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INTERACTIVE DECISION SUPPORT SYSTEMS - THE CASE OF DISCRETE ALTERNATIVES FOR COMMITTEE DECISION MAKING

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Foreword

One of the important problem in decision analysis relates to the situation, where the committee (group of decision makers) has to select the best alternative from a given, finite set. In most cases, the alternatives are evaluated on the basis of several quality factors. In the paper, the authors present the concept of decision support systems in the context of such a decision situation and discuss several issues relating to the computer implementation of group decision support systems. The presented approach is based on the theory of aspiration-led decision making and the satisfactory principle, which ensures proper structuralization of the decision process and allows proper balance of opinion between the group members.

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1. INTRODUCTION

Decision making is one of the most complicated forms of managers or designers activity (since engineering design can be also interpreted in a decision-making context). The following elements of the decision making process should be stressed here:

- successful decisions require obviously rather high level of knowledge about the problem being analyzed and, while master experts in a given field can intuitively or holistically, see Dreyfus (1984), arrive at the best decisions, there are still many situations in which aggregating opinions of a committee and using decision support systems might improve the quality of decisions;

- the effects of possible decisions on their outcomes (called also quality factors, attributes, objective outcomes) must be implicitly or explicitly predicted by the decision maker; this might be a rather difficult task, especially if the quality of the decision can be characterized by many attributes or objective outcomes;

- any decision making process is characterized by a certain level of uncertainty and this uncertainty must be taken into account when making decisions; committee decision making might represent some of the ways of coping with uncertainty;

- complex structural and logical relationships might exist between the elements - alternative decisions, their attributes or quality criteria - of the decision problem being analyzed;

- a decision making process is in fact an information processing task; therefore the decision maker must often handle large quantities of information of various nature and usually of poor quality.

Due to the facts listed above, a decision making process requires certain amount of time and resources; except for the cases of expert decision makers making repetitive decisions, the decisions made might frequently be far from optimal, or even satisfactory. Usually, the complexity of a decision making process does not allow to analyze all possible options and only a small subset can be effectively analyzed. Because of the lack of a priori knowledge and the presence of uncertainty, it can often happen that potentially good decisions are rejected on a very early stage of the decision process. The informational and logical aspects of decision making imply that a computer with its ability of handling and processing large amounts of information and analyzing complex logical relations could be a proper tool to support this activity.

The concept of a *decision support system* (DSS) became rather popular during recent years. There are many commonly accepted definitions of a decision support system. All these definitions agree that such a system must aid a decision maker in solving unstructured (or badly structured, semistructured), complex problems. However, many other aspects of these definitions are still unresolved.

One of such aspects is the relation of this concept to other fields such as operations research (OR) and management science (MS), especially to management information systems (MIS). A deeper discussion of this issue was recently given by Parker and Al-Utabi (1986). The authors reviewed about 350 papers related to this subject while trying to find the most appropriate characterization of the concept of decision support systems. The following set of characteristics was defined by the authors:

A DSS should:

- assist managers in their decision processes for semistructured tasks,

- support and enhance rather than replace managerial judgment,

- improve the effectiveness of decision making rather than the efficiency of decisions,

- combine the use of models or analytical techniques with traditional data access and retrieval functions,

- focus on features which make them easy to use in interactive mode by nonspecialists in computer science,

- emphasize flexibility and adaptability to accommodate changes in the environment or even in the decision making approach of the user.

Following the same source, we should consider a characterization of the decision process formulated by Simon (1958). According to his definition, a decision process consists of the following three steps:

- *Intelligence*: searching the environment for opportunities calling for a decision,

- *Design*: defining the decision situation, inventing, developing and analyzing possible courses of action,

- *Choice*: selecting a particular course of action from those available.

When applying the above characterization, it is possible to conclude that management information systems have made major contributions to the phase of intelligence, while management science and operational research have been useful mostly for the phase of choice. The design phase could be the field of the primary contributions of decision support systems; however, it must be stressed that for multiobjective and multiactor decision situations, the classical approaches of management science and operational research are insufficient also for the phase of choice and many decision support systems concentrate on this phase for such situations. It should be also pointed out that the design phase might be performed when using a management information system, but it starts then from the data available in the system and moves upwards to the decision maker. When using a decision support system, the design phase starts with the problem to be solved and and works down while the computer selects some appropriate subsets of data and information stored in the system and necessary to find a solution.

Other aspects of the concept of decision support systems were discussed by Keen and Scott-Morton (1978). According to them, the main area of impact of DSS is related to such decision problems, in which ".. *there is sufficient structure for computer and analytic aids to be of value, but where managers judgment is essential*". The main payoff to organization caused by application of DSS is "... *extending the range and capacity of manager's decision process to help them to improve their effectiveness*". Finally, the main relevance for managers in decision making process was specified as "*creation of supportive tools, under their own control, which does not attempt to automate the decision process, predefine objectives or impose solutions*".

The last statement deserves special attention: there exists certainly an area of human creativity directed toward automating decisions, such as in automatic control of various industrial or other processes. This, however, concerns repetitive decisions that must be made speedily and precisely, while they might be either bothering or made in a dangerous environment for humans. On the other hand, there is a vast area of decision situations in which human insight is indispensable. In such situations, the role of a decision support system is to provide support; the human is still the most important element of the decision process and the final decision is in his hands. The main purpose of the DSS in such situations is to increase the understanding of the decision problem through a support in the analysis of possible consequences of decisions to be made; other purposes might be a simplification of the access to information and knowledge necessary to find a satisfactory solution, as well as a support in filling out the details of a tentative decision once the main direction of the decision is specified by the human decision maker.

Other discussions related to methodological and organizational aspects of DSS were also published by Naylor (1982), Watson and Hill (1983), Vazsonyi (1982) and Wynne (1982). While similar to the characterizations of DSS presented above, the conclusions from these papers can be summarized as follows:

- Decision support systems allow for the *introduction of judgment*, while traditional approaches of operations research or management science are *normative or prescriptive*;

- Decision support systems deal with *unstructured or semistructured problems*, while traditional approaches of operation research and management science apply mostly to *structured problems*;

- Traditional approaches of operations research and management science provide usually *normative solutions* or *prescriptive recommendations*, while decision support systems provide at most *tentative solutions*;

- Unlike traditional approaches of operations research and management science, decision support systems *do not make an attempt to replace decision makers*, but *to support them*; hence DSS is a mind supporting device.

Another deep analysis of various organizational and methodological aspects of DSS was published by Sage (1981). This analysis reviews the concept of DSS from the point of view of various disciplines - including psychology, organizational behavior and design, information science, management science and computer science. The basis for this investigation is a critical review of over 400 publications related to decision support systems.

More recent developments, however, added new issues to the discussions about the concept of decision support systems. While the conclusions presented above remain valid, both management information systems and operations research (or even mathematical programming) have moved quite far into the field of decision support. The bottom up move, from management information systems, included the development of logical programming languages that result in the incorporation of data bases with knowledge bases, expert systems, other tools of artificial intelligence into decision support. The top down move, from mathematical programming and operations research, was based on interactive techniques of mathematical programming, multiobjective optimization and game theory that can be incorporated into decision support to provide for more powerful tools for alternative generation and evaluation and for supporting negotiations in collective decision processes. Although these two trends are beginning to meet in the middle thus resulting in new generations of decision support systems, we can still use today the following classification of DSS:

- A) *simple tools of managerial decision support* (that might be used also as building blocks of more sophisticated decision support systems) such as modern data bases, electronic spreadsheet systems, etc.;

- B) *logical base decision support systems* whose main functions relate to help in recognizing logical patterns in a decision situation; these systems might involve the use of expert system style programming, knowledge bases, other tools of artificial intelligence;

- C) *alternative generation and evaluation systems* whose main functions concentrate on the process of choice among various decision alternatives either specified a priori or generated with help of the system; such systems might include issues of planning, collective decision processes or even negotiations between many decision makers, and more advanced systems of this type might involve considerable use of mathematical programming techniques, such as optimization, game theory, decision theory, dynamic systems theory, etc.

In the last category, the mathematical programming techniques cannot be used as devices for proposing normative or prescriptive solutions; they can be only considered as tools for simplifying information complexity and for interactively generating tentative solutions in response to decision makers requirements. Such interpretation of modern mathematical programming techniques is, however, possible due to advances in multiobjective optimization and other techniques that admit multi-valued solutions together with some selection principles guided by the decision maker.

In both categories B) and C), a decision support system includes a *model of the decision situation* which might have various forms - a logical form for the systems of category B), but also for some simpler systems of category C), a mathematical programming form of various classes - linear, nonlinear, dynamic programming, various classes of game theoretical models, etc. More important, perhaps, is the role of the model in the decision process. Simple models might just describe the logic of a decision situation, more complicated models might be directly or indirectly used for alternative generation, some parts of models (provided they have not too normative character) might be also useful in alternative selection. Some authors - see Van Hee (1986) - require that a decision support system worth this name must include a model of the decision situation. While this is an important characterization of DSS, we should stress that the very concept of a model might be not sufficiently precise - see Wierzbicki (1984a) - to insist on this requirement; for example, some electronic spreadsheet formulae or even an interpretation of variables in the spreadsheet might already define a model of a decision situation. With the reservation that the concept of a model might require further specification, we shall concentrate however on decision support systems that contain a model of the decision situation.

There might be many other classifications of decision support systems:

- systems that concentrate on the selection and choice between a number of *discrete alternatives* versus systems that admit a *continuum of alternatives* and help to generate interesting or favorable alternatives among them;

- systems that are especially designed to be used by a *single user* or decision maker, versus systems that are designed to help *multiple users* or decision makers simultaneously;

- systems that support *operational decision making and planning* of repetitive type, where the role of the system is mostly filling out details for decisions intuitively selected by the user, versus systems that support *strategic decision making and planning,* confronting essentially novel situations, where the role of the system is mostly supporting learning and intuition formation by the user through the generation of various alternatives following general instructions of the user;

- *specialized decision support systems* designed to help in a very specific decision situation versus *adaptable decision support system shells* that can be modified and adapted to specific cases in a broader class of decision situations;

- systems that assume (explicitly or implicitly) a specific *framework of rationality* of decisions followed by the user versus systems that try to accommodate a broader class of perceptions of rationality.

The presented taxonomy of possible aspects of Decision Support Systems can be considered as tentative and far from being complete. It should be mentioned hovewer, that until now a uniform characterization of various aspects of theory and methodology of

Decision Support Systems does not exist - mostly due to insufficient experimental material which could be used as a background for such an analysis. When reviewing the existing literature, it is easy to conclude that all these definitions are biased by the knowledge, interests and experiences of the researcher developing a particular approach or methodology - depending on the fact wheteher this person is a specialist in data bases techniques, utility theory, optimization or operations research - see the concept of *Decision Support Schools* by Stabel (1986). An interesting analysis of such biases have been presented also by Ginzberg and Stohr (1982).

2. THE QUASISATISFICING DECISION FRAMEWORK

Since it might be argued that the designer of a decision support system should not impose on potential users his own perception of what is a rational decision, see Wierzbicki (1984), an important issue is a sufficiently broad framework for decision making that would include many possible perceptions of rationality. Following Dreyfus (1984) we should first distinguish between *calculative or analytical rationality* versus *deliberative or holistic rationality*. An expert in decision making in a given field does not need calculations of consequences of possible decisions - except in essentially novel situations, where he might need analytical support for learning about novel strategic factors. A novice in decision making in a field must use calculations until he becomes an expert. In either case, decision support systems are useful for supporting the learning by the decision maker, not for replacing the decision maker in actual decisions. The reasoning and experimental evidence given by Dreyfus explain best why we stress the word *support* when speaking about DSS.

Even if we necessarily apply logical or calculative means when constructing a decision support system, we should not try to impose a specific understanding of calculative rationality on the user. There are several frameworks for analytical rationality; we can represent them best when assuming a certain mathematical structure of the decision situation. Such a structure might consist of:

- a space of decisions (alternatives, options, controls, designs etc.) denoted by E_x; if this space is a discrete set, we speak about discrete alternatives,

- a constraint set of admissible decisions $X_o \subset E_x$,

- a space of outcomes (attributes, objective outcomes, objectives, performance indices, etc.) denoted by E_y,

- an outcome mapping $f : E_x \rightarrow E_y$, which also defines the set of attainable outcomes $Y_o = f(x_o) \subset E_y$; this mapping might be given explicitly by a *substantive model of the decision situation* or be supplied judgmentally by experts evaluating alternatives along various attributes, in which case we have *judgmental model evaluation,*

- a partial preordering in the space of outcomes that is usually implied by the decision problem and usually has some obvious interpretation, such as maximization of profit competing with the maximization of market share, etc.; a standard assumption is that this preordering is *transitive* and can be expressed by a *positive cone* $D \subset E_x$.

- a complete preordering in the space of outcomes or, at least, in the set of attainable outcomes, which is usually not given in any precise mathematical form, but is contained in the mind of the decision maker, such as how actually the preferences between the maximization of profit and the maximization of market share should be distributed in the above example.

The main differences between various frameworks of rationality that lead to diverse approaches to interactive decision support are concerned with the assumptions about this complete preordering and the way of its utilization in the DSS. This issue is also closely related with the way in which the DSS interacts with the decision maker; some variants of DSS require that the user answers enough questions for an adequate estimation of this complete preordering, some other variants need only general assumptions about the preordering, still other variants admit a broad interpretation of this preordering and diverse frameworks of rationality that might be followed by the user.

The most strongly established rationality framework is based on the assumption of *maximization of a value function or an utility function*. Under rather general assumptions, the complete preordering that represents the preferences of the decision maker can be represented by an utility function u: $E_y \rightarrow R^1$ or u: $E_x \rightarrow R^1$ such that by maximizing this function over $x \in X_o$ we can select the decision which is most preferable to the decision maker; the publications related to this framework are very numerous, but for a constructive review see, for example, Keeney and Raiffa (1976).

There are many fundamental and technical difficulties related to the identification of such utility function. Leaving aside various technical difficulties, we should stress the fundamental ones. Firstly, a continuous utility function exists if there is no strict hierarchy of values between decision outcomes, if all decision outcomes can be aggregated into one value - say, of monetary nature; this does not mean that hierarchically higher ethical considerations cannot be incorporated in this framework, but that they must be treated as constraints, cannot be evaluated in the decision process. Thus, the utility maximization framework represents *the culture of an entrepreneur facing an infinite market* which, although it represents the behavior of many human decision makers, is by no means the universal case of human rationality - see, for example, Rappoport (1984). Secondly, while the utility maximization framework might be a good predictor of mass economic phenomena, *it has many drawbacks as a predictor of individual behavior* - see, for example, Fisher (1979), Erlandson (1981), Horsky and Rao (1984). According to the results of research presented in these papers, the utility function approach can be used in a rather simple, laboratory environment, but can fail in more complex situations.

Thirdly - and most importantly for applications in decision support systems - an experimental identification and estimation of an utility function requires many questions and answers in the interaction with the decision maker. Users of decision support systems are typically not prepared to answer that many questions, for several reasons. They do not like to waste too much time and they do not like to disclose their preferences in too much detail because they intuitively perceive that the decision system should support them in learning about the decision situation and thus they should preserve the right to change their minds and preferences. Therefore, if any approximation of an utility function is used in a decision support system, it should be *nonstationary in time in order to account for the learning and adaptive nature of making process*. Such an approximation cannot be very detailed, it must have a reasonably simple form characterized by some adaptive parameters that can aggregate the effects of learning.

Another rationality framework, called *satisficing decision making*, was formulated by Simon (1969) and further extended by many researchers, see for example Erlandson (1981) for a formalization and review of this approach. Originally, this approach assumed that human decision makers do not optimize, because of the difficulty of optimization operations, because of uncertainty of typical decision environment, and because of complexity of the decision situations in large organizations. Therefore, this approach was sometimes termed *bounded rationality*, that is, somewhat less than perfect rationality; however, there are many indications that this approach represents not bounded, but culturally different rationality. While the first two reasons for not optimizing have lost today their validity (both in the calculative sense, with the development of computer technology and optimization techniques, including issues of uncertainty, and in the deliberative sense - expert decision makers can intuitively optimize in quite complex situations), the third reason remains valid and has been reinforced by the results of various studies.

For example, the studies of human behavior in situation of social traps or games with paradoxical outcomes - see Rappoport (1974) - and of evolutionary development of behavioral rules that resolve such social traps - see Axelrod (1985) - indicate that evolutionary experience forces humans to accept certain rules of ethical character that stop maximizing behavior. Any intelligent man after some quarrels with his wife learns that maximization is not always the best norm of behavior; children learn from conflicts among themselves that cooperative behavior is also individually advantageous for a longer perspective. All these observations and studies might motivate in the future the development of a new framework of *evolutionary rationality*, but certainly reinforce the conclusions of the satisficing framework that there are rational reasons to stop maximizing in complex situations. It was also noted - see, for example, Galbraith (1967) - that *satisficing behavior corresponds to the culture of big industrial organizations.*

A very important contribution of the satisficing framework is the observation that decision makers often use *aspiration levels* for various outcomes of decisions; in classical interpretations of the satisficing framework, these aspiration levels indicate when to stop optimizing. While more modern interpretations might prefer other rules for stopping optimization, the concept of aspiration levels is extremely useful for aggregating the results of learning by the decision maker: *aspiration levels represent values of decision outcomes that can be accepted as reasonable or satisfactory by the decision maker and thus are aggregated, adaptable parameters that are sufficient for a simple representation of his accumulated experience.*

There might be also other frameworks of rationality, such as the *framework of goal- and program oriented planning,* see Glushkov (1972), Pospelov and Irikov (1976), Wierzbicki (1985), that corresponds to the *culture of planning organizations.* This framework has some similarities, but also some differences to the utility maximization framework, the satisficing framework and to the *principle of reference point optimization* developed by Wierzbicki (1980) in multiobjective optimization and decision support.

In order first to include the principle of reference point optimization into the framework of satisficing decisions and then to develop a broader framework that would be useful for decision support for decision makers representing various perspectives of rationality, Wierzbicki (1982, 1984b, 1985, 1986) proposed the following *principles of quasisatisficing decision making:*

A quasisatisficing decision situation consists of (one or several) decision makers or *users* that might represent any perspective of rationality and have the right of changing their minds due to learning and of stopping optimization for any reason (for example, in order to avoid social traps) as well as of a decision support system that might be either fully computerized or include also human experts, analysts, advisors. It is assumed that:

- The user evaluates possible decisions on the basis of a set (or vector) of attributes or objective outcomes. These factors can be expressed in numerical scale (quantitatively) or in verbal scale (qualitatively), like "bad", "good" or "excellent". Each factor can be additionally constrained by specifying special requirements on it that must be satisfied. Beside this, objective outcomes can be characterized by their type: maximized, minimized, stabilized - that is, kept close to a given level (which corresponds to foregoing optimization), or floating - that is, included for the purpose of additional information or for specifying constraints. The user has the control over the specification of objective outcomes together with their types and of possible aggregation of such factors.

- One of the basic means of communication of the user with the decision support system is his specification of aspiration levels for each objective outcome; these aspiration levels are interpreted as reasonable values of objective outcomes. In more complex situations, the user can specify two levels for each objective outcome - an aspiration level interpreted as above and a reservation level interpreted as the lowest acceptable level for the given objective outcome.

- Given the information specified by the user - i.e., the specification of objective outcomes and their types, together with aspiration and possibly reservation levels - the decision support system following the quasisatisficing principle should use this guiding information, together with other information contained in the system, in order to propose to the user one or several alternative decisions that are best attuned to this guiding information. When preparing (generating or selecting) such alternative decisions, the decision support system should not impose on the user the optimizing or the satisficing or any other behavior, but should follow the behavior that is indicated by the types of objective outcomes. This means that the decision support system should optimize when at least one objective outcome is specified as minimized or maximized and should satisfice (stop optimizing upon reaching aspiration levels) when all objective outcomes are specified as stabilized. The later case corresponds actually to the technique of *goal programming*, see e.g. Ignizio (1978), hence the quasisatisficing decision support can be also considered as a generalization of this technique. By using aspiration or reservation levels for some objective outcomes as constraints, also the goal- and program oriented behavior can be supported by a quasisatisficing decision support system.

In order to illustrate possible responses of a quasisatisficing decision support system to the guiding information given by the user, let us assume that all specified objective outcomes are supposed to be maximized and have specified aspiration levels. We can distinguish then the following cases:

Case 1: the user has overestimated the possibilities implied by admissible decisions (since their constraints express available resources) and there is no admissible decision such that the values of all objective outcomes are exactly equal to their aspiration levels. In this case, however, it is possible to propose a decision for which the values of objective outcomes are as close as possible (while using some uniform scaling, for example implied by the aspiration and reservation levels) to their aspiration levels; the decision support system should tentatively propose at least one or several of such decisions to the user.

Case 2: the user underestimated the possibilities implied by admissible decisions and there exist a decision which results in the values of objective outcomes exactly equal to the specified aspiration levels. In this case, it is possible to propose a decision which improves all objective outcomes uniformly as much as possible. The decision support system should inform the user about this case and tentatively propose at least one or several of such decisions.

Case 3: the user, by a chance or as a result of a learning process, has specified aspiration levels there are uniquely attainable by an admissible decision. The decision support system should inform the user about this case and specify the details of the decision that results in the attainment of aspiration levels

In the process of quasisatisficing decision support, all aspiration levels and the corresponding decisions proposed by the system have tentative character. If a decision proposed by the system is not satisfactory to the user, he can modify the aspiration levels and obtain new proposed decisions, or even modify the specification of objective outcomes or constraints; the process is repeated until the user learns enough to make the actual decision himself or to accept a decision proposed by the system.

The process of quasisatisficing decision making can be formalized mathematically - see, e.g., Wierzbicki (1986) - and the mathematical formalization can be interpreted in various ways; let us consider an interpretation that corresponds to the framework of utility maximization. We assume that the user has a nonstationary utility function that changes in time due to his learning about a given decision situation. At each time instant, however, he can intuitively and tentatively (possibly with errors concerning various aspects of the decision situation) maximize his utility; let this tentative maximization determine his aspiration levels, denoted here by $w \in E_y$.

When he communicates the aspiration levels w to the decision support system, the system should use this information, together with the specification of the decision situation, in order to construct an approximation of his utility function that is relatively simple and easily adaptable to the changes of aspiration levels, treated as parameters of this approximation. By maximizing such an approximative utility function while using more precise information about the attainability of alternative decisions and other aspects of the decision situation - for example, expressed by the substantive model of the decision situation incorporated by expert advice into the decision support system - a tentative decision can be proposed to the user.

Such a tentative approximation of the user's utility function, constructed in the decision support system only in order to propose a tentative decision to the learning decision maker, is called here *order-consistent achievement function* or simply *achievement function* and has the form $u(y) = s(y,w)$. It should be stressed that the concept of achievement function has been also used in the context of goal programming, but without the requirement of order consistency (achievement functions in goal programming are equivalent to norms and thus satisfy the requirements of Cases 1 and 3 listed above but fail to satisfy the requirements of Case 2). By an order consistent achievement function we understand here either an order representing or an order approximating achievement function, according to the following definitions:

An *order representing achievement function* is a continuous function $s\colon Y_o \times E_y \rightarrow R^1$, with arguments $y \in Y_o$ and $w \in E_y$ interpreted as an attainable objective outcome vector and an aspiration level vector, correspondingly, that satisfies the following requirements:

a1. It is *strictly order preserving (monotone)* with respect to y and the positive cone D implied by the partial preordering (according to the types of objective outcomes) specified by the decision maker, that is, for all $w \in E_y$:

$$y_2 - y_1 \in \text{int } D \Longrightarrow s(y_1, w) < s(y_2, w)$$

a2. It is *order representing* with respect to y and the positive cone D, that is, for all $w \in E_y$:

$$\{ y \in E_y\colon s(y, w) \geq 0 \} = w + D$$

If $E_y = R^m$ and all objective outcomes are maximized, $D = R_+{}^m$, then a simple example of an order representing achievement function is:

$$s(y,w) = \min_{1 \leq i \leq m} (y_i - w_i)/a_i \tag{1}$$

where a_i represent some scaling units for subsequent objectives; because of these scaling units, this function has a cardinal form (does not depend on positive affine transformations of the space of outcomes together with scaling units), but is not separable.

An *order-approximating achievement function* is a continuous function $s\colon Y_o \times E_y \rightarrow R^1$, with arguments $y \in Y_o$ and $w \in E_y$ interpreted as an attainable objective outcome vector and an aspiration level vector, correspondingly, that satisfies the following requirements:

b1. It is *strongly order preserving (monotone)* with respect to y and the positive cone D, that is, for all $w \in E_y$:

$$y_2 - y_1 \in D \backslash (D \cap -D) \Longrightarrow s(y_1, w) < s(y_2, w)$$

b2. It is *order approximating* with respect to y and the positive cone D, that is, for all $w \in E_y$ and for some small $\epsilon > 0$:

$$w + D \subset \{ y \in E_y\colon s(y, w) \geq 0 \} \subseteq w + D_\epsilon$$

where

$$D_\epsilon = \{y \in E_y \colon \text{dist}(y,\, D) < \epsilon \parallel y \parallel\}$$

If $E_y = R^m$ and $D = R_+{}^m$, then a simple example of an order approximating achievement function is:

$$s(y,w) = \max_{1 \le i \le m} (y_i - w_i)/a_i + (\epsilon/m) \sum_{i=1}^{m} (y_i - w_i)/a_i \tag{2}$$

Intuitively speaking, we might say that if $w \in Y_o - D$, then the maximization of $s(y,w)$ over $y \in Y_o$ represents a uniform maximization of all components of the surplus $y - w \in D$; if $w \notin E_y - D$, then the same maximization represents distance minimization between the sets $w+D$ and

$$\{y \in Y_o \colon Y_o \cap (y + D \backslash (D \cap -D)) = \phi\}$$

which is the set of *generalized Pareto optimal objective outcomes in the sense implied by the positive cone D.*

Important properties of order consistent achievement functions are summarized by the following theorems, see Wierzbicki (1986):

Theorem 1. If $s(y,\, w)$ is strongly order preserving (b1) then its maximal points in $y \in Y_o$ are generalized Pareto optimal, that is, satisfy the following condition:

$$\tilde{y} = \arg\max_{y \in Y_o} s(y,\, w) \Longrightarrow Y_o \cap (\tilde{y} + \tilde{D}) = \phi$$

where

$$\tilde{D} = D \backslash (D \cap -D)$$

If $s(y,\, w)$ is strictly order preserving (a1) then its maximal points in $y \in Y_o$ are generalized weakly Pareto optimal, that is, satisfy the following condition:

$$\tilde{y} = \arg\max_{y \in Y_o} s(y,\, w) \Longrightarrow Y_o \cap (\tilde{y} - \text{int} D) = \phi$$

Theorem 2. If $s(y,\, w)$ is order approximating (b2) and $w \in Y_o$ is generalized properly Pareto optimal (with trade off coefficients bounded by ϵ and $1/\epsilon$), then the maximum of $s(y,\, w)$ in $y \in Y_o$, equal zero, is attained at $y=w$. If $s(y,\, w)$ is order representing *(a2)* and $w \in Y_o$ is generalized weakly Pareto optimal, then the maximum of $s(y,\, w)$ in $y \in Y_o$, equal zero, is attained at $y=w$.

Thus, the usefulness of achievement functions in building interactive decision support systems follows from the following properties:

- maximization of an order approximating achievement function results in Pareto optimality, no matter whether the aspiration level is attainable or not; order representing functions are less useful, because their maxima are only weakly Pareto optimal (if, for example, some component of objective outcomes is supposed to be stabilized, then the implied positive cone D has empty interior and all attainable objective outcomes are weakly Pareto optimal with respect to this cone);

- if a decision $\hat{x} \in X_o$ and the corresponding objective outcome $\hat{y} \in Y_o$ maximize an order approximating achievement function and $\hat{s} = s(\hat{y},\, w) = 0$ then the aspiration levels w are attainable and Pareto optimal (properly, that is, with bounded trade off coefficients);

- if, in the above situation, $\hat{s} < 0$, then the aspiration levels w are not attainable,

- if, in the above situation, $\hat{s} > 0$, then the aspiration levels w are attainable, but not Pareto optimal.

Therefore, an order approximating achievement function can be used for computing Pareto optimal decisions as well as for checking for Pareto optimality and attainability of an arbitrarily given $w \in E_y$. Moreover, the value of such achievement function can be meaningfully interpreted - it can be treated as a kind of *qualitative distance* between a given decision $\hat{x}$ or its objective outcome $\hat{y}$ and the aspiration level w.

Beside the forms (1), (2) of achievement functions, there are many other forms, see Wierzbicki (1986). Another example of an order representing achievement function might be:

$$s(y,w) = \max(\rho \max_{1 \leq i \leq m} (y_i - w_i)/a_i,\ (1/m) \sum_{i=1}^{m} (y_i - w_i)/a_i) \tag{3}$$

The above function is especially useful when applied to decision support systems with substantive models of linear multiobjective optimization type, when its maximization can be reduced by suitable transformation of variables to a single objective linear programming problem with additional constraints (see Lewandowski and Grauer, 1982, 1984).

Practical experiments with this approach (see, for example, Lewandowski at all., 1985, Dobrowolski and Zebrowski, 1987) have shown that the *language of aspiration levels* coincides very well with the style of thinking of practical decision makers. The information which is required from the user is easy to express, as opposed to other approaches based on pairwise comparisons, explicit weighting factors, estimation of other forms of utility functions, etc.

Theoretically, the learning process of interaction with a quasisatisficing decision support system via changing aspiration levels might be not sufficient for all decision makers: some of them might learn sufficiently to select their preferred decision, some others might still be puzzled and require some help in the convergence to their best preferred decision. There several ways of organizing such support for the user in changing his aspiration levels that the corresponding maxima of achievement functions converge to the maximum of his utility function. One way consists in the visual interactive approach of Korhonen and Laakso (1986), or *directional scanning* of aspirations and the corresponding maxima of achievement functions. Another approach proposed by Michalevich (1986) relies on quasigradient stochastic optimization and secures convergence even if we assume nonstationarity of user's utility function and stochastic mistakes of the user in specifying directions of change for aspirations; however, this approach is necessarily slow. Still another approach might consist in exploiting the ideas of the STEM procedure (see Larichev, 1979) and combining it with the maximization of an achievement function, but this approach would be also slow. Experience with applications of quasisatisficing principles in decision support systems shows that while most users welcome additional tools such as visual interactive approach, practically none of them require additional support in the convergence to their best preferred solution.

3. ALTERNATIVE BASED AND ASPIRATION LED COMMITTEE DECISION SUPPORT SYSTEM

We will further distinguish between various approaches to DSS, for the purpose of this paper, according to the method of *generating alternatives*. Two opposite situations can occur:

a. The set of alternatives is *generated* by a team of specialists (analysts, experts, other staff), on the basis of their knowledge about the decision problem being solved, possibly by employing special procedures, but without explicitly taking into consideration and evaluating all possible quality factors, objectives and attributes. This set of alternatives is submitted to the decision maker (or group of decision makers) for evaluation and selection. After performing the evaluation, some alternatives are rejected and possibly a new set is generated. Such a decision support system will be called *alternative based.*

b. The decision support system contains an explicit substantive model of the decision situation, as defined in the previous section, constructed by a team of specialists (analysts, experts). While working with such a model, using for example the aspiration led quasisatisficing decision process, alternative decisions can be generated. Such decision support systems will be called *model based.*

Evidently, what differs in these approaches is the organization of the *feedback loop between the decision maker and the mechanism for generating alternatives.* Between these two opposite approaches, there might be many intermediate organizations of this feedback loop.

For the quasisatisficing principles of decision support, both approaches have been implemented and tested. A family of quasisatisficing, model based decision support systems, named DIDAS (Dynamic Interactive Decision Analysis and Support) has been developed and applied to many practical problems, see for example Lewandowski et al. (1987). An alternative based system, named SCDAS (Selection Committee Decision Analysis and Support) for supporting decision making in group environment has been recently developed, see Lewandowski et al. (1986) and will be described in the sequel.

Many major decisions in management and engineering are delegated to committees or groups of decision makers. The institution of a committee - that averages diverse interests, combines various information sources in the face of uncertainty and provides for a forum of brain storming - remains an important element of many decision processes. It is therefore reasonable to develop decision support systems that will help to improve the process of committee decision making.

The problem of selecting one alternative from a finite set of alternatives presented to a committee is one of the most basic and classical decision problems and has received much attention in the decision-theoretical literature (between more recent contributions we should mention here Mirkin, 1979, Kuzmin, 1982, Pankova et al. 1984). There are many variants of such a problem; here, we will consider the following formulation:

A *committee* consists of several members (denoted here by $k = 1,...,K$); each member can have either equal or different *voting power* (denoted here by a voting power coefficient $v(k)$), specified a priori by the *committee charter*. In addition to the committee structure, the committee charter might specify the purpose of the committee's work, further procedural details, etc.

The problem faced by the committee is to jointly rank or select one or a few from a set of available *decision alternatives* (these might be candidates for a job, proposals for R&D projects, alternative transportation routes, proposed sites of an industrial facility, alternative computer systems, etc.). The list of alternatives needs not be complete at the beginning of the committee's work; during the decision-making process, new alternatives may be generated and subsequently evaluated.

Evaluation of alternatives is performed by the committee by first specifying *decision attributes* (such as the age, experience, professional reputation, etc., of a candidate) and then assessing each alternative with respect to each of these attributes. The list of decision attributes (denoted by $j = 1,...,J$) might be specified in the committee's charter or decided upon by the committee. In any case, decision attributes must be specified before alternatives can be evaluated and compared.

Each alternative (denoted by $i = 1,...,I$) must be evaluated by the committee or its individual members. The problem consists of proposing a *decision process* which together with an assessment of various attributes of alternatives and an aggregation of evaluations across both attributes and committee members, leads to a final ranking or selection of one or several alternatives in a way that is rational, understandable and acceptable to the committee members.

Several approaches to this problem have been developed; most of them are based on the classical multi-attribute utility theory (see e.g. Keeney and Raiffa, 1976), but there are also alternative approaches, such as the analytical hierarchy of Saaty (1982), the orderings of Roy (1971) or aggregation principle by Jacquet-Lagreze (1982, 1984). Some of these approaches have been also implemented as microcomputer-based decision support systems: an interesting implementation is that of analytical hierarchy (EXPERT CHOICE, 1983) or the non-procedural package DEMOS (1982) used for probabilistic evaluation of alternatives. Another commercially available implementation (LIGHTYEAR, 1984), based on utility theory and weighting coefficients specified by the user, employs a rather simple decision process and is restricted to only one user, hence it is not applicable in committee decisions.

Most of these approaches rely on either user-supplied rankings of attributes and alternatives for each attribute, pairwise comparisons of alternatives, or some other comparisons such as based on the uncertainty equivalence principle (that is, comparisons to a lottery). Such type of information is rather difficult to obtain during discussions with committee members. We describe here instead an aspiration led approach based on quasisatisficing decision principles and on the concept of achievement function.

Beside an *aspiration level* which expresses a reasonable (or satisfactory) value for each attribute, members of the committee can specify a *reservation level*, which represents a minimum acceptable level for each attribute (e.g. investment cost should not exceed some given a priori value). If an alternative is evaluated below the reservation level on even one attribute, it is considered unacceptable; if it is evaluated at least equal to aspiration levels for all attributes, it is considered highly desirable. The extension of an aspiration led quasisatisficing decision process to alternative based committee decision making was first proposed by Johnson (1984); details of the procedure, theoretical background and principles of implementation were also presented in the paper by Lewandowski et al. (1986).

3.1 Procedural Framework

One of the basic features of the presented method is a *structuralization of the decision process*: it is assumed that the process consists of several well defined stages. According to this procedure, it is possible to advance the decision process forward only if all committee members successfully completed all previous stages. Details of the procedure must be defined during the initial stage of the decision process. Let us consider in detail all stages of this decision making process.

The first stage or point on the agenda is to define the procedures by which the committee will operate. The questions addressed here should include the following:

(a) What is the expected product of the committee work and how does it influence the selection of the details of the procedure? The answer to this question depends on the committee's charter and its perceived role. For example, if the expected product is a short list of significantly different alternatives, procedural rules will be different from the case when the expected product is a consensus opinion on one, "best" alternative.

(b) What rules for aggregating opinions across the committee should be adopted, in particular, should outlying opinions be included in or excluded from aggregation?

(c) Should the committee be allowed to divide and form coalitions that might present separate assessments of aspirations, attribute scores and thus final rankings of alternatives?

The second objective of the first stage is problem specification. Neither the list of alternatives, nor their descriptions need be complete at this stage; moreover, this information might be not known to the committee members at this stage, if they wish to avoid the bias in specifying attributes and their aspiration levels. The important issue at this stage that requires discussion and specification by the entire committee is the definition of the attributes of the decision and their scales of assessment.

Various studies in decision theory suggest that a reasonable number of attributes should not exceed seven to nine (see e.g. Dinkelbach, 1982); if more attributes are suggested, they should be aggregated. For example, there might be a large number of qualitative indicators that are all related to the ecological impacts of the planned investments; instead of using all these indicators, it is better to ask committee members to evaluate subjectively the attribute "ecology", that is, to translate the information about all these indicators into one assessment. Such an assessment might be given originally on a verbal scale from "unacceptable" to "excellent", and later transformed into a quantitative scale, say from 0 to 10. Another possible option is to introduce a hierarchy in the set of objectives, which, however, makes the procedure more complicated.

During *the second stage* of the the decision process, aspiration and/or reservation levels for all attributes are determined separately by each committee member. After these values are entered into the decision support system, all necessary indicators (disagreement indicators, dominant weighting factors - see further comments) can be computed.

The third stage has again two objectives. One is the analysis and discussion of aspirations by the entire committee. These discussions are supported by the computed indicators and their graphic interpretations. In these discussions, the committee might address the following questions:

(a) Do the computed indicators accurately reflect the perceptions of individual committee members about the relative importance of various attributes (if not, should the aspirations or reservations be corrected)?

(b) What are the relevant differences of opinions between committee members and do they represent an essential disagreement about decision principles?

(c) Does the entire committee agree to use joint, aggregated aspirations (reservations), or will there be several separate sub-group aggregations?

The second objective of the third stage is a survey of alternatives. Discussions might center on the following issues:

(a) Are the available descriptions of alternatives adequate for judging them according to the accepted list of attributes? If the answer is negative, additional information should be gathered by sending out questionnaires, consulting experts etc.

(b) Which of the available alternatives are irrelevant and should be deleted from the list? Such preliminary screening can be done in various ways. The committee might define some screening attributes and reservation levels for them (of a quantitative or simple logical structure): for example, we do not accept investments which are more expensive than a given limit.

The fourth stage of the decision process is the individual assessment of alternatives. The evaluation of each attribute for each alternative is the main input of committee members into the system. Each member specifies evaluation scores; the decision support system helps him by displaying the evaluations already made and those still to be entered.

When all evaluations are entered, a committee member should proceed to the individual analysis of alternatives, based on calculations of an achievement function that leads to a ranking of all alternatives for the given committee member. This ranking is the main source of learning about the distribution of alternatives relative to aspirations.

The questions addressed by each member at this point might be as follows:

(a) Do the rankings along each attribute correctly represent the individual's evaluations of alternatives; does the achievement ranking, based on individual aspirations, correctly represent the aggregate evaluation (if not, should the scores be modified)?

(c) If the committee member agrees with the individual achievement ranking proposed by the system, what are the differences between this ranking and that based on individual scores but related to committee aggregated aspirations? Are these differences significant, or can he accept them as the result of agreement on joint decision principles?

The fifth stage of the decision process relates to an aggregation of evaluations and rankings across the committee and consists of a discussion of essential differences in evaluations, followed by a discussion of disagreements about a preliminary ranking of alternatives aggregated across the committee. These discussions are supported by the system; the system computes indicators of differences of opinion and prepares a preliminary aggregated ranking.

The questions addressed by the committee at this point might be the following:

(a) On which attributes and alternatives the largest differences in evaluations between committee members are observed? Do these disagreements represent essential differences in information about the same alternative?

(b) What is the essential information (or uncertainty about such information) that causes such disagreements? Should additional information be gathered, or can certain committee members supply this information?

(c) Would the results of these discussions and possible changes of evaluations influence the preliminary aggregated ranking list proposed by the system? This can be tested by applying simple sensitivity analysis tools.

(d) Does the preliminary ranking proposed by the system correctly represent prevalent committee preferences?

After these discussions, a return to any previous stage of the process is possible. If the committee decides that the decision problem has been sufficiently clarified, it can proceed conclude the fifth stage by the final agreement on the aggregated ranking or selection of one or more alternatives. It is important to stress again that the committee needs not stick to the ranking proposed by the system, since the purpose of this ranking - as well as of all information presented by the decision support system - is to clarify the decision situation rather than to prescribe the action that should be taken by the committee.

3.2 Formalization of the Decision Process

In the previous section we presented the general structure of the decision process. The decision support system supervises the progress of the discussion within the committee - its role is to process all the information necessary to perform the discussion, compute all necessary informative indicators, display graphic information and ensure proper structuralization of the process. In the sequel, we will consider in more detail the functions of the decision support system during each stage of the decision process.

3.2.1 Setting and discussing aspirations

Most judgmental decision processes require a choice of scales of evaluation for each decision attribute. The scales are often qualitative, such as unacceptable, bad, acceptable, good, very good, excellent, though they can be transformed into quantitative scales for computational purposes. When asked to specify aspiration and reservation levels on these scales at an early stage of the decision process, the decision maker is better prepared to make consistent evaluations across alternatives. However, we cannot expect and we should not require full consistency in any judgmental decision process, since not all relevant attributes might be evaluated and the relevant information about alternatives is never completely shared by all committee members. If each committee member is asked independently to specify his aspiration and (or) reservation levels for each attribute, a comparison of such results across the committee and across attributes serves several purposes:

(a) the relative importance of each attribute for each committee member and across the committee, as implied by the more or less attainable levels of aspirations, becomes more apparent, as discussed below.

(b) the division of opinions among the committee members can be discussed: if a significant subset of the committee has high aspirations (reservations) for an attribute and another subset has low aspirations (reservations), it is a case of a clear disagreement on decision principles. The committee might then discuss this disagreement and come to a consensus; or agree to disagree by allowing the formation of coalitions that rally for the importance of various attributes (for example, when deciding on siting an industrial facility, a part of the committee might be more concerned with environmental impacts, another more concerned with economic impacts).

(c) if the discussion shows that the reason for disagreement stems from different perceptions by various committee members about the exact meaning of a particular attribute and its scale of evaluation, the result might be a better specification of, or at least corrections in, the list of attributes.

(d) if the committee (or a coalition inside the committee) agrees to use averaged aspiration and (or) reservation levels, each committee member has a better perception of the anchor points to be used when evaluating alternatives.

In order to support these discussions, a number of indicators can be computed. Denote the individually specified aspiration levels for attribute j by the committee member k by $p(j,k)$ and the corresponding reservation levels by $r(j,k)$. Then the committee "voting" procedure might specify an averaging of individual inputs, weighted by the voting power coefficients $v(k)$ as follows:

$$p(j) = \sum_{k=1}^{K} v(k)p(j,k) / \sum_{k=1}^{K} v(k) \tag{3a}$$

$$r(j) = \sum_{k=1}^{K} v(k)r(j,k) / \sum_{k=1}^{K} v(k) \tag{3b}$$

Such an average is subject to manipulations by committee members who have an incentive to distort their true aspirations in order to influence the entire committee. A classical remedy, successfully used in subjective evaluations of certain sport performances (e.g. ice skating or ski jumping) is to exclude outlying opinions, in this case deleting the highest and the lowest $p(j,k)$ or $r(j,k)$ across all k before aggregating. This procedural option motivates committee members to state their preferences carefully since they will have no impact if they voice the outlying opinions. If the committee adopts this option (or if it is imposed by the committee charter), then an aggregation of opinions can be characterized by:

$$p(j) = \sum_{k \neq \bar{k}(p,j),\, \underline{k}(p,j)} v(k)p(j,k) / \sum_{k \neq \bar{k}(p,j),\, \underline{k}(p,j)} v(k) \tag{4}$$

where

$$\bar{k}(p,j) = \arg\min_{1 \leq k \leq K} p(j,k); \quad \underline{k}(p,j) = \arg\max_{1 \leq k \leq K} p(j,k)$$

denote the committee members with outlying aspiration levels who are therefore excluded from the averaging. The calculations are similar for aggregation of reservation levels $r(j)$

with corresponding $\bar{k}(r,j)$ and $\underline{k}(r,j)$. Evidently, computing the average is the only one of possible approaches to aggregating individual aspirations. Another approach was suggested by Mirkin (1979) who proposed computing the median as a good aggregation principle. The basic advantage of median is its robustness - the median is naturally insensitive on data outliers. This approach, however, has been not tested yet.

3.2.2 Assessing disagreement

The disagreement about aspiration (reservation) levels for an attribute among the committee can be measured in various ways. Clustering algorithms can be used in the case of very large numbers of committee members to identify the positional structure of the committee. Or, one could evaluate various statistical moments of the distributions of $p(j,k)$ and $r(j,k)$ across k, although moments of a distribution do not typically indicate the configuration of dissent. A good indicator of disagreement should distinguish between the case when there are two or more sizable dissenting groups of committee members, each representing a uniform opinion, and the case when the differences of opinion are distributed uniformly or attributed mainly to outlying opinions. To identify these differences, a *disagreement indicator* can be defined in the following way.

First let us consider the absolute change of aspirations:

$$\Delta P(j,K) = p(j,1) - p(j,K)$$

where committee members are renumbered such that

$$p(j,1) \geq p(j,2) \geq \ldots p(j,K-1) \geq p(j,K)$$

Now $\Delta P(j,k)$ can be split into the distribution of individual changes of opinion:

$$\Delta p(j,k) = p(j,k) - p(j,k-1), \quad k = 1,\ldots K-1 \tag{5}$$

In these equations, k can be interpreted as the index of the pairwise comparison between two ranked committee members. If large differences occur only at the ends of the range of k, corresponding to outlying opinions or small minority groups, they are not as significant as when they occur in the middle of the range. To correct for this, we introduce a coefficient $c(k)$.- for example, in the form:

$$c(k) = 16(k-1)^2(K-1-k)^2/(K-2)^4 \tag{6}$$

Other formulae can also be used for this coefficient; the above has been selected after empirical tests. The maximum value of $c(k)$ for any (K,k) is one. Also, for all K, $c(k) = 0$ for both $k = 1$ and $k{=}K-1$ since outlying opinions are not counted in the aggregation. It is useful to define the disagreement indicator as:

$$DI(p,j)=\sum_{k=2}^{K-2} c(k)\Delta p(j,k) \tag{7}$$

This disagreement indicator is bounded by the absolute difference of aspirations, $\Delta P(j,K)$; but $DI(p,j){=}\Delta P(j,K)$ only if the committee is split into two equal fractions of equal aspirations in each fraction. Note that the disagreement indicator (5) has a peculiar property: it is always equal to zero if $K \leq 3$. Clearly this is because a committee of three always has two outlying opinions and only one will therefore be counted in the aggregation.

Similarly, disagreement indicators $DI(r,j)$ for the distribution of reservation levels $\Delta r(j,k)$ can be computed. If both aspiration and reservation levels are used, the committee might be interested in disagreement indicators for averages, $DI(pr,j)$, computed for the distribution of $pr(j,k)$, defined as:

$$\Delta pr(j,k) = 0.5(\ \Delta p(j,k) + \Delta r(j,k)) \tag{8}$$

It should be stressed that the above indicators serve only to draw the attention of the committee to the attributes and aspirations that cause dissent, for which a discussion of differences of opinion might be useful. Similar disagreement indicators can be used when comparing the differences between individual assessments of specific alternatives.

Another type of indicator relates to the relative importance of various attributes as implied by specified aspirations (reservations). Various types of indicators can also be used here. We choose ***dominant weighting factors implied by aspirations*** as relevant indicators because they are consistent with the function used later for the evaluation of alternatives.

To be consistent with our theoretical decision model, the weighting factors for attributes are constructed as follows: If a committee member specifies aspirations for one attribute that are "closer" to the upper end of its evaluation scale than for another attribute, then this implies that the former attribute is more important to him than the latter one. More specifically, an indicator should be inversely proportional to such a distance and, if the indicators are interpreted as weighting coefficients, they should be normalized so that they sum up to one across all attributes. To avoid computational errors, the indicators should be calculable even in such an unreasonable case that a committee member specifies aspirations equal to the upper end of the scale. Hence, we extend the upper bound slightly, denoting it by $ub(j)$, and for simplicity normalize all scales so that the lower bounds of the scales of all attributes are zero. Then the dominant weighting factors implied by aspiration levels p of attributes j for committee member k are computed as follows:

$$w(p,j,k) = (ub(j)/(ub(j) - p(j,k)))/\sum_{\bar{j}=1}^{J}(ub(\bar{j})/(ub(\bar{j}) - p(j,k))) \tag{9}$$

Weighting factors implied by stated reservation levels $w(r,j,k)$ are calculated similarly.

These weighting factors can also be calculated for the preferences aggregated across the committee. In all cases, the indicators serve only as feedback signals to individuals or to the committee to check whether their aspirations correctly reflect their perception of the relative importance of various attributes. Any observed inconsistencies can be easily corrected.

3.2.3 Evaluating alternatives by individual committee members

An essential part of the decision process is an individual assessment and analysis of all alternatives by each committee member. In the approach followed in this paper, it is assumed that the assessment is performed not by rankings or pairwise comparisons but simply by assigning evaluation scores for each attribute to each alternative (as a teacher would assign grades for each subject of learning to each pupil). Uncertainty in each assessment could be expressed by supplying a range of scores or a probability distribution for the scores; however, we consider here only the simpler case without individual uncertainty of evaluations. The scores of the k-th committee member for the j-th attribute of the i-th alternative are denoted here by $q(i,j,k)$.

In order for each committee member to see what the scores imply and check for any scoring errors, rankings of alternatives by various attributes can be produced in the system by listing the alternatives, starting with the best score on a given attribute and ending with the worst score. However, the committee member is also interested in an aggregate ranking which takes into account scores on all attributes to test whether his intuitive opinion about which alternatives are best is consistent with the results of the scoring procedure.

A special approximation of a utility function implied by aspiration levels is applied in order to produce such an aggregate ranking; this approximation is called an (order-consistent) achievement function.

Consider the following question (Wierzbicki, 1986). Suppose the user knows the upper and lower bounds of an assessment scale and has specified a reservation and an aspiration level for each decision attribute; these four points we denote respectively by $lb(j)$, $ub(j)$, $r(j)$ and $p(j)$, where

$$lb(j) < r(j) < p(j) < ub(j).$$

Suppose a satisfaction (utility) value of zero is assigned to an alternative whose attribute assignments are all equal to reservation levels, and a satisfaction (utility) value of one to an alternative whose attributes are all equal to aspiration levels. We assume further that alternatives which have scores satisfying all their reservation levels are preferred to any alternative which has at least one score not satisfying the corresponding reservation level. And similarly, alternatives which have scores satisfying all their aspiration levels are preferred to any alternative which has at least one score not satisfying the corresponding aspiration level. Finally, let an (unlikely) alternative with scores all equal to the lower bounds of the scales have the value of $-b$ (a negative number) and an (unlikely) alternative with scores all equal to the upper bounds have the value of $1 + a$ (a number greater than one). What is the simplest cardinal utility function (i.e. a function that is independent of all linear transformations of the assessment scales) that is consistent with all of these assumptions?

The simplest function that meets these requirements can be constructed by using linear approximations between the points for which its values are known ($-b$, 0, 1 and $1 + a$). Such a function, called also an order-representing achievement function, has the following form:

$$s(q(i,k),p,r) = \min_{1 \le j \le J} u_j(q(i,j,k),p(j),r(j)) \tag{10}$$

where

$$u_j(q(i,j,k),p(j),r(j)) = \begin{cases} b((q(i,j,k) - lb(j))/((r(j) - lb(j))-1), \\ \quad \text{if } lb(j) \le q(i,j,k) < r(j) \\ (q(i,j,k) - r(j))/(p(j) - r(j)), \\ \quad \text{if } r(j) \le q(i,j,k) \le p(j) \\ a(q(i,j,k) - p(j))/(ub(j)-p(j))+1, \\ \quad \text{if } p(j) < q(i,j,k) \le ub(j) \end{cases} \tag{11}$$

and $q(i,k) = (q(i,1,k),...,q(i,j,k),...,q(i,J,k))$ is the vector of scores given by the k-th committee member to the i-th alternative. Thus the achievement function maps a vector of attributes into a scalar value for each alternative. Additionally, $p = (p(1),...,p(j),...,p(J))$ and $r=(r(1),...,r(j),...,r(J))$ are vectors of aspiration and reservation levels aggregated across the committee in a way that is acceptable to all members. In its middle range, the function (10) can also be interpreted as a distance from reservation level scaled by the difference between aspiration and reservation levels for each attribute.

However, the above achievement function has some disadvantages. Suppose the scales of assessments for all attributes are from 0 to 10, and the reservation levels are all 3 while the aspiration levels are all 7. Compare two alternatives: one with all scores equal to 5 so that the value of the achievement function (10) equals 0.5, while the second alternative has scores of 7 for all attributes but one, which has the score 4 so that $s(q,p,r) = 0.25$. But the second alternative might be considered better: the better achievements on many attributes could compensate for a worse achievement on one attribute. In order to correct for this consideration, we propose a modified form of the function (10), that is an order-approximating achievement function:

$$s(q(i,k),p,r) = \tag{12}$$

$$= \min_{1 \leq j \leq J} \left\{ u_j(q(i,j,k),p(j),r(j)) + (\epsilon/J) \sum_{j=1}^{J} u_j(q(i,j,k),p(j),r(j)) \right\} / (1 + \epsilon)$$

where $u_j(q(i,j,k),p(j),r(j))$ are defined as in (11). The parameter ϵ in this function represents the intensity of correction of the worst (under-)achievement by the average (over-)achievement. In the example considered above, if $\epsilon = 1$ and there are 5 attributes, then the first alternative has a value of the achievement function (10) equal to 0.5 (due to the subdivision by $1 + \epsilon$ in (10), this does not depend on ϵ if all u_j are equal) but the second alternative has the corresponding value of 0.55. Hence the second alternative is preferred. If, however, $\epsilon = 0.5$, then the first alternative has an achievement value equal to 0.5 but the second alternative has an achievement value of 0.45, hence the first alternative is now preferred.

The choice of the parameter ϵ is left to the committee: if its members feel that the worst achievement matters most, they should choose slight correction (say, $\epsilon = 0.1$); if they feel that the average achievement matters most, they should choose very strong correction (say, $\epsilon = 2$), indicating that average achievement is twice as important as worst achievement. A good interpretability of the values of the achievement function (10) by the users is obtained if $a{=}b{=}1$ and the values of $s(q(i,k),p,r)$ are multiplied by 10. Then the achievement range is from -10 (corresponding to all scores equal to 0) through 0 (all scores on reservation levels), through 10 (all scores on aspiration levels) to 20 (all scores maximal, equal to 10).

We should also mention here some mathematical interpretations of the dominant weighting factors implied by aspiration or reservation levels in connection with achievement functions in the forms (8) and (10). These achievement functions are nonlinear, hence their derivatives (corresponding to the classical concept of a weighting factor in a linear utility function) depend on $q(i,k)$. In fact, these achievement functions are nondifferentiable, hence they do not possess derivatives in the classical sense at some points - and, in particular, at the anchor points, that is, if $q(i,k) = r$ or $q(i,k) = p$. The dominant weighting factors indicate directions in the J-dimensional space of the assessment vectors $q(i,k)$, on which the points of nondifferentiability are located ; they are also representatives of so called subdifferentials of these functions at such points. While these properties of the dominant weighting factors are important mathematically, the reader should remember two points: the dominant weighting factors are not specified a priori or supplied explicitly, rather they are *implied* by the choice of aspiration and/or reservation levels for various attributes; on the other hand, they indicate the relative importance of various attributes as implied by aspiration and/or reservation levels.

The achievement function (10) is used to aggregate scores given by a committee member to various attributes of an alternative and then to rank various alternatives according to their achievement values. This can be done when using either individual aspirations (reservations) of a committee member or aggregated aspirations (reservations). In the former case, the ranking proposed by the system serves as a feedback to the committee member: he should compare it with his intuitive perception of ranking of alternatives. If the ranking does not match his intuitive perception, he or she should check whether he did not make any errors in scoring; another reason for such mismatch might be his disagreement with the correction coefficient ϵ adopted by the committee. If the ranking does match his intuitive perception, he or she should be prepared to accept the fact that the ranking based on aggregated aspirations (reservations) might be different; but the committee member cannot protest if he or she accepts the right of the committee to impose aggregated decision principles on the collective group.

3.2.4 Aggregating individual assessments across the committee

There are various interpretations of the process of aggregating preferences across a group of decision makers. Typically, the interpretation is related to the concept of fairness; however, various paradoxes in decision theory (Saari, 1982) show that there is no absolute meaning in this concept. In this paper, we simply require that the committee specify a set of procedures that is accepted as fair by the group. For example, if the charter of the committee specifies the voting power of each member, the procedurally "fair" aggregation is to take the weighted average of evaluations. The members with greater voting power are supposedly either more responsible (consider, say, the role of the chairman of the committee), more concerned with the outcome of the decision process, or more knowledgeable in a certain substantive area.

Hence, a final ranking of alternatives for the entire committee can be proposed by the decision support system by computing the (weighted) averaged achievement values for each alternative:

$$S(i) = \sum_{k=1}^{K} v(k) s(q(i,k),p,r) / \sum_{k=1}^{K} v(k) \tag{13}$$

with $s(q(i,k),p,r)$ defined as in (10) or (12).

This aggregation procedure gives reliable results under certain assumptions, of which two are most important. First, we assume that committee members do not bias their opinions in order to manipulate the outcome of the decision process. In order to discourage such manipulations, it is advisable to exclude outlying opinions from the averaging process, as was done in (2) for the aggregation of aspiration levels:

$$S(i) = \sum_{k \neq \underline{k}(i),\bar{k}(i)} v(k) s(q(i,k),p,r) / \sum_{k \neq \underline{k}(i),\bar{k}(i)} v(k) \tag{14a}$$

where

$$\underline{k}(i) = \arg\min_{1 \leq k \leq K} s(q(i,k),p,r) \tag{14b}$$

$$\bar{k}(i) = \arg\max_{1 \leq k \leq K} s(q(i,k),p,r)$$

Second, we assume that committee members possess the same information about alternatives. This very demanding assumption is never fully satisfied in practice. The decision process encourages discussion and exchange of information about alternatives between committee members in part by including concise descriptions of alternatives and requiring agreement at certain stages. When disagreement is indicated by major differences in individual rankings of alternatives or by large values of the disagreement indicators, this should tell the committee to stop and search for sources of disagreement. If the disagreement is due to a difference in the information base between individuals, then the problem can be resolved by sharing and exchanging information. A graphic representation of the diverging scores for an attribute of an alternative helps greatly in such discussions; a committee member with a dissenting opinion can either convince the committee that he or she has specific valuable information to share, or be convinced that his opinion cannot be substantiated. This serves as an additional disincentive for attempting to manipulate the outcome of the decision process by biasing assessments. The interested reader should also consult Tversky et al. (1983) for discussions about biases in decision-making.

After such discussion, the committee can either decide to return to some earlier stage of the decision process (for example, to correct the evaluation scores) or conclude the process. When adopting the final decision (a ranking or a selection of alternatives) the committee is by no means constrained by the aggregate ranking proposed by the decision support system, but merely guided by the results.

4. IMPLEMENTATION OF ALTERNATIVE ORIENTED GROUP DECISION SUPPORT SYSTEM

The framework presented in previous sections constituted the basis for an implementation of an experimental version of decision support system for committee decision making. The availability of inexpensive personal computers with strong graphic capabilities and with network interfaces made it possible to apply modern computer technology for the development of easy to use, user friendly and effective prototype system. It is necessary to mention that implementation of the decision support system is rather not a trivial task. The basic difficulty relates to the fact, that the decision maker *is not a computer specialist* and usually is not familiar with the theory which is behind of the system. Therefore, even the best methodological concept will be rejected by the decision maker, if the usage of the system requires too much specific knowledge, is not robust or too complicated. Several comments relating to the problem of *user friendliness* can be found in a paper by Lewandowski (1985) and in the book by Sprague and Carlson (1982).

Other problems arise in the case of implementation of group decision support systems. This is mostly connected with the *communication aspects* of such systems as well as is caused by large variety of possible communication and information exchange procedures (or protocols) which should be taken into consideration. These aspects have been studied extensively by Bui and Jarke (1986), Jarke (1986) and Jelassi (1987). The materialization of these concepts are the Co-oP system (Bui, 1986) and the Mediator (Jarke, 1985). There are several other group decision support systems described in the literature (see, for example, Gray, 1986) but there is not too much information published relating to their design principles and details of implementation.

Rather detailed classification of possible group communication situations have been proposed by Bui (1986) and Jarke (1986). They propose the four characterizing the decision environment:

- *Spatial distance.* This factor relates to the organization of the decision making process with respect to the physical location of the participants - especially, whether full face-to-face communication between them can take place, and such a way of communication augments the features offered by the Decision Support System,

- *Temporal distance.* This factor relates to the *time synchronization* of the decision process - whether decision makers are submitting their responses the same time, during the meeting, or in different points in time,

- *Commonality of goals.* This factor describes the "decision making environment" - whether the group wants to solve the problem cooperatively, or there are the contradictory interests and the whole decision process is more oriented to conflict resolution and bargaging,

- *Structure of the process ("Control").* This factor distinguishes the situation where all group memebrs share equal rights and the decision making procedure is supervised by the system, against the situation where one of the committee members has special rights and can be considered as the *Committee President* or the *Mediator*.

Beside of the *computer oriented* aspects of the system design, the most important are however the *methodological and procedural assumptions* relating to the designed system.

The mentioned above Mediator and Co-oP systems, being software products designed in consistent way, are newertheless lacking such a uniform "decision scientific" methodological bacground. Both leave the decision about the method used to the disposal of the decision maker; moreover they support methods differing essentially in their assumptions and methodology, like ELECTRE and Saaty's analytical hierarchy approach. If different methods are being used by committee members, there is no reasonable way for a consistent comparison of the results or for aggregating the results of individual evaluation.

The basic design assumptions of the aspiration oriented group decision support system (SCDAS) are as follows:

- The system should be implemented on the IBM (or IBM compatible) personal computers, connected through a network. If the network is not available, the system should run on a single computer,

- The decision process is initiated by the *committee president*; he is treated by the system as a *super-user* which has privileged access to information which can be hidden to other committee members. He is the only person, who can change the problem definition - list of attributes, alternatives and committee members. He also decides about the procedure, especially about a possible recourse in decision process,

- The committee member has full freedom to analyze and change his data during each current stage, as well as to have a read-only access to data specified by other members, according to the procedure defined by the committee president.

- The progress of the decision making process is performed by the supervisory program, which in particular, does not allow to change the data defined during previous stages, and ensures the proper advancement of the decision process,

- The system is equipped with an electronic mail, which can be used for distributing commonly available information (e.q. detailed information about alternatives) and for communication between the committee president and the committee members.

Summarizing, according to the mentioned above characteristic factors, the implemented version of the system can support the face-to-face as well as remote meetings (depending on the available hardware), the committee members can submit their decisions at different points of time, the decision process has hierarchical structure and is cooperative in its nature.

The existing (see Lewandowski, 1987) implementation is mostly experimental and does not completelly fulfill all of the specified above design assumptions. It was however successfully used for solving practical problems - the results of these experiments have validated the design principles and have proven the usfulness of the existing implementation (Dobrowolski and Zebrowski, 1987).

5. EXTENSIONS OF THE SCDAS METHODOLOFY AND FURTHER RESEARCH

The area of group decision support system is a relatively new one. There are several open questions, relating to the theory, the methodology as well as to the methods of efficient implementation. Some of the possible open questions and their sources have been discussed by Jarke (1986). According to our understanding of the problem, such questions can be splited into the following groups:

Methodological problems.

a. Rather frequently *the alternatives are not independent*. If for example, the committee decides that a road from A to B is not necessary, probably there is no reason to build a road from B to C. Therefore, some logical relationships between alternatives can exist and must be taken into consideration in the decision process.

b. The attributes (goals, objectives) have usually a *hierarchical structure* that can be reflected in the organization of the committee. Usually, the committee can be divided into subgroups, responsible for separate aspects of the project. Therefore, an attribute aggregation procedure must be developed following, for example, the lines presented in Vlacic et al. (1986).

c. The *value and quality of the information* available to the committee members as well as the information generated by the committee members must be taken into account during the decision making process. Frequently, the initial information is not complete and, even more frequently, a committee member might be not able to give a precise answer concerning either his aspitations or the quality of a given alternative. It is important to consider such sources of uncertainty in the analysis in order to evaluate the overall uncertainty of the final result. Therefore, *sensitivity analysis* should be performed on every step of the procedure, what in the case of alternative selection problem can create certain conceptual and computational difficulties.

d. The *role of the model* in the alternative oriented group decision support systems must be investigated more deeply. In particular, model can be used on the stage of *evaluation of alternatives* as well as can be used as the tool for *generating alternatives.*

Problems of interaction principles.

An other group of problems relates to the *human interaction with the system.* Although the problem is very general, we will mention here some more important issues related to the subject of organizing the dialogue and cooperation with the user:

a. The principles of *man-machine communication,* in the broad understanding of this term - relate mainly to the development of a *conceptual language* for describing the problem and the results. This is especially important in the case of group decision support systems, where all the committee members participating in the decision process should have the same understanding of the goals, procedural details and the interpretation and meaning of every component of the language used during the process (for example, if the attributes are measured in a numerical scale, it should be clear to everybody how to interpret the values on this scale). Therefore, an additional phase in SCDAS procedural framework, preceeding the cottent initial phase would be necessary.

b. The role of the user during *design phase,* and consequently, the *flexibility of the system design* which would allow participation in the design process by the user. This is a very important issue and a much attention has been paid recently to this problem. According to O'Mahony (1987): *"...in general, the system development process involves several distinct activities starting with the formulation of business strategy and ending with the implementation ... System users must participate in the entire process. Otherwise, the result may be a system that is technically excellent, but that fails to fit the business or the users..."*. The other aspects of the user particitation in the design or modification process is the *"end-user programming syndromme"* discussed in detail by Seybold (1987); several other approaches to this problem have been investigated by Martin (1982).

c. Another aspect relates to the *information processing abilities* of the user. This influences strongly the possible tools and approaches to information presentation, information analysis and possible approaches to information exchange between the system and the user. Various ways of graphical information presentation and information aggregation should be developed and implemented in the system (for the review of some existing approaches, see Lansdown, 1982). The other important part of the system is a *tutoring and explanatory module*; the importance of such a module in decision support systems has been pointed out by Jelassi (1986). Several approaches for implementation of such a module, utilizing the artificial intelligence and expert systems concepts (although these concepts were developed in different areas of computer applications) have been already proposed, see, for example, Mason, 1986.

Problems of computer engeneering.

The last group of open problems relates to *computer engineering* aspects of implementation of group decision support systems. The most important points are as follows:

a. The general *system architecture*. It must be decided how to split functions of the system between the components of a computer network. If we consider a typical structure of the computer cluster - the *server* and the *client* computers, it is necessary to decide, what functions should be implemented on what machine. Moreover, the existing software - like databases, electronic mail and teleconferencing systems, document exchange systems must be taken into account and the designed decision support system must be correctly and efficiently interfaced to these components,

b. Reliability, flexibility and user friendliness. It is also necessary to decide, how to provide necessary level of reliability, flexibility and user friendliness of the system as the software product - especially in the context of all mentioned above problems and design requirements.

6. REFERENCES

Axelrod, R. (1985). The Evolution of Cooperation. Basic Books, New York.

Bonczek, R.H., C.W. Holsapple and A.B. Whinston (1981). Foundations of Decision Support Systems. Academic Press, New York.

Bui, X. T. and M. Jarke (1986). Communication Design for Co-oP: A Group Decision Support System. ACM Trans. on Office Information Systems, Vol. 4, pp. 81-103, April 1986.

Dinkelbach, W. (1982). Entscheidungsmodelle, Walter de Gruyter, Berlin, New York.

Dobrowolski G. and M. Zebrowski (1987). Ranking and Selection of Chemical Technologies: Application of SCDAS Concept. In: A. Lewandowski and A. Wierzbicki, Eds., Theory, Software and Testing Examples for Decision Support Systems, WP-87-26, International Institute for Applied Systems Analysis, Laxenburg, Austria.

Dreyfus, R.E. (1984). Beyond rationality. In: M. Grauer, M. Thompson, A.P. Wierzbicki, Eds: Plural Rationality and Interactive Decision Processes. Proceedings, Sopron, Hungary, 1984. Lecture Notes in Economics and Mathematical Systems, Vol. 248. Springer-Verlag, Berlin.

EXPERT CHOICE, Decision Support Software Inc., 1983.

Erlandson, F.E. (1981). The satisficing process: A new look. IEEE Trans. on Systems, Man and Cybernetics, Vol. SMC-11, No. 11, November 1981.

Fisher, W.F. (1979). Utility models for multiple objective decisions: Do they accurately represent human preferences? Decision Sciences, Vol. 10, pp. 451-477

Galbraith, J.K. (1967). The New Industrial State. Houghton-Mifflin, Boston.

Genser, R. (1986). Learning in decision making. In: Large Scale Modelling and Interactive Decision Analysis, Proceedings, Eisenach, GDR, 1985. Lecture Notes in Economics and Mathematical Systems, Springer Verlag, Berlin.

Ginzberg M.J. and E.A. Stohr (1982). Decision Support Systems: Issues and Perspectives. In: M.J. Ginzberg, W.R. Reitman and E.A. Stohr, Eds.: Decision Support Systems, Proceedings of the NYU Symposium on Decision Support Systems, New York, 21-22 May, 1981. North-Holland Publ. Co.

Glushkov, V.M. (1972). Basic principles of automation in organizational management systems (in Russian). Upravlayushcheye Sistemy i Mashiny, 1.

Grauer, M., A. Lewandowski, and A.P. Wierzbicki (1984). DIDAS - theory, implementation and experiences. In: M. Grauer and A.P. Wierzbicki, Eds: Interactive Decision Analysis, Proceedings, Laxenburg, Austria, 1983. Lecture Notes in Economics and Mathematical Systems, Vol. 229. Springer Verlag, Berlin.

Gray, P. (1986). Group Decision Support Systems. In: E. McLean and H.G. Sol. Eds: Decision Support Systems: A Decade in Prespective, Proceedings of the IFIP WG 8.3 Working Conference on Decision Support Systems, Noordwijkerhout, The Netherlands.

Henrion, M. (1981). An Overview of DEMOS. Dept. of Engineering and Dept. of Public Policy, Carnegie-Mellon University, Pittsburgh.

Horsky, D. (1984). Estimation of attribute weights from preference comparisons. Management Science, Vol. 30, No. 7, July 1984.

Ignizio, J.P. (1978). Goal programming - a tool for multiobjective analysis. Journal for Operational Research, 29, pp. 1109-1119.

Jacquet-Lagreze, E. (1982). Binary preference indices - A new look on multicriteria aggregation procedures. European Journal of Operational Research, Vol. 10, No. 1, May 1982.

Jacquet-Lagreze, E. and M.F. Shakun (1984). Decision Support Systems for Semi-Structured Buying Decisions. European Journal of Operational Research, Vol. 16, pp. 48-58.

Jarke M, M.T. Jelassi and M.F. Shakun (1985). MEDIATOR: Towards a Negotiation Support System. Discussion Paper #290, Graduate School of Business, Indiana University, Bloomington/Indianapolis.

Jarke, M. (1986). Group Decision Support through Office Systems: Developments in Distributed DSS Technology. In: E. McLean and H.G. Sol. Eds: Decision Support Systems: A Decade in Prespective, Proceedings of the IFIP WG 8.3 Working Conference on Decision Support Systems, Noordwijkerhout, The Netherlands

Jelassi M.T. (1986). MCDM: From Stand-Alone Methods to Integrated and Intelligent DSS. Proceedings of 7th International Conference on Multiple Criteria Decision Making - Toears Interactive and Intelligent Decision Support Systems, Kyoto, Japan, August 1986 (to be published by Springer Verlag).

Jelassi M.T. and R.A. Bauclair (1987). An Integrated Framework for Group Decision Support System Design. IRMIS Working Paper #W703, Institute for Research on the Management of Information Systems, School of Business, Indiana University.

Johnson, S. (1984). Decision support for committee selection, manuscript, International Institute for Applied Systems Analysis, Laxenburg, Austria.

Keen, P.G.W and M.S. Scott Morton (1978). Decision Support Systems - An Organizational Perspective. Addison-Wesley Series on Decision Support.

Keeney, R.L. and H. Raiffa (1976). Decisions with Multiple Objectives: Preferences and Value Tradeoffs, Willey, New York, 1976.

Kuzmin, W.B. (1982). Group Relations in Fuzzy and Non-Fuzzy Binary Relation Spaces. Nauka Publ., Moscow (in Russian).

Lansdown R. J. (1982). Business Graphics - State of the Art Report. Infotech State of th Art Series, Ser. 10, No. 3, Pergamon Infotech Limited.

Larichev O.I. (1979). The Science and the Art of Decision Making. Nauka Publ., Moscow, 1979 (in Russian).

Lewandowski, A. (1987). Selection Committee Decision Anlaysis and Support Systems (SCDAS) - Users Manual V. 2.0. International Institute for Applied Systems Analysis, Laxenburg, Austria (in preparation).

Lewandowski, A., T. Rogowski, and T. Kreglewski (1985). A trajectory-oriented extension of DIDAS and its application. In: M. Grauer, M. Thompson, A.P. Wierzbicki, Eds: Plural Rationality and Interactive Decision Processes. Proceedings, Sopron, Hungary, 1984. Lecture Notes in Economics and Mathematical Systems, Vol. 248. Springer-Verlag, Berlin.

Lewandowski, A., S.Johnson, and A.P. Wierzbicki (1986). A prototype selection committee decision analysis and support system, SCDAS: theoretical background and computer implementation. Working Paper WP-86-27, International Institute for Applied Systems Analysis, Laxenburg, Austria.

Lewandowski, A., T. Kreglewski, T. Rogowski and A.P. Wierzbicki (1987). Decision support systems of DIDAS family. In A. Lewandowski, A.P. Wierzbicki, Eds: Theory, Software and Testing Examples for Decision Support Systems. Working Paper WP-87-26, International Institute for Applied Systems Analysis, Laxenburg, Austria.

LIGHTYEAR - The Decision Support Software, Lightyear, Inc., 1984.

Mason M.V. (1986). Adaptive command prompting in an on-line documentation system. Int. J. Man-Machine Studies, Vol. 25, pp. 33-51.

Michalevich, M.V. (1986). Stochastic approaches to interactive multicriteria optimization problems. Working Paper WP-86-10, International Institute for Applied Systems Analysis, Laxenburg, Austria.

Mirkin B.G. (1979). Group Choice. John Willey & Sons, New York.

Naylor, T.H. (1982). Decision support systems or whatever happened to MIS? INTERFACES, Vol. 12, No. 4.

O'Mahony R. (1987). Successful Systems: New Ways to Involve Users. The Consultant Forum, Vol. 4, No. 2, Digital Equipment Corporation.

Pankova, L.A., A.M. Petrovski and M.W. Schneiderman (1984). Organization of Expertise and Analysis of Expert Information. Nauka Publ. Moscow (in Russian)

Parker, B.J. and G.A. Al-Utabi (1986). Decision support systems: The reality that seems to be hard to accept? OMEGA Int. Journal of Management Science, Vol 14, No. 2, 1986.

Pospelov, G.S. and V.A. Irikov (1976). Program- and Goal Oriented Planning and Management (in Russian). Sovietskoye Radio, Moscow.

Rappoport, A. (1984). The uses of experimental games. In: M. Grauer, M. Thompson, A.P. Wierzbicki, Eds: Plural Rationality and Interactive Decision Processes. Proceedings, Sopron, Hungary, 1984. Lecture Notes in Economics and Mathematical Systems, Vol. 248. Springer-Verlag, Berlin.

Roy, B. (1971). Problems and methods with multiple objective functions, Math. Programming, Vol.1, pp. 233-236.

Saari, D. (1982). Inconsistencies of weighted Voting Systems. Math. of Operations Res. Vol. 7.

Saaty, T.L. (1982). Decision Making for Leaders: The Analytical Hierarchy Process for Decisions in a Complex World, Lifetime Learning Publ., Belmont.

Sage, A.P. (1981). Behavioral and organizational considerations in the design of information systems and processes for planning and decision support. IEEE Trans. on Man, Systems and Cybernetics, Vol. SMC-11, No. 9, September 1981.

Simon, H. (1958). Administrative Behavior, McMillan, New York.

Seybold P. (1987). Key Issues In End-User Programming. The Consultant Forum, Vol. 4, No. 2, Digital Equipment Corporation.

Sprague, R.H. and C. Carlson, Eds. (1982). Building Effective Decision Support Systems. Prentice Hall, Inc.

Stabel C.B. (1986). Decision Support Systems: Alternative Perspectives and Schools. In: E. McLean and H.G. Sol. Eds: Decision Support Systems: A Decade in Prespective, Proceedings of the IFIP WG 8.3 Working Conference on Decision Support Systems, Noordwijkerhout, The Netherlands

Tversky, A., D. Kaheman and P. Slovic (1983). Judgment Under Uncertainty: Heuristic and Biases, Cambridge University Press.

Watson, H.J. and M.M. Hill (1983). Decision support systems or what didn't happen with MIS. INTERFACES, Vol. 13, No. 5, October 1983.

Vazsonyi, A. (1982). Decision support systems, computer literary and electronic models. INTERFACES, Vol. 12, No. 1, February 1982.

Vlacic, Lj., B. Matic and A.P. Wierzbicki (1986). Aggregation Procedures for Hierarchically Grouped Decision Attributes with Application to Control System Performance Evaluation. International Conference on Vector Optimization, Darmstadt, 1986.

Wierzbicki, A.P. (1980). The use of reference objectives in multiobjective optimization. In G. Fandel and T. Gal, Eds: Multiple Criteria Decision Making, Theory and Applications. Springer Verlag, Heidelberg.

Wierzbicki, A.P. (1982). A mathematical basis for satisfying decision making, Math. Modelling, Vol. 3, pp. 391-405.

Wierzbicki, A.P. (1983). Negotiation and mediation in conflicts: The role of mathematical approaches and methods. In H. Chestnut et al., Eds: Supplemental Ways to Increase International Stability. Pergamon Press, Oxford 1983.

Wierzbicki, A.P. (1984a). Models and Sensitivity of Control Systems. Elsevier, Amsterdam 1984.

Wierzbicki, A.P. (1984b). Interactive decision analysis and interpretative computer intelligence. In: M. Grauer and A.P. Wierzbicki, Eds: Interactive Decision Analysis, Proceedings, Laxenburg, Austria, 1983. Lecture Notes in Economics and Mathematical Systems, Vol. 229. Springer Verlag, Berlin.

Wierzbicki, A.P. (1985). Negotiation and mediation in conflicts: Plural rationality and interactive decision processes.

Wierzbicki, A.P. (1986). On the completeness and constructiveness of parametric characterizations to vector optimization problems. OR-Spektrum, Vol.8, pp. 73- 87.

Wynne, B. (1982). Decision support systems - a new plateau of opportunity or more emperor's clothing? INTERFACES, Vol. 12, No.1, February 1982.