A Procedure for Negotiating Efficient
and Non-Efficient Compromises

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An interactive procedure for group decision-making problems is presented in this paper. The procedure is based on the aspiration theory and utilizes both satisficing and optimizing approaches. The possibility of decision-makers forming coalitions is taken into account. The outcome of the modelled decision process is a compromise decision which can fulfill fairness and equity criteria. The compromise may also be an efficient solution. The procedure can be the basis for a group decision support system and such a system for a microcomputer network is discussed.

Keywords: Group decision support system, Negotiation support system, Group decision-making, Negotiations, Conflict resolution, Multiple-criteria decision-making, Goal programming, Microcomputer applications.
1. Introduction

The majority of real-world decision-making problems involve many decision-makers (DMs). Therefore, formalized procedures describing group decision-making (GDM) problems are of growing interest. Several interactive procedures, based on multicriteria decision analysis, have been proposed by Freimer and Yu (1976), Isermann (1985), Nakayama et al. (1979) and Wendel (1980). The procedures assume rational behavior on the part of DMs: DMs possess all the information about the decision-making problem, and they are consistent and coherent in the decision process. Thus, the problem lies in the determination of individual, and then group, utility functions. Once these are determined, a compromise decision can be found. The compromise is an efficient (Pareto optimal) solution.

The rational behavior of a DM in individual decision-making has not yet been proved. Tversky and Kahneman (1981), Haines and Ratchford (1983) and Maclean (1985) give examples in which people systematically violate the requirements of consistency and coherence, and which indicate that their preferences may be intransitive.

Decision-making in a social setting, such as GDM, introduces new aspects. DMs can evaluate a decision not only from the point of view of its objective performance levels, but from the point of view of its fairness and equity. DMs who take into account fairness and/or equity may obtain a non-efficient compromise (Kersten, 1985b; Kirkwood, 1979).

In GDM, in contrast to individual decision-making, DMs may incorporate different and varying strategies. Raiffa (1982) presents an example of a DM who incorporated the objectives of another DM to improve her negotiating strategy. He also shows how irrelevant alternatives can influence the chosen compromise. It means that utility functions are non stationary. Fogelman-Soulie et al. (1983) and Schaffers (1985) state that, in real GDM, different standards with respect to rationality arise, in contrast to the normative views of decision-making. Fisher and Ury (1983) argue that DMs do not like to disclose their real interests (objectives). Hence, it may be impossible to determine a group utility function.
All the above aspects of DMs' behavior undermine the traditional, utility-based approach to modelling GDM. The emerging approaches assume nonstationarity of the individual utility functions or replace utility with aspirations. In these approaches the focus changes from determining "the best" compromise (optimal, efficient) with an initial DMs' input, onto support in determining a compromise with iterative and changing DMs' input. This enables DMs to change their goals, preferences and requirements (aspirations). Shakun (1981) proposes to use a dynamic system to conflict resolution in GDM. He assumes that both the decision set and the outcome (goal) set may change during the decision process. While this is the general case, an effective support for such a case leads to difficulties with DMs' control over the decision space. Jarke, Jelassi and Shakun (1987) developed a support system which performs the mediation function for a given and constant decision set.

The approach proposed here is based on the aspiration theory (Tietz and Bartos, 1983) which is a generalization of the satisficing approach proposed by March and Simon (1958). It does not require defining utility functions or ranking of alternatives, and it aims at support of decision process in a group setting and not at solving a group decision problem. This approach allows strategic interaction (Young, 1975), i.e. dependence of individual choices of one DM on choices and perceived interests of other DMs.

2. The group decision problem

We consider here a GDM problem which can be represented in terms of certain functions with known properties. A group of DMs wants to reach consensus in a choice of a decision which is represented as vector $x$, $x \in R^n$. The process of choice is iterative and particular DMs submit their compromise proposals and contr-proposals for group consideration. The decision process is terminated when (i) all DMs agree on one decision - a compromise, (ii) a subgroup of DMs agree on one decision and this subgroup has enough power to implement the chosen decision (e.g. majority-type compromise), or (iii) a group is deadlocked and no decision is chosen.
Kersten and Szapiro (1986) present a framework which can be used in describing different GDM problems. The proposed framework allows for the different behavior of DMs and changes in their strategies, and does not assume the existence of individual and group utility functions. It does not require that a DM discloses his/her onterests to another DM, and also allows a combination of the satisficing and optimizing approaches.

In decision-making, DMs often form aspiration levels to secure their interests or formulate compromise proposals. The latter can also be defined by aspiration levels. DMs may also have their own objectives and want to achieve them on the highest/lowest possible levels. While aspiration levels define acceptable alternatives, objectives allow their comparison.

We assume here that aspiration levels take the form of right-hand sides (RHSs) of constraints which are controlled by DMs. These constraints are called soft constraints because DMs can change (replace) these constraints or only their RHSs when their interests or strategy change.

Group decision-making is a dynamic process. The process begins at the moment \( t = 0 \) when soft constraints, RHSs (aspiration levels) of chosen constraints and/or a compromise proposal are chosen. Then DMs at moments \( t = 1, 2, \ldots \) simultaneously or subsequently reformulate their aspiration levels, compromise proposals and/or search for spheres where mutual agreement is possible. The process ends at \( t = T \) when a compromise is achieved or the group reaches deadlock.

Let us formalize the last statements. Assuming for the sake of simplicity that all possible soft constraints are known a priori, we can define soft constraints for DM \( m \), i.e.,

\[
g_{im}(x) \geq a_{im}(t), \quad i \in I_m; \quad m \in M; \quad t = 0, \ldots, T-1
\]  

(1)

where \( a_{im}(t) \in R \) is the aspiration level defined by DM \( m \) at the moment \( t \), \( I_m \) is the set of soft constraints indices of DM \( m \) and \( M \) is the index set of DMs. Function \( g_{im}(.) \) transforms the alternative's characteristics into the aspiration value \( (g: R^n \rightarrow R) \).

Some or all left-hand sides (LHSs) of (1) may describe DM \( m \) objectives, so we can consider them as objective functions; at the moment \( t \) set \( J_m(t) \) (\( J_m(t) \subset I_m \)) is the set of indices of objectives chosen by DM \( m \). For simplicity's sake, we assume here that DMs want to achieve their objectives
on the highest possible levels, and the vector of the aspiration levels \( \mathbf{a}_m(t) = [a_{im}(t)] \) of DM \( m \) describes the lower bounds of vector function \( \mathbf{g}_m(.) = [g_{im}(.)] \).

GDM is always conducted in a given setting, and DMs are assumed to have no influence on it. The setting is described by hard constraints. Alternative \( \mathbf{x} \) is feasible if it satisfies the set of hard constraints,

\[
X = \{ \mathbf{x} : \mathbf{h} \mathbf{(x)} = \mathbf{0} \}
\]  

(2)

where \( X \subseteq \mathbb{R}^n \), \( \mathbf{h} \) is the vector function, \( \mathbf{h}: \mathbb{R}^n \to \mathbb{R}^k \), and \( \mathbf{0} \) is the null \( k \)-vector.

An alternative which is feasible and acceptable to DM \( m \) is called an \( m \)-feasible alternative. The set of \( m \)-feasible alternatives is

\[
X_m(t) = \{ \mathbf{x} : \mathbf{x} \in X \cap \mathbf{g}_m(\mathbf{x}) \geq \mathbf{a}_m(t) \}.
\]  

(3)

The compromise decision is an alternative which is \( m \)-feasible for every \( m \in M \). Thus, the intersection of \( m \)-feasible sets

\[
X(t) = \bigcap_{m \in M} X_m(t)
\]  

(4)

is the compromise set also called the set of \( M \)-feasible alternatives at the moment \( t \). Depending on the aspiration levels defined by DMs, \( X(t) \) can be an empty or a non-empty set. The two cases are presented in Fig 1. The soft constraints of DM 1, DM 2 and DM 3 are respectively \( s_1 \), \( s_2 \) and \( s_3 \). In Fig. 1a the \( M \)-feasible set is empty. Changes of the soft constraints of the three DMs lead to non-empty \( M \)-feasible set, as indicated in Fig. 1b.

FIG. 1. (ABOUT HERE)

Usually DMs define such aspiration levels at the beginning of the decision process in which the \( M \)-feasible set is empty. In this case they decrease some or all of their aspiration levels to expand the \( m \)-feasible sets. Expansion of the sets does not mean that some alternatives may not be dropped. However, new alternatives have to be added, so that eventually the expansion process
leads to a non-empty $M$-feasible set. The expansion process is presented in Fig. 2a. DM 1 added new alternatives to his/her feasible set. DM 2, through redefining the aspiration level, dropped some old alternatives and added new ones; DM 3 did not change his/her feasible set.

**FIG. 2. (ABOUT HERE)**

When the $M$-feasible set is non-empty, the negotiating problem is to choose one element from it. Faced with this choice, DMs will increase their aspiration levels to contract the compromise set to a single point. By *contraction* we mean here the dropping of some alternatives in the $M$-feasible set. Addition of new alternatives is also possible, but repeated contraction leads to a one-element set - a compromise. The contraction is presented in Fig. 2b. Comparing the $M$-feasible sets in Fig. 1b and in Fig. 2b we can see that some new alternatives have been added and some old ones dropped. This was caused by changes in the aspiration levels introduced by DM 2 and DM 3.

From the above, it is clear that the GDM process is an iterative process of changes in aspiration levels aimed at achieving a compromise or a deadlock. The process is controlled by DMs and changes in aspiration levels reflect the DMs' attitudes to maximizing objective performance levels, their understanding of fairness and equity, their applied strategy and their evaluation of unused resources for a given alternative. One should note here that if DMs take into account only objective performance levels the utility approach is appropriate.

### 3. The interactive procedure

GDM can be considered as a two-stage process. In the first stage (for $t = 0$) one or more DMs formulate a *compromise proposal*, i.e., an alternative which he/she considers a possible compromise. Since this is an individual decision by a DM, we do not consider this stage here. A DM may use any procedure in individual decision-making.
In the second stage of the process DMs interact, make concessions and try to reach consensus. For this stage we present the procedure in a step-by-step manner; the procedure describes GDM problems but in this section we do not consider its applications, i.e., we do not consider its computational complexity. If the procedure is to be used to design a group decision support system (GDSS), as we propose in Section 4, it is necessary to specify the properties of the functions and algorithms for solving problems formulated in the particular steps. We assume here that the formulated problems can be solved.

We assume that (i) during the first stage DMs learn about the problem, identify some "optimal" alternatives and the initial aspiration levels, (ii) DMs exchange information on aspiration levels and/or compromise proposals, and (iii) a DM may not want to share information about his/her objectives with others, about aspiration levels of all or some of the soft constraints and about the soft constraints in themselves.

The outcome of the first stage is set $N(0)$ of DMs who have defined aspiration levels in this stage and sets $X_m(0) \neq \emptyset$, $m \in N(0)$ of $m$-feasible alternatives.

**Step 1.** Let $t$ be the iterations index and set $t = 1$.

**Step 2.**
If $|N(t)| = 1$ (where $|N(t)|$ is the number of DMs who at least once have defined aspiration levels in iterations 0, 1,..., $t-1$) then the one determined proposal is presented to DMs.

If $|N(t)| \geq 2$ solving goal programming (GP) problem

$$\min f(t) = \exists \sum_{m \in N(t)} L(g_m(x), a_m(t))$$

s.t.

$$x \in X,$$

where $L(.,.)$ is a distance function

check if $\exists X_m(t) \neq \emptyset$.

Let $(f^*(t), x^*(t))$ be the optimal solution of (5). The alternative $x^*(t)$ fulfils "as closely as possible" the aspiration levels of all those DMs who have defined them in iteration $t$. We call the al-
alternative an \(N(t)\)-compromise proposal. \(f\) is the measure of "distance" between the present state of GDM and consensus for \(|N(t)|\) DMs.

If \(f^*(t) = 0\) and \(|N(t)| = |M|\) the group has reached consensus. In the last case go to Step 13.

**Step 3.** Formulate and solve \(|N(t)|\) GP problems

\[
\min f_m(t) = L(\mathbf{x}, x^*(t))
\]

s.t. \(g_m(\mathbf{x}) \leq a_m(t), \quad (6)\)

\(x \in X,\)

where \(L(., .)\) is a distance function.

Let \((f^*_m(t), x^*_m(t))\) be the optimal solution of (6). The alternative \(x^*_m(t)\) is as "close as possible" to the \(N(t)\)-compromise proposal. \(f^*_m(t)\) is the measure of distance between the \(N(t)\)-compromise proposal and the \(m\)-acceptable alternative.

**Step 4.** Present the actual state of GDM described by \(a_m(t), x^*_m(t)\) and \(x^*(t)\), \(m \in N(t)\) to all the DMs and ask them to define/redefine their aspiration levels. Let \(N'(t+1)\) be the set of DMs who want to define/redefine their aspiration levels. If \(N'(t+1) = \emptyset\) the process has reached deadlock because there is no DM who wants to present a new compromise proposal. If this is the case DMs have to choose as a compromise one of the previously determined alternatives, redefine the set of hard constraints, or break the decision process. **End.**

**Step 5.** Set \(t = t + 1\) and update set \(N(t); N(t) = N(t-1) \Delta (N'(t) - N(t-1))\).

**Step 6.** Ask DM \(m\) \((m \in N'(t))\) if he/she wants to consider the possibility of forming a coalition with the others. If not, go to Step 8.

**Step 7.** For DM \(m\) \((m \not\in N'(t))\) solve GP problem

\[
\min \sum_{n \in N(t)/m} I v_n
\]

s.t. \(g_m(\mathbf{x}) \geq a_m(t), \quad (7)\)

\(g_n(\mathbf{x}) - v_n = a_n(t), \quad n \not\in N(t)/m\)
\[ x \in X, \]

where \( I \) is \( |J_m| \)-vector in which all elements equal 1.

Present to DM \( m \) values \((Iv_n^*) (n \in N(t)/m)\), where \( v_n^* \) is part of the optimal solution of (7). If DM \( m \) wants to form a coalition with one or more DMs from \( N(t) \), present to him/her those aspiration levels which should be changed in order to decrease the distance from his/her \( m \)-feasible set to the feasible sets of the chosen DMs. One can use here the optimal simplex tableau of (7).

**Step 8.** DM \( m \) \((m \in N'(t))\) is asked to (i) set aspiration levels \( a_m(t) \), (ii) define a set of objectives \( J_m(t) \) and, optionally, (iii) set preferences (weights) \( w_i(t), i \in J_m(t) \), with regard to the objectives.

**Step 9.** For DM \( m \) \((m \in N'(t))\) formulate and solve GP problem. If DM \( m \) does not specify his/her objectives the problem differs from (6) in replacing \( x^*(t) \) with \( x^*(t-1) \) in the objective function. Otherwise solve the GP problem

\[
\min f_m(t) = \{P_1 L(x, x^*(t-1)) - P_2 \sum_{i \in J_m(t)} w_i(t) g_i(x)\}
\]

s.t. \[ g_m(x) \geq a_m(t) \]

\[ x \in X, \]

where \( P_1 >> P_2 \).

The optimal solution \( f^*_m(t), x^*_m(t) \) is \( m \)-feasible and "as close as possible" to the compromise proposal. If there are more such solutions, the one that meets DM \( m \) objectives on the highest levels is chosen.

We assume here that DM \( m \) formulates aspiration levels which it is feasible to achieve. However, it is possible to remove this assumption and accordingly modify problem (8).

**Step 10.** Present DM \( m \) with \( f^*_m(t), x^*_m(t) \) and ask if he/she wants to redefine his/her aspiration levels. If the answer is yes, return to Step 6.

**Step 11.** Calculate the coefficients of changes in the group and the individual distance from the compromise proposal,
d(t) = f^*(t-1) / f^*(t-2)

and for m: \( f_m^*(t-1) \neq 0, \)

\[ DM(t) = f_m^*(t) / f_m^*(t-1), \quad m \in M. \]

Coefficient \( d(t) \) describes the effects of concessions made by the group in two consecutive iterations. Coefficient \( DM(t) \) describes the change in the DM \( m \) position caused by his/her concessions and/or by the concessions of others in two consecutive iterations. When \( DM(t) > (<) 1 \) DM \( m \) has increased (decreased) his/her relative distance from the compromise. One should note that the coefficient describes the distance in relation to the current state of the GDM process. Thus, it may happen that DM \( m \) made effective concessions with regard to a previous compromise proposal but the others made such concessions that the \( DM(t) > DM(t-1) \). It may also happen that DM \( m \) did not change his/her aspiration levels in iteration \( t-1 \) but, because of the changes made by others, his/her position improved, i.e., \( DM(t) < DM(t-1) \).

**Step 12.** Present coefficients \( d(t) \) and \( DM(t), m \in M \) to all DMs and go to Step 2.

**Step 13.** The group has reached consensus; a non-empty \( M \)-feasible set has been determined. If the set has more than one element the procedure can be continued or any solution from the set can be chosen. The latter seems reasonable when an \( M \)-feasible set has no alternatives which DMs evaluate differently. To check if this is the case, we may solve an optimization problem for each DM - a problem with the objective function determined by the DM's objectives and with an \( M \)-feasible set as the set of feasible solutions.

If DMs evaluate optimal solutions of the outlined problems and do not agree on a compromise the decision process is continued, but now DMs are asked to increase their aspiration levels. This should lead to contraction of the \( M \)-feasible set until a set of compromise alternatives which are acceptable to DMs is found.

**Remark 1.** If, in the step 2, \( f^*(t) = 0 \), i.e., the intersection of sets \( X_m \ (m \in N(t)) \) is non-empty, \( |N(t)| \) DMs have reached consensus. They may form a coalition and from now on act as one DM. Inclusion of the process of forming a coalition in the procedure requires updating of the set \( M \), and
incorporating, in the objective function (5), weights reflecting coalition's size. To simplify the notation we may assume, that the coalition members choose in the consecutive iterations the same soft constraints and input the same RHS values. Thus, the power of the coalition, measured by its influence on the \( M \)-compromise proposal determined in (5), is defined by its size. A DM leaves coalition when his/her compromise proposal (determined in (6)) is different then proposals of other coalition members.

**Remark 2.** It is assumed that DMs may also use other information than the one obtained from the procedure. They may communicate with other means than these given in step 4, e.g. in forming a coalition DMs may define a common strategy choosing soft constraints and aspiration levels for several consecutive iterations.

**Remark 3.** The procedure can be used for GDM with a compromise determined by a given number of DMs (e.g. a majority). If this is a case, we have to verify in Steps 2 and 7 if there is a sufficient number of DMs who reached consensus and according to it we choose the alternative they accept as the compromise or continue the process.

**4. Group decision support**

The procedure described in Section 3 can be used in designing a GDSS. Depending on the available software for solving optimization problems a system can be developed for certain GDM problems. We took a similar approach in the development of the system NEGO (Kersten, 1985a and 1985b). NEGO was designed for a mainframe computer IBM 370/148. Experiments with NEGO and its verification in solving real-life problems showed shortcomings which provided feedback for the proposed procedure. We consider the procedure more flexible and open than the one NEGO is based on. It makes it possible to support problems with a discrete set of alternatives, assists in forming coalitions and gives additional information with regard to DMs' relative positions. The procedure does not require DMs to unveil their objectives, and contrary to NEGO, it allows independent calculations for each DM separately. DMs may formulate their proposals simul-
taneously, as in NEGO, but they can also formulate proposals subsequently, one after another, or subgroup after subgroup, either in a predetermined order or not. Thus, the procedure makes it possible to design a distributed GDSS.

The distributed GDSS called Group Decision Support 1 (GDS1), based on the procedure for a network of microcomputers, has been developed. The simplest case, i.e., when all functions are linear or can be represented as linear, is considered. Discrete and quadratic programming problems will be included in the future.

The configuration of GDS1 is presented in Fig. 3. The system is designed to work on several IBM-compatible microcomputers in a network, with one micro serving all the others. This micro may be considered as a service machine; it serves the micros used by DMs.

![FIG. 3. (ABOUT HERE)](image)

The database describing the decision problem (e.g., hard constraints and some or all soft constraints) is set up on this micro, as well as all the programs of the procedure. Programs containing algorithms used for solving individual decision problems are set up on micros used by DMs. The database contains information available to all DMs. Thus, if required, it is downloaded to the machines used by individual DMs and these machines may be used in a stand-alone mode. The machine is used in this mode when a DM wants to analyse the possible outcomes of changes in the soft constraints. This can be done in any iteration of the decision process. Once he/she accepts an alternative, the information which was used to determine this alternative (soft constraints, weights) is send to the service machine and used to create and solve problems (5) and (7). The optimal solutions are send back to the individual machines and problems (6) and (8) are created and solved.

The information used to determine a compromise proposal of DM $m$ is not available to others. Other DMs obtain compromise proposal of DM $m$ in terms of their soft constraints together with the values of decision variables $x$. 
DMs use the integrated spreadsheet package LOTUS 1-2-3 as the interface with programs solving individual decision problems and with the programs residing in the service machine (written in Microsoft QuickBasic 2.0). LOTUS 1-2-3 is also the interface with a graphical input/output program. Part of the information sent by the service machine to DMs is also input into the worksheet. The worksheet is used as a "window" environment; it is divided into parts which can be accessed from the customized LOTUS 1-2-3 menu. One part of the worksheet is used for hard constraints description, another for soft constraints. If the user wants to determine $m$-feasible alternatives, or alternatives which are as close as possible to his/her aspiration levels, he/she uses a part of the worksheet which is restricted to individual decision-making. All the compromise proposals are inputed to the still another part of the worksheet. Also, the history of the decision process (individual and group) is recorded in the worksheet.

Other information, like DMs' comments, proposals for forming coalitions, requests for concessions, etc., may be sent directly to the user with the help of a communication package. GDS1 is used on the IBM Token Ring Network and DMs may use the IBM TRN Message System to pass information which is not included in the GDS1 (e.g. comments, suggestions, remarks). The outline of the system is given in Fig. 4.

**FIG. 4. (ABOUT HERE)**

Fig. 4 shows the system's modules which are set up in the user's machine, the system's input and output and the modules set up in the service machine. This machine can be used by the group "facilitator" who controls and coordinates the whole decision process, or by a mediator. Such a user can be supported by LOTUS in a similar way as can DMs. He/she can also have the prerogative to ask particular DMs to define their aspiration levels and to make concessions.

5. **An example**
GDS1 was tested and experimentally used in simulation of negotiations between management and trade unions. The example was adapted from the problem of managerial compensation planning (Steuer, 1986, pp. 504-513). While Steuer considers an individual decision problem with one DM having many objectives, we discuss a problem with two DMs having one or more objectives or aspirations.

The negotiating problem involves the determination of an average increase in salaries for four groups of unionized employees and for two groups of management; each group belongs to a different job class. The management is interested in

(i) changing the structure of salaries for both unionized and non-unionized employees, so that it will reflect relative job worth this is described by a soft constraint

6. Comments

We have presented here an approach to designing group decision support procedures and systems. It seems that the approach can facilitate GDM problems, which can be described in terms of hard constraints, and when DMs can define their soft constraints. It does not decrease DMs' freedom of choice and it does not require one constant strategy.

According to the aspiration theory DMs make decisions using aspiration levels. This activity is modelled in the procedure. Moreover, the procedure allows incorporation of objectives, if DMs can formulate them. It is also possible to use utility functions when known, or to add a module for calculating individual and group utility functions. The flexibility of the approach lies in its ability to allow different DMs to use the procedure. Some may agree on the utility approach and try to reach consensus using it; others may negotiate through aspiration levels only. The compromise can be an efficient decision but it can also be a non-efficient one. This depends on the DMs' behavior and their strategies.

Huber (1984) states that the existing GDSS were designed by task-driven or technique-driven strategies. We believe GDS1 is an example of an activity-driven design strategy. We considered
DMs' activities in GDM and tried to develop a procedure which would describe these activities. The assumption was that the system should not require other information than that used in real life, but should provide users with new information. Therefore we proposed to calculate coefficients \( r(t) \) and \( r_m(t) \).

For similar reasons we use a spreadsheet package as the interface. The spreadsheet contains not only an optimal solution, but the optimization model and dual variables as well. Hence the user can manipulate the values of the decision variables (alternative characteristics). This should help him/her in making decisions with regard to aspiration levels. Integrated packages, such as LOTUS 1-2-3, are well known and this may facilitate the use of the system. The package is able to store the history of the decision process (alternatives, coefficients) and the user can consider this in decision-making. Since users work independently and the presence of a facilitator or a mediator is not required, familiarity with the interface seems to be important.

References


