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Feedback–oriented group decision support

by

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The paper introduces a feedback-oriented approach to group decision support. This approach is based on the notion that in many cooperative group settings, an agreement is not reached by making concessions but by gradually changing the preferences of group members. Two possible ways of such preference changes are identified and formal methods for them are developed. The approach is illustrated by an example using the reference point approach as evaluation technique.

Keywords: Group Decision, Multiple Criteria, Feedback, Preference Changes

1. Introduction

The problem of supporting group decision processes has been approached in the literature from different perspectives, assigning different roles to Group Decision Support Systems (GDSS). Following the classification of DeSanctis and Gallupe (1987), the function of a GDSS may be to remove communication barriers between members (Level 1 systems), to reduce uncertainty and noise in the decision process (Level 2 systems) or to guide the group's decision process (Level 3 systems). Systems have been built for experimental purposes at all three levels and Level 1 systems in particular are actually used in practice (e.g. Nunamaker et al., 1989a). This paper deals with an extension to the architecture now commonly found in level 3 systems as e.g. Co-oP (Bui/Jarke, 1986; Bui, 1987), MEDIATOR (Jarke et al., 1987) or SCDAS (Lewandowski, 1989).

The design of these systems follows a hierarchical approach, which strictly separates the determination of individual opinions and their aggregation at the group level. These two stages are also considered to be distinct steps over time: Individual calculations are carried out first, and aggregation is performed after the individual stage has been completed.

However, in actual group processes there is no such clear-cut distinction between successive steps. In group discussions, individual opinions change in view of opinions presented by other group members. These changes may be caused by additional factual information on decision alternatives obtained through group discussions. Furthermore, members change the way in which they evaluate information and the importance which they give to certain aspects of the problem because of other members' opinions.

These phenomena are widely recognized in the GDSS literature (e.g. Kersten, 1985; Lewandowski et al., 1987). But up to now such feedback effects have rarely been explicitly modelled and supported. This lack of support for an important aspect of real group decision situations might be one reason for the low acceptance of normatively oriented Level 3 systems.

In this paper, we develop a general concept for incorporating feedback effects into group decision support systems. The paper is structured as follows: Section two reviews the importance of feedbacks for group decision situations and approaches to their support in GDSS. Section three develops a general concept for feedback-oriented GDSS, for which a specific example based on reference point optimization is presented in section four. Section five summarizes the development so far and provides an overview of ongoing and future research.

2. The Role of Feedbacks in Group Decision Support

The important influence of (preliminary) group results on individual evaluations is clearly recognized in the group decision support literature, as can be seen from the following quote from Kersten (1985, p.333):

> "It is relatively easy to formulate individual utility function when there are no interactions among D*[ecision]*M*[aker]*s, when each DM seeks a decision which is optimal for him. In such a case the assumption about DM's rational behavior holds. One might think that DM behaves irrationally when working in a group when changing his preferences or objectives. However, in a group DM interacts, learns other people's interests, learns the problem itself and makes concessions. All these may affect his judgments - he may change his objectives and preferences and become interested in other DMs' objectives and in many cases it is rational."

Empirical research has indicated that such feedback effects linking individual behavior to group results play an important role in actual group decision situations. One well known phenomenon in the social psychology literature is the so-called "choice shift" effect (Pruitt, 1971). Groups tend to choose different, especially more risky solutions than their members would choose when facing the same problem alone.

Other studies (e.g. Castore/Murnighan, 1978) have shown that changes in individual opinions induced by group level results also have important consequences for the subsequent behavior of members. Group members whose individual opinions more closely correspond to the final group outcome show stronger support for the decision afterwards, even if close agreement is a result of changes during the group process.

In view of this evidence, it is surprising that feedback effects have rarely been explicitly modelled in GDSS. In most of the Level 3 systems presented so far, a group result is determined based on a normative solution concept and presented to the group members. It is assumed that simply providing this result will cause members to revise their opinions accordingly. Some approaches (e.g. Korhonen et al., 1980; Lewandowski et al., 1987) go one step further and calculate a measure of deviation from the group opinion, which indicates which member should change his or her evaluation most. But no support is provided on how this revision should be carried out.

Feedback processes and changes in individual opinions are, however, taken into account in systems to support negotiations between adversaries. One example is the NEGOPLAN system (Kersten et al., 1987; Matwin et al., 1989; Kersten/Szpakowicz 1990; Kersten et al., 1991). NEGOPLAN is a rule-based system, which uses inference techniques from artificial intelligence to develop bargaining strategies. It contains metarules (called restructuring rules) which allow the goal structure to be changed in response to the opponent's estimated reaction to a proposal. Similarly, the PERSUADER system (Sycara, 1991), which is also based on artificial intelligence techniques, uses rules to perform problem restructuring by removing or adding goals or changing aspiration levels for goals.

While both systems are based on a concept of changing individual preferences, they deal with bargaining situations between hostile opponents. No similar concepts are used in systems to support decision making within cooperative groups, although preference changes are even more likely in these situations.

3. Design of Feedback-Oriented GDSS

3.1. Overview

Figure 1 illustrates how the common hierarchical design of existing Level 3 GDSS can be extended to support feedback effects. The hierarchical design provides one part of the entire feedback loop. Here, information coming from a common database is first processed by an individual evaluation system. The resulting individual evaluations are then aggregated, leading to a group result. In a feedback-oriented approach, these (preliminary) group results re-enter the individual evaluation process through a *modification model* denoted by MM in figure 1.

Following the approaches taken by the systems mentioned earlier (Co-oP, MEDIATOR, SCDAS and similar systems), we suppose that the individual evaluation phase in figure 1 is performed by applying a multi-attribute decision method to the problem to be solved by the group. At this stage of the process, the group member's attitudes towards different aspects of the problem enter into the decision process.

While individual attitudes towards other problem characteristics such as

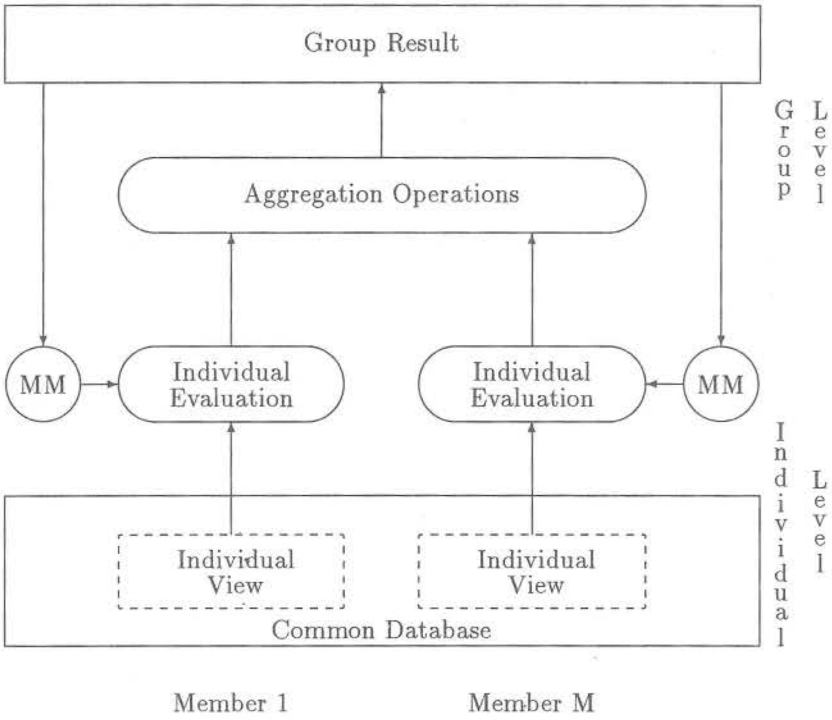

Figure 1. Overall Design of a Feedback-Oriented GDSS

risk or temporal distribution of results are also an important factor in decision processes, we follow the example of most other approaches presented in the literature by considering only multiple attributes. This simplification may be justified by noting that in group decision contexts, many differences in individual opinions will arise from different areas of functional expertise of the group members, which are reflected in their attitudes towards different attributes of the problem. For example, in a new product design problem, marketing representatives, engineers and financial planners will treat attributes such as sales volume, technical performance and investment costs quite differently, if they consider them at all (Jacquet-Lagreze/Shakun, 1988).

In this paper, we will develop a general approach to feedback-oriented group decision support which is independent of the decision-making technique used to obtain individual evaluations. The specific formulation of modification models, which form the linkage of group results to individual decision processes, depends, of course, on the decision technique used. In section four, we will show how such modification can be performed if the members use a reference-point approach. Other models are developed in Vetschera (1991a).

Since we are mainly interested in highlighting specific aspects of feedback-oriented group decision support, we will not discuss aggregation techniques used to generate a group solution from individual evaluations in this paper. The choice of a suitable aggregation technique which is compatible to the individual decision-making techniques is, however, an important step in the actual development of a feedback-oriented group decision support system. In the case of the reference-point method considered in the example of section four, aggregation techniques have been developed e.g. in the work of Bronisz et al. (1989).

3.2. The Role of Modification Models

Modification models are the central component in closing the feedback loop from group level results to individual evaluation systems. In a DSS framework, their function is to support the user (i.e. the individual group member) in performing changes in his/her evaluation system, which will bring his/her own evaluations closer to the (preliminary) group results. This function can be performed in two distinct ways, which correspond to the "what if" and "how to" concepts frequently mentioned in the DSS literature (Jelassi et al., 1987; Roy, 1987).

In the "what if" approach, the user specifies a possible modification of his/her evaluation system and the system subsequently determines whether this modification brings individual and group evaluations closer together at all and if so, to what extent. This approach, however, has several disadvantages for the present problem. First, it requires a method to measure differences between individual and group evaluations. The definition of this measure depends on the form of the group result. For most applications, the group result consists of an ordinal ranking of alternatives. Although several techniques to measure the difference of ordinal rankings have been proposed in the literature (e.g. Cook/Seiford, 1982;

Cook/Kress, 1985) their application for our purpose is problematic. They are often based on axiomatic definitions of "similarity" with which the user need not agree. Those which are not based explicitly on an axiomatic definition nevertheless contain hidden assumptions, which also might not be shared by the user. Even if the assumptions are accepted, interpretation of such measures might pose a problem to users who are not thoroughly familiar with the theoretical concepts involved. Similar criticism can also be raised against difference measures for cardinal evaluations (e.g. Korhonen et al., 1980; Lewandowski et al., 1987).

Another problem of the "what if" approach is the lack of active support in determining modifications of the evaluation system. A user who is willing to change his/her evaluation system sufficiently to achieve agreement with the other group members might not be able to do so because he/she is not able to find the necessary modification.

We therefore propose a method which is based on the "how to" approach. Here the system takes a more active role in the process. The user first specifies the degree of agreement with the group result which he/she would like to achieve by modification of the individual evaluation system. The system then generates one or more change proposals which would lead to the desired degree of agreement. In a decision support framework, the user is not required to actually carry out the proposed modifications in full. It is also possible for the user to implement suggested changes only partially or even not at all and to maintain differences with the group evaluation. But for users willing to modify their evaluation system, the proposals made by the GDSS form a valuable guide-line.

For this form of support, it is also necessary to define a measure for the degree of agreement, which is now pre-specified by the user. However, there are two differences to the previous case. On the one hand, since the user has to specify a degree of agreement in advance, it is even more important that the measure is intuitive and easily understandable. On the other hand, it is not necessary to measure the "distance" between arbitrary evaluations precisely. The measure used must only indicate whether a certain extent of agreement has been achieved. Since the extent is specified by the user, a rough scale containing only a few distinct levels can be used to simplify the user's task.

Agreement between group members must also be seen in the context of the decision problem faced by the group. Many practical decision problems consist in selecting one alternative or in ranking some or all alternatives (Roy, 1980). For all these problems, (partial) agreement on the ordinal ranking of alternatives is sufficient. The measure of agreement used here is therefore defined on ordinal rankings.

As a flexible and simple measure of agreement on ordinal rankings, we propose the concept of c-agreement. Two rankings are in c-agreement, if the first c alternatives in both rankings are the same. By specifying a value for c, the group member can provide an indication of the amount of agreement he/she wants to achieve. This concept is both easily understandable by group members and well suited for the formulation of modification models, as will be shown below.

The modification process of individual evaluation systems therefore consists of three steps: first, the user indicates the degree of agreement which he/she wants to achieve with the group opinion by selecting a value of c. In the next step, the modification model generates one or several possible modifications of the user's evaluation system which would bring about such c-agreement. Finally, the user decides whether he/she is willing to make any of the proposed modifications, partially or fully.

3.3. Forms of Modification

The modification model generates proposed changes to the user's evaluation system which will lead to c-agreement between individual and group evaluations. Before presenting specific model formulations, we introduce a general framework describing what we mean by "modification of an evaluation system".

The member's evaluation system ranks alternatives which are described in several attributes. Specifically, we consider a decision problem of N alternatives $(n = 1, \ldots, N)$, which are evaluated in K attributes $(k = 1, \ldots, K)$. We assume that the evaluation system leads to a cardinal evaluation of alternatives and we represent it by an evaluation function $v(X_n, P)$. Here, X_n is a K-dimensional attribute vector describing alternative n and P is a vector of parameters describing the group member's preferences.

While this representation implies that the group member's preferences are complete and transitive at any given point in time, it is still very general. We do not presume a specific functional form for $v(X_n, P)$ (like an additive utility function with weights P) and we also do not require parameter vector P to be stable over time.

On the contrary, one way to modify the member's evaluation system consists in a change of the parameter vector P to a new vector P'. Since in this kind of modification the group evaluation only implicitly enters the member's evaluation system, it will be called "implicit modification".

The group opinion can also be explicitly considered in the individual evaluation system as an additional attribute. The evaluation function $v(X_n, P)$ is then extended to a function $v'(X_n, P, x_{n,g}, p_g)$. Here $x_{n,g}$ is the group evaluation of alternative n. Since the attribute vector for alternative n is enlarged by one element, the parameter vector is also extended. Element p_g is used to represent the importance given to the group opinion in the same way as the other elements of vector P represent the importance of other attributes.

Both forms of modification have certain advantages and disadvantages. Implicit modification corresponds closely to the intuitive notion of convincing group members, e.g. about the importance of certain aspects of the decision problem. If a group member is being convinced that a particular aspect of the problem has more importance than he/she previously thought, this means that the decision weight for this criterion should be increased.

To implement the concept of implicit modification, a modification model determines a new parameter vector P', which leads to c-agreement between individual and group rankings. Since there might be several such vectors, we will formulate the model to choose a vector P' corresponding to a minimal change in parameters in the sense of some distance function $d(P, P')$.

One problem of implicit modification is that, depending on the method by which the group ranking is determined, it might be impossible to find a parameter vector P' which leads to c-agreement with the group ranking. For example, if group members consider different attributes in their evaluations, the group as a whole might rank an alternative very high which is bad according to all attributes which one particular member takes into account.

This problem does not exist with explicit modification. Explicit modification also has a plausible interpretation. In cooperative groups, members often explicitly take into account what other members think about the decision alternatives. This is especially important in groups where members are experts in different fields and base their evaluations on different attributes. The group opinion can then be seen as a condensed representation of the expertise of other members in those areas with which one is not familiar.

As in implicit modification, the task of the modification model is to determine a minimal change leading to c-agreement between individual and group rankings. The amount of change in explicit modification can conveniently be measured by the parameter p_g, which represents the importance given to the group opinion in the modified evaluation system.

The two forms of implicit and explicit modification are not mutually exclusive. It is possible to change both the evaluation function from $v(X_n, P)$ to $v'(X_n, P, x_{n,g}, p_g)$ and the parameter vector from P to P' simultaneously. From the combination of both forms of change, we obtain a modified evaluation system as $v'(X_n, P', x_{n,g}, p_g)$.

Table 1 summarizes the main properties of the three forms of modification.

	Before modification	Implicit modification	Explicit modification	Combined modification
Evaluation Function	$v(X_n, P)$	$v(X_n, P')$	$v'(X_n, P, x_{n,g}, p_g)$	$v'(X_n, P', x_{n,g}, p_g)$
Preference Parameter	P	P'	P	P'
Number of Attributes	K	K	$K+1$	$K+1$
Measurement of Change	n/a	$d(P, P')$	p_g	both

Table 1. Forms of modification

3.4. Requirements for Modified Evaluation Systems

Both forms of modification result in a change of the member's evaluation system. This change, however, should not be arbitrary but should take into account the group opinion in some systematic way. We therefore formulate two requirements which a modified evaluation system should fulfil.

The first requirement concerns *consistency.* If the member's initial evaluation ranked an alternative better than another alternative and the group as a whole has the same ranking of the two alternatives, then the modified evaluation system should also lead to the same conclusion. Formally, the consistency requirement can be specified as follows:

$$\begin{aligned} &v(X_1,P) \geq v(X_2,P), x_{1,g} \geq x_{2,g} \\ &\quad \Rightarrow v'(X_1,P',x_{1,g},p_g) \geq v'(X_2,P',x_{2,g},p_g) \end{aligned} \tag{1}$$

Even if the group evaluation is treated formally like the other attributes, some multicriteria decision methods do not fulfil the requirement (1). One such example is the Reference Point Method by Wierzbicki (1980) when a scalarizing function of the form

$$v(X_n) = \rho \min_k (x_{n,k} - \overline{x_k}) + \sum_k (x_{n,k} - \overline{x_k}) \tag{2}$$

is used (Vetschera, 1991a).

A second group of requirements concerns the case in which the member's initial evaluation and the group evaluation do not lead to the same ranking of alternatives. In this case, the modification process should lead to the same ranking as the group evaluation if the group evaluation is given sufficient importance and it should agree with the initial evaluation if the group evaluation is given little importance. Furthermore, the switch to the group ranking should occur at a unique threshold of the importance coefficient p_g. For explicit modification, this leads to the following *controllability* condition:

$$\begin{aligned} &v(X_1,P) \geq v(X_2,P), x_{1,g} < x_{2,g}: \\ &\exists \overline{p_g}: \quad p_g \geq \overline{p_g} \Rightarrow v'(X_1,P,x_{1,g},p_g) < v'(X_2,P,x_{2,g},p_g) \\ &\qquad\quad\; p_g < \overline{p_g} \Rightarrow v'(X_2,P,x_{2,g},p_g) \geq v'(X_1,P,x_{1,g},p_g) \end{aligned} \tag{3}$$

This condition ensures that any increase of p_g above the threshold will not cause the modified evaluation system to contradict the group evaluation. This behavior conforms with the intuitive interpretation of p_g as the "importance" given to the group opinion.

For implicit modification, the consistency condition is more complicated since several parameter vectors P' might exist which have the same distance $d(P,P')$ from the original vector P. If the modification is small, any possible change in P should still lead to the member's initial ranking of alternatives. On the other hand, for large changes, one cannot preclude that some modified evaluation systems still lead to the initial ranking. It is only possible to require that for large changes, at least one solution exists which reproduces the group ranking. Formally, the consistency requirement for implicit change can thus be specified as:

$$\begin{array}{l} v(X_1, P) \geq v(X_2, P), x_{1,g} < x_{2,g} : \\ \exists \overline{d} : \ \forall P' \in \{P' : d(P, P') < \overline{d}\} : v'(X_1, P', x_{1,g}, p_g) \geq v'(X_2, P', x_{2,g}, p_g) \\ \qquad \forall d' \geq \overline{d} : \exists P' : d(P, P') = d'; \ v'(X_1, P', x_{1,g}, p_g) < v'(X_2, P', x_{2,g}, p_g) \end{array} \tag{4}$$

3.5. Modification Models and Trade-Off Curves

The task of a modification model is to determine modification proposals which lead to c-agreement with the group ranking while minimizing both the amount of implicit and explicit modification needed. Assuming that alternatives are numbered according to the group ranking (i.e. the group prefers alternative number one to alternative number two and so on) we obtain the following general formulation of a modification model:

$$\begin{array}{ll} \text{minimize} & d(P, P') \\ \text{minimize} & p_g \end{array}$$

$$\begin{array}{rcl} v'(X_1, P', x_{1,g}, p_g) & > & v'(X_2, P', x_{2,g}, p_g) \\ & \vdots & \\ v'(X_{c-1}, P', x_{c-1,g}, p_g) & > & v'(X_c, P', x_{c,g}, p_g) \\ v'(X_c, P', x_{c,g}, p_g) & > & v'(X_{c+1}, P', x_{c+1,g}, p_g) \\ & \vdots & \\ v'(X_c, P', x_{c,g}, p_g) & > & v'(X_N, P', x_{N,g}, p_g) \end{array} \tag{5}$$

The constraints in (5) represent the condition of c-agreement. The first set of constraints ensure the proper ranking of the first c alternatives, while the second set forces the remaining alternatives to be ranked behind alternative number c.

Model (5) is a bi-criterion optimization model. It is therefore possible for the GDSS to determine several proposals for modification on the efficient frontier of the solution set to (5) or to present the entire trade-off curve between implicit and explicit modification to the user.

It can be shown that trade-off curves for lower values of c dominate curves for higher values. Given a modification which leads to an agreement about the ranking of the first c alternatives, it is possible to reach an agreement on a smaller number of alternatives requiring at the most the same amount of implicit and explicit modifications.

The function v' in (5) is used to denote the cardinal evaluation of alternatives resulting from a specific decision-making technique. Depending on the decision-making technique used by group members, additional constraints may be necessary in the modification model, e.g. to maintain an overall scaling of the parameter vector P'. The constraints shown in (5) might also become more complex for specific decision-making techniques. An example for such a model will be provided in the next section.

4. Example

As an example, we will present a modification model for the reference point approach (Wierzbicki, 1980;1986) to multi-attribute decision making. In this approach, the user's preferences are articulated via a reference point of aspiration levels in criteria space. Parameter vector P defined above therefore corresponds to a vector of reference levels, which will be denoted by $\overline{X} = (\overline{x_1}, \dots, \overline{x_K})$.

The basic idea of the reference point approach is compatible with several scalarizing functions $s(X_n, \overline{X})$, which are used to relate performance levels of alternatives to the reference point levels and to aggregate across criteria. The overall evaluation of an alternative is therefore given by its value of the scalarizing function. In this paper, we will use the simple scalarizing function

$$s(X_n, \overline{X}) = \min_k (x_{n,k} - \overline{x_k}) \tag{6}$$

which can be extended to incorporate group evaluations in a way that is compatible with the requirements formulated above.

Implicit modification of this kind of evaluation system is obtained by shifting the reference point to a new point $\overline{X}$. The new reference level in each attribute k can be expressed as the sum of the old value and a positive or negative deviation component for that attribute:

$$\overline{x_k}' = \overline{x_k} + \delta_k^+ - \delta_k^- \tag{7}$$

where δ_k^+ represents the increase of the reference level of attribute k, δ_k^- its decrease, and both δ_k^+ and δ_k^- are non-negative variables. The distance function $d(\overline{X}', \overline{X})$ can now be expressed as an aggregation of the δ_k^+ and δ_k^- over all k. For simplicity, we will use the sum of deviations as a distance function, although other functions can also be used and lead to similar results (Vetschera, 1991a, chapter 5.2).

For explicit modification, scalarizing function (6) has to be extended to take into account the group evaluation as an additional attribute. It is possible to incorporate this additional attribute in the same way as the other attributes. Thus the extended scalarizing function s' becomes:

$$s'(X_n, \overline{X}', x_{n,g}, \overline{x_g}) = \min \left[\min_k (x_{n,k} - \overline{x_k}); (x_{n,g} - \overline{x_g}) \right] \tag{8}$$

where $\overline{x_g}$ is a "group reference level" and $x_{n,g}$ is the group evaluation of alternative n. It can be shown that function (8) fulfils both the consistency and the controllability conditions formulated above and parameter $\overline{x_g}$ is a control parameter as required by the controllability condition.

Assuming again that the alternatives are numbered according to the group ranking, c-agreement is obtained if

$$\begin{array}{rcll} s'(X_n, \overline{X}', x_{n,g}, \overline{x_g}) & > & s'(X_{n+1}, \overline{X}', x_{n+1,g}, \overline{x_g}) & \text{for } n < c \\ s'(X_c, \overline{X}', x_{c,g}, \overline{x_g}) & > & s'(X_n, \overline{X}', x_{n,g}, \overline{x_g}) & \text{for } n > c \end{array} \tag{9}$$

Substituting (8) into (9), we note that these conditions require that the minimum of one set of values be larger than the minimum of another set. They therefore cannot be directly formulated as constraints for most mathematical programming packages, although there are some exceptions as the DNLP (nonlinear programming with discontinuous derivatives) model type in GAMS (Brooke et al., 1989). This class of models, however, can only be solved approximately and only to local optimality.

It is, however, possible to formulate mixed integer programming constraints for these conditions. As an illustration, we will explain in detail the formulation for constraints relating to alternatives n and $n+1$, the other constraints involving alternative number c can be transformed in the same way.

The left hand side of a constraint (9) can be expressed by introducing a new variable z_n, which is less than or equal to the minimum of all values on the left side. Therefore, z_n must be less than or equal to all those values and we obtain a set of constraints:

$$\begin{array}{rcl} z_n & \leq & (x_{n,1} - \overline{x_1'}) \\ & \vdots & \\ z_n & \leq & (x_{n,K} - \overline{x_K'}) \\ z_n & \leq & (x_{n,g} - \overline{x_g}) \end{array} \tag{10}$$

But z_n must only be larger than one of the values on the right hand side of the original constraint, it can be smaller than the other values. This can be achieved by introducing a set of binary variables λ and the following constraints:

$$\begin{array}{l} \left. \begin{array}{rcl} z_n & > & (x_{n+1,1} - \overline{x_1'}) - \lambda_{n,1} M \\ & \vdots & \\ z_n & > & (x_{n+1,K} - \overline{x_K'}) - \lambda_{n,K} M \\ z_n & > & (x_{n+1,g} - \overline{x_g}) - \lambda_{n,g} M \end{array} \right\} \quad (a) \\ K \geq \sum_k \lambda_{n,k} + \lambda_{n,g} \qquad\qquad\qquad\qquad (b) \end{array} \tag{11}$$

where M is a suitably large constant. Part (a) of constraints (11) ensures that z_n is greater than a right hand term of the original constraint if the corresponding λ is equal to zero, but z_n may be smaller if λ is one. Part (b) of the constraint guarantees that at least one λ is zero for each original constraint.

Combining those elements, we obtain the following formulation for a modification model based on the reference point method:

$$
\begin{array}{ll}
\text{minimize} \sum_k \delta_k^+ + \sum_k \delta_k^- & \\
\text{minimize} \, \overline{x_g} & \\
 & \\
\overline{x_k}' = \overline{x_k} + \delta_k^+ - \delta_k^- & \forall k \\
 & \\
z_n \leq (x_{n,k} - \overline{x_k}') & n = 1, \ldots, c-1; \ \forall k \\
z_n \leq (x_{n,g} - \overline{x_g}) & n = 1, \ldots, c-1 \\
 & \\
z_n > (x_{n+1,k} - \overline{x_k}') - \lambda_{n,k} M & n = 1, \ldots, c-1; \ \forall k \\
z_n > (x_{n+1,g} - \overline{x_g}) - \lambda_{n,g} M & n = 1, \ldots, c-1 \\
 & \\
K \geq \sum_k \lambda_{n,k} + \lambda_{n,g} & n = 1, \ldots, c-1 \\
 & \\
z_n \leq (x_{c,k} - \overline{x_k}') & n = c, \ldots, N-1; \ \forall k \\
z_n \leq (x_{c,g} - \overline{x_g}) & n = c, \ldots, N-1 \\
 & \\
z_n > (x_{n+1,k} - \overline{x_k}') - \lambda_{n,k} M & n = c, \ldots, N-1; \ \forall k \\
z_n > (x_{n+1,g} - \overline{x_g}) - \lambda_{n,g} M & n = c, \ldots, N-1 \\
 & \\
K \geq \sum_k \lambda_{n,k} + \lambda_{n,g} & n = c, \ldots, N-1 \\
 & \\
\lambda_{n,k} \in \{0,1\} & n = 1, \ldots, N-1; \ \forall k \\
\lambda_{n,g} \in \{0,1\} & n = 1, \ldots, N-1
\end{array}
\tag{12}
$$

Extensions and numerical examples for such models, heuristics to increase the solution speed and trade-off curves resulting from their solution are presented in (Vetschera, 1991a).

5. Conclusions and Topics of Future Research

In this paper, we have presented a general framework to incorporate and support feedback processes in group decision-making. This general framework was illustrated by a specific model based on the reference point approach. Similar models can be developed for other multi-attribute decision techniques including multi-attribute utility theory and some forms of fuzzy programming (Vetschera, 1991a). Using multi-attribute utility theory as the underlying decision technique, an experimental GDSS has been developed to implement the feedback-oriented approach (Vetschera, 1991b). This experimental implementation will be used in future empirical research on feedback-oriented group decision support.

Beside from this empirical research, the feedback-oriented approach to group decision support presented here is also open to further theoretical developments. One important area of theoretical research concerns extending the range of modification proposals which can be made to the user. The model (5) presented here allows the system to generate different modification proposals on the efficient trade-off curve between implicit and explicit change. Experience gained so far has shown that these proposals tend to be structurally similar in the sense that the same parameters are modified. Techniques like the HSJ-approach (Brill et al., 1982) can be used to generate modification proposals concerning different attributes. The entire problem of changing process parameters can be seen as a multicriteria problem and appropriate (interactive) techniques for solving this problem will eventually be incorporated into the feedback-oriented approach.

Another important topic for further research is the integration of feedback models into global concepts of group decision support and office automation. This integration of formal decision support models into the environment, commonly used by decision makers, is often seen as a crucial factor for gaining user acceptance (Lewandowski, 1988; Nunamaker et al., 1989b). These issues are also being addressed in connection with the further development of current prototype implementation.

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