \upsilon_i^-)^2}, \tag{S1.25.4}$$

where υ_i^- is equal to the $\upsilon(\nu_{ij})$ of the α_j that performs least optimally with respect to κ_i. The overall value, $\upsilon(\alpha_j)$, of each α_j is calculated using

$$\upsilon(\alpha_j) = \frac{\delta_j^+}{(\delta_j^+ - \delta_j^-)}. \tag{S1.25.5}$$

The alternatives are then ranked on the basis of their assigned priorities, such that for any two alternatives, α_e and α_f, $\alpha_e \succ \alpha_f$ if and only if $\upsilon(\alpha_e) > \upsilon(\alpha_f)$, with the difference in value between α_e and α_f equal to $\upsilon(\alpha_e) - \upsilon(\alpha_f)$.

Advantages:

1. TOPSIS produces a weak linear ordering of the alternatives.

2. TOPSIS allows the difference in value between any two alternatives to be quantified.

Disadvantages:

1. Though TOPSIS requires the assignment of a quantitative weight to each criterion it fails to provide any method with which to make these assignments.
2. Because the hypothetical optimum used to assign values to the alternatives is not a feasible alternative and, therefore, distances from it may be meaningless.

Remarks:

The aggregate value function produced by TOPSIS is identical in form to those functions produced by the AHP and MAVT. The methodology employed by TOPSIS is likewise quite similar to that of these methods, though in TOPSIS the performance of the alternatives is evaluated on the basis of their position in Euclidian space whereas in the AHP and MAVT, this evaluation is based upon a set of pairwise comparisons and the construction of a value function, respectively. Consequently, the decision to employ TOPSIS, as opposed to these alternative methods, is likely to be motivated either by a desire to use Euclidian distances to ground the evaluation of alternatives, or, more likely, a desire to avoid the explicit use of a value function in the evaluation of A. It is unclear, however, whether or not anything is in fact gained by such avoidance.

Applications to CAN Design:

Bojórquez-Tapia, L., Brower, L., Castilleja, G., Sánchez-Colón, S., Hernández, M., Calvert, W., Díaz, S., Gómez-Priego, P., Alcantar, G., Melgarejo, D., José Solars, M., Gutiérrez, L., & Juárez, M. (2003) Mapping expert knowledge: redesigning the Monarch Butterfly Biosphere Reserve.

Conservation Biology, **17**, 367 -379.

Phua M. & Minowa, M. (2005) A GIS-based multi-criteria decision making approach to forest conservation planning at a landscape scale: a case study in the Kinabalu Area, Sabah, Malaysia. *Landscape and Urban Planning*, **71**, 207 -222.

Sources for the Method:

Nijkamp, P., Rietveld, P., & Voogd, H. (1990) *Multicriteria evaluation in physical planning*. North-Holland, Amsterdam.

Memtsas, D. (2003) Multiobjective programming methods in the reserve selection problem. *European Journal of Operational Research*, **150**, 640 -652.

Yoon, K., & Hwang, C. (1995) *Multiattribute decision making: an introduction*. Sage Publications, London.

Software:

SANNA; Triptych.

Sources for the Software:

Jablonsky, J. (2000) *SANNA*: <*http://nb.vse.dz/~jablon/sanna.htm*> [accessed July 2005].

Statistical Design Institute (2005) *Triptych* <*http://www.stat-design.com/Software/Triptych/TOPSIS.htm*> [accessed July 2005].

S1.26. UTA

Assumptions:

1. There exists a subset, $\mathrm{A}^* \subset \mathrm{A}$, consisting of alternatives that can be directly ranked.
2. A quantitative value, ν_{ij}, can be assigned to each alternative, α_j, on the basis of each criterion, κ_i.
3. The criteria are mutually difference independent.
4. The performance of each alternative relative to each criterion can be evaluated on the basis of a common scale.

Use of the Method:

Let A^* be the set consisting of alternatives in A that can be directly ranked. For each $\alpha_j \in \mathrm{A}^*$, let ν_{ij} represent the performance of α_j with respect to κ_i. A single criterion value function is defined for each κ_i with which a value, $\upsilon(\nu_{ij})$, is assigned to each ν_{ij}. For each $\alpha_j \in \mathrm{A}^*$, let the value, $\upsilon(\alpha_j)$, of α_j be defined by

$$\upsilon(\alpha_j) = \sum_{i=1}^{n} \upsilon(\nu_{ij}), \qquad \text{(S1.26.1)}$$

where $\sigma(\alpha_j)$ represents an error term relative to $\upsilon(\alpha_j)$. Introducing an error term, $\sigma(\alpha_j)$ into (S1.26.1) results in

$$\upsilon(\alpha_j) = \sum_{i=1}^{n} \upsilon(\nu_{ij}) + \sigma(\alpha_j). \qquad \text{(S1.26.2)}$$

A rank order of the elements of A^* is produced and on the basis of these rankings, a linear program is defined and used to produce (S1.26.1) by minimizing the sum of the $\sigma(\alpha_j)$ in (S1.26.2) subject to the requirements that: (i) for any two alternatives α_e and α_f in A^*, $\alpha_e \prec \alpha_f$ if and only if $\upsilon(\alpha_e) > \upsilon(\alpha_f)$ while $\alpha_e \sim \alpha_f$ if and only if $\upsilon(\alpha_e) = \upsilon(\alpha_f)$; (ii) each of the single criterion value functions is monotonic; (iii) if α_o is the optimal alternative in A^* then $\upsilon(\alpha_o) = 1$; and (iv) if α_l is the least optimal alternative in A^* then $\upsilon(\alpha_l) = 0$.

Once (S1.26.1) has been so defined, the value, $\upsilon(\alpha_j)$ of each $\alpha_j \in A$ is determined and used to rank order the alternatives in A such that, for any two alternatives α_e and α_f, $\alpha_e \succ \alpha_f$ if and only if $\upsilon(\alpha_e) > \upsilon(\alpha_f)$, with the difference between α_e and α_f equal to $\upsilon(\alpha_e) - \upsilon(\alpha_f)$.

Advantages:

1. UTA produces a weak linear ordering of the alternatives.
2. UTA allows the difference in value between any two alternatives to be quantified.
3. UTA does not assume that quantitative weights can be directly assigned to the criteria.

Disadvantages:

1. This method assumes that there exists a subset of alternatives in A that can be directly ranked by the decision maker; however, it is unclear exactly how this ranking of alternatives should be produced.

2. It is likely that if the decision maker is in need of an MCDM method for the analysis of A, the decision maker will be unequipped to directly rank even a subset of the alternatives in A. Consequently, in many decision scenarios this method will prove inapplicable.

Remarks:

In those decision scenarios in which the decision maker is sufficiently familiar with a subset of A to allow for the ranking of these alternatives without the aid of a MCDM method, UTA allows for the construction of an aggregate value function with which to rank order the alternatives in A without first evaluating the importance of the criteria.

Applications to CAN Design:

None.

Sources for the Method:

Jacquet-Lagreze, E. & Siskos, J. (1982) Assessing a set of additive utility functions for multicriteria decision-making, the UTA method. *European Journal of Operational Research*, **10**, 151 -164.

Bouyssou, D. & Pirlot, M. (2005) Conjoint measurement tools for MCDM: a brief introduction. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueira, J., Greco, S., & Ehrgott, M.), pp. 79 -130. Springer, Berlin.

Siskos, Y., Grigoroudis, E., & Matsatsinis, N. (2005) UTA methods. *Multiple criteria decision analysis: state of the art surveys* (ed. by Figueira, J., Greco, S., & Ehrgott, M.), pp. 297 -343. Springer, Berlin.

Software:

PREFCALC; MIDAS; MUSTARD; UTA+

Sources for Software:

Beuthe, M. & Scannella, G. (1999) *MUSTARD user's guide*. Facultés Universitaires Catholiques de Mons.

Jacquet-Lagrèze, E. (1990) Interactive assessment of preferences using holistic judgements: the PREFCALC system. *Readings in multiple criteria decision aid* (ed. by Bana e Costa, C.), pp. 225- 250. Springer, Berlin.

Kostkowski, M., & Slowinski, R. (2005) *UTA+:* <*http://www.lamsade.dauphine.fr/english/software.html#uta+1*> [accessed July 2005].

Siskos, Y, Spyridakos, A., & Yannacopoulos, D. (1999) Using artificial intelligence and visual techniques in preference disaggregation analysis: the MIDAS system. *European Journal of Operational Research*, **113**, 281 - 299.