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Modelling and supporting the process of choice between alternatives: the focus of ASTRIDA

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Abstract

This paper describes the backgound to the development of ASTRIDA[1], and its forefathers MAUD and ZAPROS, each of which is a system capable of supporting individual, group and organisational decision making at a strategic level. We start by rejecting the philosophy of providing strategic decision support by "bootstrapping the decision maker" in favour of focusing on problem structuring, and we review how this idea was developed in MAUD within the context of multiattribute utility theory (MAUT). The advantages of procedures based on MAUT are discussed, as are their drawbacks, particularly their tendency to land the decision maker in "black holes" in the preference space. We examine how this problem was avoided in ZAPROS in constructing partial orderings of multiattributed alternatives within a verbal decision model. Remaining difficulties in providing support are traced to MAUD's and ZAPROS's inherent process modelling limitations. The basis for improving process modelling is explored in the context of *dominance search theory* and its practical application in ASTRIDA is detailed. We show how ASTRIDA's process model and thoroughly developed interactive dialogue facilitates problem structuring and choice between alternatives on the basis of the decision maker's preferences expressed in his own natural language. We conclude by examining how ASTRIDA supports the generation and reality-testing of new potential alternatives on the basis of an analysis of the difficulties experienced while considering the current ones.

[1] ASTRIDA is the product of a project within the framework of the agreement on scientific cooperation between the London School of Economics and Political Science (LSE) and the All-Union Research Institute for Systems Studies of the USSR Academy of Sciences (VNIISI). The project is partially funded by the Suntory-Toyota International Centre for Economics and Related Disciplines (ST/ICERD), LSE, London.

1. INTRODUCTION

ASTRIDA (Advanced STRategic Intelligent Decision Aid) provides a comprehensive problem definition and problem structuring environment in support of strategic decision making. In such decision making, the best courses of action (alternatives) are usually not among those initially considered. Rather, they are synthesised out of elements of those considered and/or of others discovered on the way of developing the complexity of the real basis for preferred courses of action in the current problem situation. Furthermore, the alternatives themselves are likely to be compared on the basis of verbal (rather than numerical) descriptions of the attractiveness of their particular attributes. Using numerical scales to order the attractiveness of attributes on criteria may make the task of the decision aid simpler, but does not help the decision maker's problem of how to convert his descriptions of alternatives into numbers in order to establish his preferences between them.[2]

ASTRIDA's basic mode of operation is based on the premise that the decision maker possesses, in principle, the knowledge both about the problem he is facing and about the way he would like to handle it. The system is used for the purpose of (a) organising and developing the decision maker's thoughts about the problem and the best alternatives to choose between, and, (b) suggesting to the user how the "best" alternative may be *developed* in practice (rather than merely be selected).

ASTRIDA comprises two fundamental interlocking functions: (1) problem structuring, and, (2) developing the choice of the best alternative (which does not have to be one of those originally considered). Thoroughly developed interactive dialogue facilitates problem structuring on the basis of the decision maker's preferences. The whole interaction with the user is predicated on the use of his own natural language (i.e., in describing his problem, creating and developing alternatives and criteria, and estimating the attractiveness of alternatives on these criteria). A special procedure for guiding the process of choice of the best alternative is developed which is based on pairwise comparisons of multiattributed alternatives. Throughout the process of comparison, the decision maker is presented with the possibility of developing the description of alternatives (e.g., via decomposing and/or aggregating criteria, introducing additional information) and also of generating new alternatives on the basis of an analysis of the problems experienced while considering the current alternatives.

ASTRIDA is capable of supporting individual, group and organisational decision making at a strategic level. ASTRIDA builds on and provides Ban enhancement of the capabilities of two DSSs, MAUD and ZAPROS, developed separately by LSE and VNIISI, respectively. Naturally, it draws a great deal from the extensive field studies of both these systems which have been carried out during the past eight years. It utilises a new synthesis of descriptive and normative approaches to decision making, providing a decision making support environment which allows the implementation of

[2] There is some general confusion in the literature on the use of the terms *attribute* and *criterion*. In this paper, we use *attribute* to express an intrinsic quality of an alternative and *criterion* to indicate an ordered scale on which the decision maker may assess the attractiveness of an attribute.

psychologically valid methods of information elicitation and problem structuring.

In the following, we outline the problems involved in providing effective computer-based support to people facing strategic decision problems, and describe how MAUD and ZAPROS were each able to overcome some, but not all of these problems, and we indicate how decision process modelling enables ASTRIDA to build on as well as go beyond the achievements of MAUD and ZAPROS.

2. WHAT TO SUPPORT?

Sprague and Carlson's (1982) definition of decision support systems as "*computer-based systems that help decision makers to confront ill-structured problems through direct interaction with data and analysis models*" has promoted, with some success, the belief that computer-based systems which offer direct interaction with data and analysis models will, somehow, help decision makers confront ill-structured problems. This has resulted in the construction of many decision support systems which help decision makers explore data and analysis models (Sprague, 1987), but few of these have focused on how to *aid the confrontation of the decision problem.* That is, once one has established the set of potential decision alternatives, how can one be aided in the process of actually choosing one? In the following, we describe our evolving understanding of this process and how MAUD, ZAPROS and ASTRIDA attempt to support it.

2.1. Support focusing on bootstrapping the decision maker

Initially, it was generally believed that the best way to provide support was through *bootstrapping* the decision maker by automating a normatively prescribed decision rule assumed to be superior to the intuitive composition rule which would be employed by the decision maker when unaided (Goldberg, 1970; Dawes and Corrigan, 1974; Humphreys, 1977; Larichev 1979). Alternatives to be considered were assumed to have already been decomposed (or to be immediately decomposable without difficulty) into their profiles of part-worths on a set of criteria which, together, described the *preference structure* within which they were comparatively evaluated through the application of the appropriate composition rule. Aiding the process of developing this preference structure was thus generally overlooked in favour of bootstrapping the decision maker. Not surprisingly, research on methods and processes which might aid decision making also concentrated on advantages and limitations of various composition rules which might be normatively prescribed (e.g., Keeney and Raiffa, 1976; Rivett, 1977; Svenson, 1979, 1983).

Montgomery (1983) organised the results of such research into a general taxonomy, distinguishing between

(i) *non-compensatory rules*, which do not allow an unattractive aspect of an alternative on one attribute to be compensated by an attractive aspect on another attribute, or vice versa, and,

(ii) *compensatory rules,* which require that the drawbacks and advantages of all the attributes of each alternative assessed by the various criteria in the preference structure be integrated into a total attractiveness measure.

Non-compensatory rules were found to have serious disadvantages in practical applications due to limited applicability and neglect of important information. Nevertheless, they were usually simple to understand and direct in application.

Compensatory rules, particularly those based in Multi-Attribute Utility Theory (von Winterfeldt and Fischer, 1975; Keeney and Raiffa, 1976; Humphreys, 1977), have the advantage that they can, in theory, be used in any situation and allow the decision maker to consider all the information within the preference structure which is relevant to his decision. However, four major problems were associated with their use in practical applications:

(a) Use of compensatory rules may require over-complex value judgements.

(b) It may be difficult to have a good overview of the arguments for and against choice of particular alternatives based on compensatory rules.

(c) The attractiveness measures on criteria associated with the use of compensatory rules may be experienced as too abstract.

(d) Compensatory rules emphasise that one has to give up some good things in order to get some other good things, which people usually hate doing (Montgomery, 1983, p. 348).

Despite these problems, the conclusion consistently drawn from empirical studies of bootstrapping intuitive decision making in the 1980s has been that it is difficult to justify in practice the prescription of any non-compensatory rule over a MAUT-based compensatory rule (Fischhoff et al, 1981; de Hoog and Wittenboer, 1986; Van Dijk and de Hoog, 1989; Rohrman and Borcherding, 1989).

2.2. Support focusing on problem structuring: MAUD

Most of the research on the decision rules suitable for bootstrapping embedded their use within well-structured accounts of decision problems given to subjects ("decision-makers") in experimental situations. These situations usually had little to do with real life strategic decision making (Edwards, 1983) where there is uncertainty about the characterisation of alternatives on attributes whose attractiveness on criteria will vary according to the goals of the decision maker, where different stakeholders involved in the decision may hold different goals, or where goal confusion or goal conflict may exist (Humphreys and McFadden, 1980; Vari and Vecsenyi, 1984; Larichev, 1987; Hawgood and Humphreys, 1988).

Strategic decision making problems with these characteristics may be encountered in governmental organisations (Oseredko, Larichev and Mechitov, 1982), private companies (Phillips, 1989) and private life (Jungermann, 1980). In each case, effective decision support has been found to be delivered principally for assistance in *problem structuring* rather than through automating the composition rule (Humphreys and McFadden, 1980; Phillips, 1984; Humphreys and Berkeley, 1985). This is because no composition rule will be able to provide results which offer a secure basis for decision making until uncertainties about the operational goals of the decision maker and the requisite preference structure have been resolved.

MAUD (Multi Attribute Utility Decomposition; Humphreys and Wisudha, 1982), one of ASTRIDA's forefathers, was one of the first computer-based decision aids employing a MAUT-based composition rule that was also able to deliver support for problem structuring and reduction of goal confusion over a wide range of contexts (Humphreys and McFadden, 1980; Bronner and de Hoog, 1983; John, von Winterfeldt and Edwards, 1983; Kimbrough and Weber, 1990).

In operation, MAUD starts by asking the user to name the choice alternatives under consideration. It then proceeds to help in eliciting aspects relevant in choosing between these alternatives by asking the user to specify differences and similarities between triads of alternatives, following Kelly's (1955) *minimum context* or *difference* method (Fransella and Bannister, 1977). The words elicited in this way are used to represent the poles of an attribute dimension (which may be changed if the user is not satisfied with it). The user is then asked to rate all alternatives on an interval scale between these poles and to specify the ideal (most preferred) point on the scale for each attribute dimension elicited. MAUD then *folds* the elicited ratings about the ideal point into an *individual preference (I)* scale (Coombs, 1964; Dawes, 1972; Humphreys, 1977), thus obtaining numerical estimates of alternatives on criteria scaled appropriately for input to a MAUT-based composition rule.

When the decision maker has successfully generated two attribute dimensions which are significant to him for choosing between the alternatives, MAUD, henceforth, allows him to specify poles of dimensions directly (using a heuristic known as the *opposite* method; Epting, Suchman and Nickeson, 1971) rather than through considering similarities and differences between triads of alternatives as was previously done.

MAUD monitors the I-scaled estimates on the criteria established by the user, checking each set as soon as it is elicited with the sets of estimates on all other criteria currently in the preference structure. The aim is to ensure that conditional utility independence is maintained between these sets of estimates as required by MAUT (Keeney and Raiffa, 1976). In the case of a violation of utility independence, restructuring is accomplished by the decision maker, in interaction with MAUD, through the deletion of the offending attribute dimensions and their replacement with a dimension which expresses their shared meaning more appropriately.

When the user thinks that a sufficient number of attribute dimensions representing all the important aspects of the problem have been specified and MAUD is satisfied with the coherence of the structure and its contents, MAUD investigates value-wise importance weights and relative scaling factors for all the criteria in the preference structure. These quantities have to be determined so that MAUD can apply a MAUT-prescribed additive composition rule (von Winterfeldt and Fischer, 1975). In early versions of MAUD this was done by constructing reference gambles (BRLTs) in the manner defined within MAUT (Raiffa, 1969) for determining trade-off ratios between pairs of attributes clustered into a hierarchy. However, field tests of MAUD (Humphreys and Wooler, 1981; John, von Winterfeldt and Edwards, 1983) indicated that, by doing this, MAUD was in danger of falling foul of Montgomery's problem (a) for compensation-rule-based systems: that is, many people found that BRLTs involved value judgements which were too complex for them. Hence, in later versions of MAUD, the BRLT-based procedure was replaced by a more concrete procedure based on Sayeki's (1972) *allocation of importance* axiom system. This is a theoretically optimal procedure for computing "riskless" utility functions (von Winterfeldt, Barron and Fischer, 1980) which, in the form developed for MAUD, requires only that the decision maker adjusts ratings on attribute dimensions anchored on the attractiveness values of real alternatives in the decision.

At the end of each session, or at any other time, at the decision maker's request, MAUD produces a summary showing the assessed preference values for alternatives and the value-wise importance of the criteria. This summary also gives the original ratings of the alternatives on attribute dimensions and their corresponding I-scaled estimates on criteria. Any dominance relations between alternatives (across all currently defined attributes) are explicitly pointed out. This largely overcomes Montgomery's problem (c): that is, overall attractiveness measures on their own are not sufficient; they become much more meaningful when the decision maker can explore in concrete terms how they were composed.

The decision maker can also use sensitivity analysis provided within MAUD to explore the effects of varying the relative importance of the attributes in the preference structure on the preference orderings of the considered alternatives. These operations, based on MAUT compensation rules, provide a good overview of the basis for choice across all current alternatives but cannot always provide the full argument which would explain why the decision maker (rather than MAUD) would wish to choose a particular alternative over another. Thus, Montgomery's problem (b) is only partially overcome.

While user satisfaction with MAUD's procedures is in general quite high, users still find that the most difficult part of the process lies in determining trade-offs between criteria (Berkeley, 1986). When more than a small number of criteria and alternatives are involved, determining trade-offs between criteria can demand a lot of cognitive effort on the part of the decision maker. Much of this effort is psychological: the procedure involves *giving up* desired characteristics of alternatives rather than trying to find ways to restructure the situation so that *all* the desirable characteristics *could be retained* thus avoiding post-decisional regret (Festinger, 1964; Janis and Mann, 1977; Sjoberg, 1980). This is the essence of Montgomery's problem (d).

Moreover, MAUD treats attributes as dimensions within an essentially continuous preference space. Any position in this space could, in theory, characterise a hypothetical alternative, and thus may be explored during the adjustments on attribute dimensions involved in applying the *allocation of importance* procedure. In practice, decision makers sometimes experience "black holes" in the preference space: certain patterns of ratings on attribute dimensions never occur for real alternatives, and are unimaginable, or at least incredible. In these regions, the space itself collapses since trade-off ratios between criteria are not establishable there.

2.3. Avoiding "black holes" through using a verbal decision model: ZAPROS

The enduring encountered with MAUD can be traced back to a single issue: the MAUT compensation rule is not just powerful and comprehensive; on many occasions it is *too* powerful and *too* comprehensive. It organises within a single rule all the information required to complete the composition, starting from fully decomposed alternatives located at defined points within a hypothetically continuous preference space. But a consistent preference structure does not have to be defined in this way. In practice, multiattributed alternatives may be verbally described at ordered levels of increasing (or decreasing) preference on criteria, with no intermediate continuity (which would involve mixtures of discrete verbal descriptions). Through local comparisons of particular levels on pairs of criteria, quasi-orders can, in theory, be built up within an essentially non-dimensional *verbal decision model.* This model can allow one to define dominance relations between alternatives, or groups of alternatives, which have particular profiles of levels of attractiveness on criteria (Larichev, Zuev and Gnedenko, 1979).

In practice, realisation of this idea would imply that the decision maker could use a series of simple, direct, non-compensatory rules to define local preference conditions between levels of attractiveness on pairs of criteria within the verbal decision model. Then, when actual alternatives were assessed, compensatory rules would only have to be applied in a local, concrete way in making trade-offs between particular subsets of alternatives at particular pre-defined levels on criteria where no clear dominance relations could be deduced. The psychological effort of making trade-offs would be reduced as one would not have to worry about hypothetically giving up things wherever one could escape doing so in reality, and "black holes" would never accidentally be entered in determining dominance relations between alternatives.

Substituting the use of a single all-embracing composition rule by a series of local comparison and local composition rules in this way offers promise in overcoming both of Montgomery's problems (a) and (d) but raises the question of how to direct the comparison and composition process in determining preferences between alternatives progressively. ZAPROS is a computer-based method for developing a partial ordering of multicriteria alternatives (Larichev, 1982) which has tackled this problem with some success in practical applications (Zuev, Larichev and Chujev, 1979; Humphreys, Larichev, Vari and Vecsenyi, 1983). In ZAPROS, each multiattributed alternative is represented at a particular level (expressed verbally) depending on its degree of preference on each of the criteria in the set.

ZAPROS is useful in cases where there is a rather large number of alternatives which need to be "trimmed" down before considering them further (e.g., proposals on R&D development). In such situations, it is often sufficient to have some partial ordering of the alternatives under consideration showing how some alternatives (or groups of alternatives) can definitely be preferred to (i.e., dominate) the remaining ones, and identifying subgroups of alternatives within which a definite choice of preferred alternatives can be only made after further comparative investigation of their relative merits.

ZAPROS uses a high-level decision maker's preferences to fix his policy for the assessment of complex alternatives *before* the alternatives are actually assessed. The advantages of ZAPROS result from its attempts to structure the problem using the decision maker's own language. That is, the criteria for estimating alternatives are elicited in terms of verbal statements provided by the user and they are used to create ordinal scales of levels of attractiveness expressed on each of several criteria (up to ten with, usually, no more than five levels on each criterion).

Quasi-order relations within this preference structure are established through preference comparisons made by the decision maker between pairs of hypothetical alternatives, described in his own words in terms of various levels of attractiveness on criteria. ZAPROS checks inconsistencies and uses the preference ordering relations it detects in the semi-ordered preference structure, as it develops, to optimise the sequence of the comparisons it presents to the decision maker as the problem-structuring session progresses. This makes the session much shorter and more interesting to the decision maker than would be the case when using conventional pair-comparison methodology.

Once the verbal decision model has been elicited and interactively confirmed between ZAPROS and the decision maker, it is ready for use. Alternatives are assessed as they arrive in terms of their level of judged attractiveness on the decision maker's verbally expressed criteria. A quasi-ordering of preference rankings for all the alternatives (according to the detected dominance relations between them) is automatically computed on the basis of the comparison rules which define the verbal decision model. The decision maker has then only to consider the trade-offs to be made between those alternatives which are not sufficiently discriminated on the basis of this quasi-ordering. Thus, ZAPROS provides a flexible function for eliciting information about the decision maker's preferences necessary for comparison of those real alternatives.

Some problems still remain in employing ZAPROS to support the actual process of strategic decision making. One problem is that ZAPROS concentrates on developing information about ordered preferences between *all* the alternatives under consideration and, as such, does not provide a very efficient function for use in the case where one's aim is to choose *one* (the best) alternative amongst several. Another problem is that the structure of the verbal decision model is determined before any real alternatives are explicitly considered and remains fixed during the assessment of these alternatives. This is useful in cases where the model is designed to represent the *fixed* preferences of the decision maker (i.e., his "policy"), and where other judges may subsequently need to develop preferences between alternatives precisely on the basis of this policy. Hence, ZAPROS does not permit dynamic modelling of the criteria in the decision model in interaction with a consideration of the *real* alternatives that they must discriminate between, as MAUD does. This is likely to be a serious limitation on ZAPROS's effectiveness in supporting strategic decision making, as the support that MAUD could give in initiating and guiding criteria restructuring is typically the most important form of support that it has to offer in real-life applications (Humphreys and McFadden, 1980).

3. DYNAMIC PROCESS MODELLING IN DECISION MAKING: DOMINANCE SEARCH THEORY

Both MAUD and ZAPROS possess some highly successful capabilities in supporting strategic decision making but, perhaps, fail to offer a really high level of support throughout the whole process of strategic decision making due to their inherently limited process modelling capabilities. In this section, we examine how we can develop a model of the process of strategic decision making before describing, in the next section, how it may be used to integrate the best features of MAUD and ZAPROS in providing truly comprehensive support.

As a starting point, we shall consider how people really make decisions in real life taking into account the results of some of the descriptive investigations reviewed by Aschenbrenner (1979) and Larichev (1980), particularly studies of human behaviour in comparing relatively small number of multiattributed alternatives (as is usually the case in strategic decision making). These studies indicate that there is only a limited number of strategies used by people in comparing alternatives and in choosing the best one. These strategies can be divided roughly into two groups, following Montgomery's (1983) distinction of the type of decision rules used:

(i) *compensation rules,* where people try to compare estimates of one alternative with the estimates of the other alternative; and,

(ii) *elimination rules,* where people try to exclude alternatives not satisfying their requirements upon one or several criteria.

Using various methods (e.g., eye-fixation, Russo and Rosen, 1975; think-aloud protocols, Montgomery and Svenson, 1976; information board, Payne, 1976), it was shown that compensation strategies were most often used in the task of choosing the best alternative out of several. Moreover, when 6 to 10 alternatives were presented in terms of sets of estimates on attribute dimensions, subjects would usually compare them in a pairwise manner, keep the best one of the pair, and then, turn to the next one (Montgomery and Svenson, 1976).

Montgomery (1977, 1983) synthesised these and related results into a *dominance search* process model of decision making, for which he gave the following rationale:

> "When making decisions, people attempt to find arguments which make it possible to stick to a certain line of action whatever happens (within limits given by the decision problem). If the chosen alternative can be seen as dominating other alternatives, the decision maker will have access to arguments which may serve such a function. Because of this, decision makers search for a cognitive representation in which a promising alternative can be seen as dominant." (Montgomery, 1987, p. 222)

The process model Montgomery proposed was organised into four phases:

1. *pre-editing,* where the decision maker delimits the decision problem, selecting the alternatives and attributes that are to be included in the dominance structure;

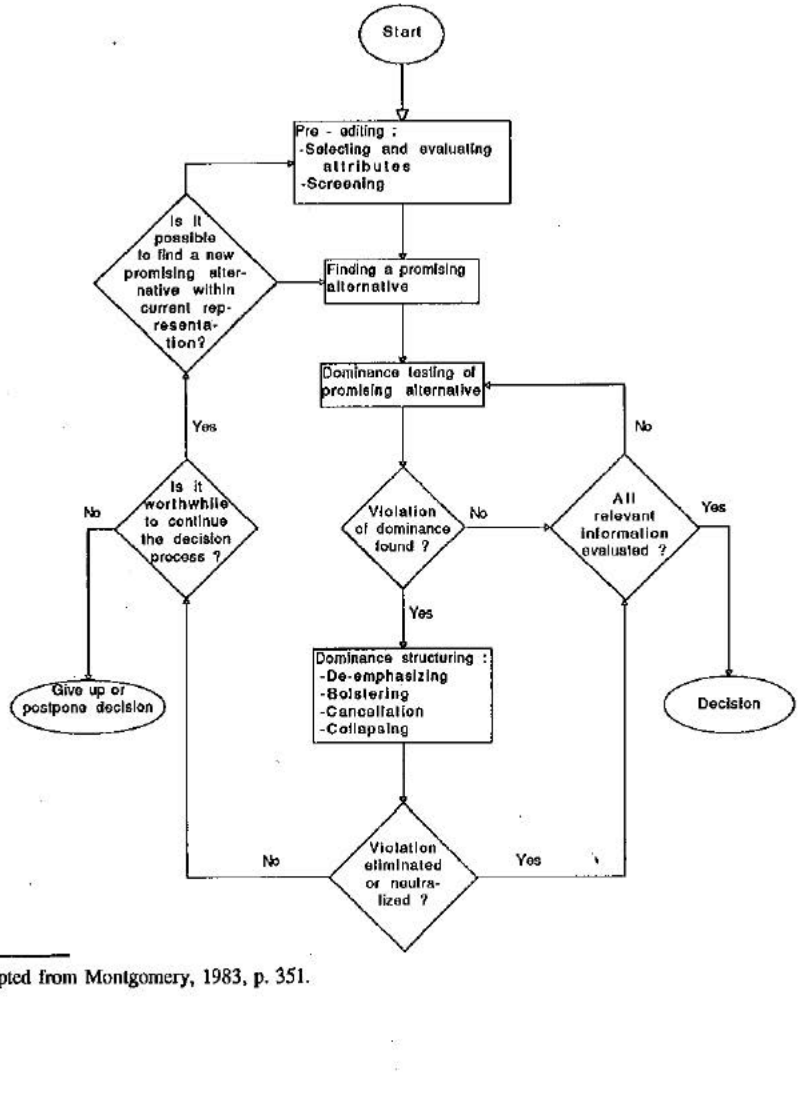
2. *find promising alternative* (i.e., one that has a reasonable chance to be dominant over the others selected in the pre-editing phase);

3. *dominance testing,* consisting of pairwise comparisons with other alternatives to find out whether a promising alternative can be seen as dominant; and,

4. *dominance structuring*, where the aim is to eliminate or neutralise all violations of dominance for a promising alternative that have been found in a dominance testing phase.

Montgomery (1983) described how the decision process, moving through these phases, can be viewed as following the flowchart shown in figure 1 (with the caveat that it should not be taken too literally).

Figure 1: Flowchart for the dominance search process model of decision making[3]



[3] Adapted from Montgomery, 1983, p. 351.

In Montgomery's view, the aim in dominance structuring is not to change the most promising alternative which only partially dominates the others but, rather, to *change the characteristics of the decision model* such that the impression of dominance is strengthened. This may be done by *de-emphasising* an attribute on which it scores relatively poorly, or *bolstering* support for it by enhancing its attributes across alternatives. This is in line with cognitive dissonance theory's claim that people need to reduce dissonance (which is the aim of techniques like de-emphasising and bolstering; c.f. Festinger, 1964), but has led to accusations by Beach and Mitchell (1987b), among others, that this is done, according to dominance search theory, by deceiving oneself. Instead, Beach and Mitchell (1987b) propose that, in such cases, one should try to improve the most promising alternative itself, not just its representation. They write,

> "when progress is insufficient, rectification consists of abandoning the inadequate plan (action) and thinking things through again in an attempt to come up with something better, not in trying to salvage an obviously failed decision." (p. 232)

This proposal receives support from case studies of strategic decision making carried out in VNIISI (Oseredko, Larichev and Mechitov, 1982; Larichev, Nagiskaya and Mechitov, 1974) where, in each case, we observed the intention of the decision maker to find a multiattributed alternative that dominated the others (from the various points of view of the active participants in the decision process). In cases where it was impossible to find such an alternative, the decision maker would try to change one of the promising alternatives to create a new alternative which would meet the requirements of *all* the participants that it should dominate the others on their own criteria.

These results indicate that, while the basic structure of Montgomery's dominance search process model still holds good, the dominance structuring phase should guide the synthesis and construction of new alternatives in order to provide support for improved strategic decision making *in reality* (rather than just support the decision maker's fantasies).

4. COMPREHENSIVE SUPPORT FOR THE PROCESS OF DEVELOPING AND EVALUATING ALTERNATIVES: ASTRIDA

ASTRIDA is a microcomputer-based decision support system which was designed to build on the merits of both MAUD and ZAPROS while overcoming their relative disadvantages (Berkeley, Humphreys, Larichev and Moshkovich, 1989). Both MAUD and ZAPROS respect the decision maker's desire to express the problem in his own language and terms, and partially support this desire, but in different ways. In ASTRIDA, this aspect is brought to the fore by building on, and extending, the best functions employed to this end in both MAUD and ZAPROS, while also greatly improving on the process modelling capabilities possessed by either of them.

The MAUT-based composition rule employed in MAUD and the verbal decision model employed in ZAPROS are designed to permit comparison of a given set of alternatives. As such, they can be used only at a stage in the decision making process where the structure of the problem is fully developed (in terms of alternatives, criteria, assessments of attributes of alternatives on criteria) and is considered to be fixed. But in tasks of strategic choice, as we have seen above, it very often turns out that a decision maker, in the process of decision making, begins to understand that he is not satisfied with any of the existing alternatives.

In this case, provision of effective decision support can only be achieved through guiding the decision maker in *generating* a new alternative on the basis of the current ones, or in working out requirements for a new problem formulation. While both MAUD and ZAPROS allow decision makers to edit, delete, redefine and add alternatives during sessions with them (and re-compute accordingly), neither is able to provide much information, on the basis of the internal analyses available within their decision models, which would allow the generation of some hypotheses on how best the decision maker could restructure the set of alternatives and/or the problem formulation. The more powerful process modelling facilities in ASTRIDA, however, allow this to be done in a very comprehensive way.

4.1. Process modelling in ASTRIDA from the user's point of view

Fundamentally, process modelling in ASTRIDA is used for the purpose of organising the decision maker's thoughts about the alternatives and for articulating and making explicit aspects of preferences between their attributes which are not as yet clear in the decision maker's mind. It employs preference structuring rules which serve to pull together the elements which are essential for the decision maker to reach a choice.

Given these premises, ASTRIDA's process model works as follows:

1. In starting a session with ASTRIDA, the user needs to identify himself as *the* decision maker. He is able to review a library of his own problems, or of public problems which have been developed previously by decision makers working with ASTRIDA. The user may also review a library of his own preference templates[4], or those developed originally for use on other problems, but which are now available for public use. The decision maker must identify the problem and preference template by name before proceeding further. If the name given does not match an entry in the relevant library, then ASTRIDA assumes that this will be a new, initially empty, problem or preference template description which will be developed from scratch by the user during the current session.
2. The decision maker is asked to define the problem he is facing by providing a global description of it and by recording any information of interest about the stakeholders in the problem and the implementation of its solution.[5]

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[4] A *preference template* is a set of criteria with levels on those criteria defined but without any definition of alternatives, or estimates of alternatives on criteria.

[5] Problems often tend to have a number of different stakeholders concerned with them either by being directly involved in the decision (i.e., taking it) or by virtue of the fact that they have a stake in the decision (e.g., having to bear its consequences). Even if the problem is a personal one, one often may have to consider how it impinges on other persons. Thus, at this stage, ASTRIDA enquires about other stakeholders involved in the problem. Information gained through this enquiry can be used to check whether the concerns expressed in describing the particular problem also include issues of concern to other stakeholders in the problem.

3. Elaboration of the problem (corresponding to Montgomery's *pre-editing* phase) starts either by developing the alternatives considered in solving the problem, or developing the criteria which have a bearing on how the concerns of the problem will be addressed by ASTRIDA and the decision maker.

   In the case where the user wishes to start by considering some predefined alternatives, he is encouraged to use the alternative-developing avenue within ASTRIDA. In the case where the user does not wish to start from considering specific alternatives but from an image of his preferred solution (c.f. Beach and Mitchell, 1987a), then developing the criteria on which solutions to the problem may be judged can be the immediate goal. Here, ASTRIDA's criteria structuring heuristics (developed from those originally implemented in MAUD) can offer assistance.

   In the case of a repeated problem (as when an organisation has had experience with a certain kind of problem in the past and has thus already defined the criteria on which such problems may be considered against), the relevant preference template (identified in step 1) can be edited accordingly in this step as a basis for developing both alternatives and criteria into a form appropriate for the current problem.

4. If the decision maker has chosen to start in step 3 by developing alternatives, step 4 involves describing the criteria on which the alternatives will have to be judged. Conversely, if the decision maker had first retrieved a pre-existing preference template or started one from scratch, step 4 involves identifying alternatives in the manner described in step 3, above.

5. By this stage, both criteria and alternatives have been developed to the point that the decision maker can now estimate the attractiveness of attributes of alternatives in terms of identified levels on the elicited criteria. Thus, at this step, each alternative is described in verbal terms indexing the levels each of its relevant attributes reaches on each of the elicited or pre-existing criteria.

6. Once alternatives have been estimated on criteria, the decision maker is asked to make an initial identification (if possible) of the *potentially* best alternative amongst the ones he has defined.[6] This is equivalent to the initiation of Montgomery's *find promising alternative* phase. However, if the decision maker is not capable of making a holistic choice concerning the potentially best alternative at this stage, the initial identification of the potentially best alternative is made by ASTRIDA on the basis of a formal analysis.

7. At this step, two alternatives (one of which is the current potentially best alternative) are selected as the basis for pairwise comparisons to be performed by the decision maker. However, when comparing complex alternatives, decision makers find it very hard to maintain in memory all the benefits and disbenefits associated with each alternative. Hence, ASTRIDA employs a special sub-analysis to

[6] Psychological investigations have shown that, when people are asked to choose one alternative amongst several, they usually tend to choose the one which they, at first, consider to be the best. Then, through comparing this potentially best alternative with the remaining ones, sometimes the decision maker's view of which is the potentially best alternative changes.

determine what disbenefit (or complex of disbenefits) may be compensated by what benefit (or complex of benefits) offered by the alternatives in the pair. Thus, in order to compare the real, complex, alternatives a series of *reference objects* (i.e., special alternatives which differ on no more than two or three criteria) are prepared by ASTRIDA. Pairs of reference objects are displayed and the decision maker is asked to indicate his preference in each case.

In the case where the decision maker is unable to compare these reference objects, an additional analysis is carried out wherein the decision maker provides more detailed descriptions of alternatives on the pair of criteria on which they differ, through decomposing these criteria to a more detailed level.

8. This step comprises an analysis of the information gained so far to find out if it is possible to compare the two *real* alternatives selected in step 7 according to the principle of pairwise compensation. If it is possible, the less preferable alternative is eliminated (temporarily) from further consideration, and the more preferable alternative is identified as potentially best. This operation lies within Montgomery's *dominance testing* phase.

9. If ASTRIDA had not been able to compare the alternatives unambiguously in step 8 (i.e., it could not determine which one dominates the other), the decision maker is asked to try to find a basis on which the alternatives can be compared so that a dominant alternative can be identified. If the decision maker cannot compare the alternatives on the basis of the information at hand (i.e., their estimates on the existing criteria in the current preference template), he is asked to merge criteria within the preference template thus identifying new (revised) criteria on a more general level. He may also wish to delete and/or add individual criteria at this stage. The pair of alternatives under consideration are then estimated on the revised criteria.

10. If the decision maker is unable to choose between the pair of alternatives (even after trying to restructure the criteria on which they are estimated), he is asked to indicate the minimal changes[7] required before he can state that *one* alternative of the pair is preferable to the other. The results of these changes in estimates on the pair of alternatives are stored as *adjusted* estimates, the original estimates being left unchanged. The now preferred alternative of the pair is added to the list of *adjusted best* alternatives.

    This is partially equivalent to Montgomery's *dominance structuring* phase with one very important difference: the detailed descriptions of the *adjusted best (hypothetical)* alternatives are remembered, but are carefully distinguished from *potentially best real* alternatives. Adjusted best alternatives are never treated as if they were directly available for choice, without first checking out that they are actually realisable in the way described below.

11. When the process of comparing pairs of alternatives is exhausted, ASTRIDA analyses the results and presents them for review by the decision maker. If an *actual*

[7] This is done in the direction of greater attractiveness of the original estimates of one or the other of the pair of alternatives on some criterion or criteria the decision maker selects.

best alternative can be identified (i.e., one based upon the decision maker's *original* estimates on criteria for it), the goal of identifying that alternative as the *actual choice* has been attained. If, however, the analysis reveals that the selection can only be made on the basis of alternatives with adjusted estimates on criteria, the list of *potentially best* alternatives is presented to the decision maker for review together with proposals about any further analysis he may wish to carry out concerning the objectives to be met through realisation of any of these alternatives in the world of implementation.

In this review, the decision maker carries out, in interaction with ASTRIDA, an analysis of all the changes between original and adjusted estimates for the set of *adjusted best* alternatives so that, in each case, the "image" of a new, desirable, but still hypothetical alternative is created (c.f. Beach and Mitchell, 1987a). The following question is posed to the decision maker:

"is it possible to achieve the realisation of such an alternative (i.e., one with the characteristics indicated through the set of its adjusted estimates on the criteria) in the real world of implementation?"

If this is possible for only one alternative, the decision maker is advised to seek the realisation of this alternative according to its adjusted estimates. If more than one adjusted best alternative is declared potentially realisable by the decision maker, a choice has to be made between the particular alternatives in this set of potentially realisable alternatives (which *all* dominate the other, actually realisable, alternatives). This involves returning to step 6, and carrying on by considering now only this reduced set of alternatives.

If the decision maker considers that it is *not* possible to realise any of the adjusted best alternatives, he will need to change the initial statement of the problem (returning to step 2). This may involve finding new alternatives, obtaining new information, increasing (or decreasing) the number of criteria, and so on.

4.2. Process modelling in ASTRIDA from the system designer's point of view

The software architecture of the ASTRIDA system comprises:

(i) a *dialogue manager*, which handles "top-level" interactions with the user and the selection of functions within ASTRIDA in the process of developing a representation of the problem;

(ii) a set of *process modules*, which handle specifically focused interactions with the user, and implement the specific algorithms and procedures required to develop the relevant aspects of the problem representation;

(iii) a *data conceptual schema*, which is an object-oriented database holding all information about the problem and its development which needs to be shared across process modules;[8] and,

(iv) a *front end* infrastructure, which contains the supporting set of user interface functions for window management, menu management, etc.

[8] For details, see Berkeley, Humphreys, Larichev and Moshkovich, 1989.

Figure 2: Global design of ASTRIDA, showing the principal process modules and their interrelations in a state-transition net

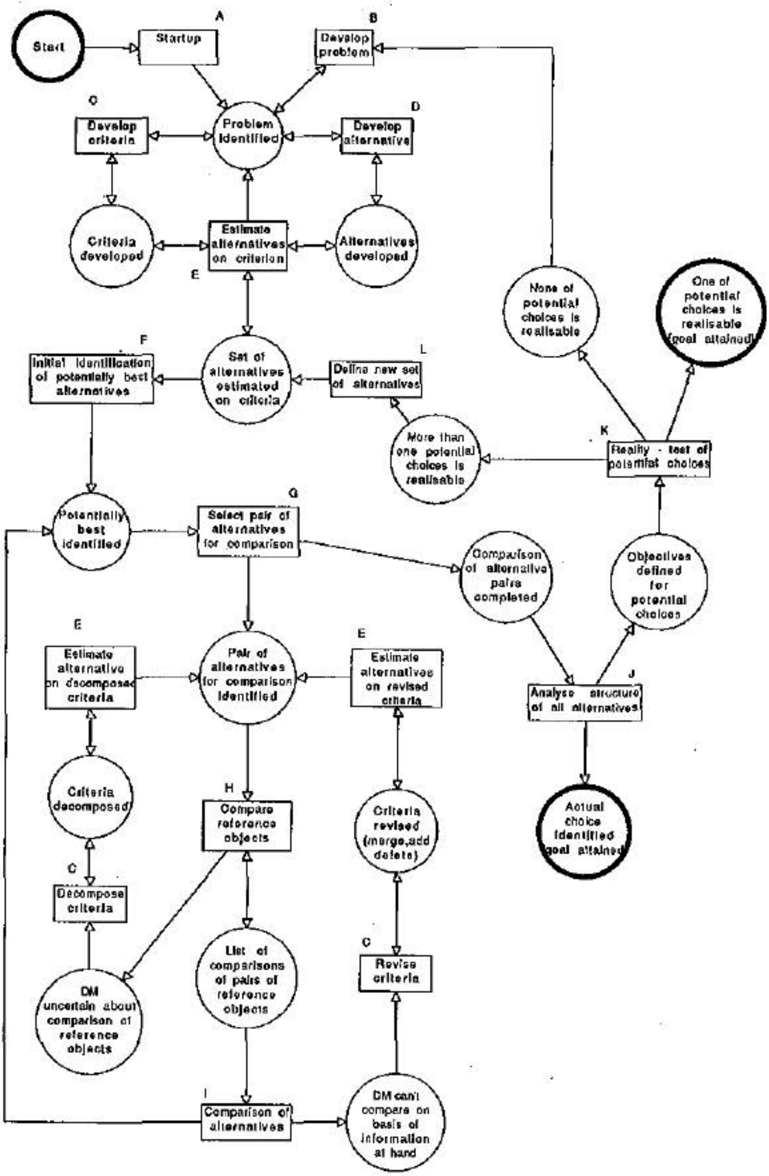


Figure 2, provides a state-transition net showing the modules (A through L) implemented within the ASTRIDA system, and their relationships. The process modelling steps described in the previous section from the user's point of view can be traced as transitions in that net. Note that the net also gives a better indication of the dynamism in the process than does the superficially linear presentation necessitated by the verbal description given in section 4.1.[9]

The detailed design of ASTRIDA followed the approach linking process modelling to object-oriented data conceptual schema development described in Berkeley, de Hoog and Humphreys (1990). A predicate-transition formalisation of each process module is refined to the point that operations on instances of object classes within the conceptual schema are specified. In this way, the software design is completed without introducing ad-hoc components or concepts which depart from the functional requirements of the process model for supporting strategic decision making that we have developed throughout this paper.

5. EMBEDDING ASTRIDA WITHIN A GENERAL PROCEDURAL SCHEMA FOR PROBLEM STRUCTURING AND DECISION MAKING

ASTRIDA, like MAUD and ZAPROS, assumes that the decision problem has been defined well enough *prior to its application*, for scenarios for the initial set of strategic decision alternatives to exist in the mind of the decision maker. As such, it provides support for the later rather than the earlier activities within the whole process of problem structuring and decision making. This process starts from the point where there is merely an awareness of a problem and cycles through to the point where a firm commitment is made to attempt to implement a chosen alternative in reality.

Figure 3 illustrates a general procedural schema for this process, presented as a *state-transition net* model.[10] Here, each of the major activities in the process is shown as a *transition* (inscribed in a rectangular box) through part of the schema. The postconditions which may be achieved through each transition are shown as *states* (inscribed in circular boxes) reached through the arrows (links) pointing out from the transition box. These may also serve as preconditions for subsequent activities as indicated by arrows pointing into the relevant transition boxes. The seven major activities in the schema are:

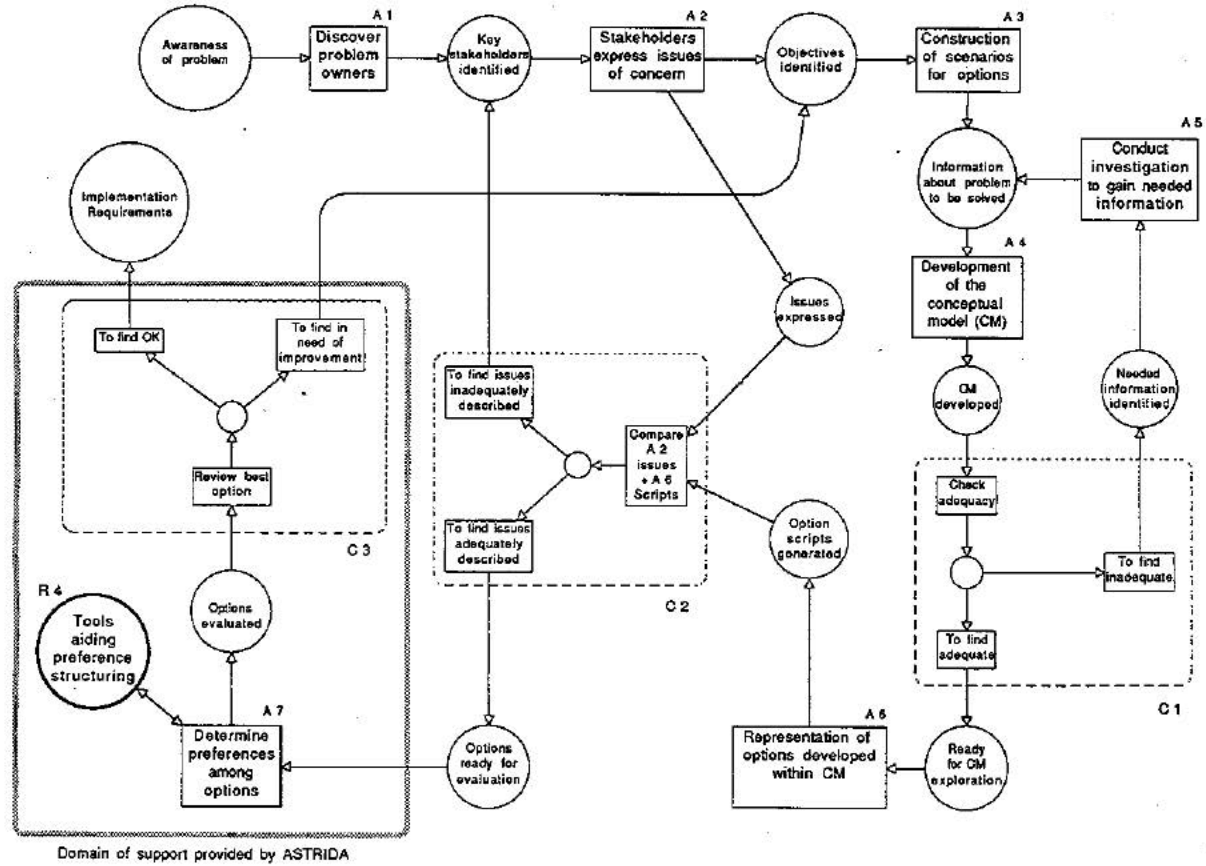
A1: initiation;

A2: expression of desire for improvement in the situation;

[9] Where a module is shown in more than one position, the *same* module is being employed in different contexts, with different preconditions.

[10] This schema was developed from one first proposed within the framework of Checkland's (1981) soft systems methodology (Humphreys and Berkeley, 1987; Humphreys, 1989). Variants of this procedural schema have been applied successfully in analysing applications of many varieties of systems and decision making methodologies within organisations in transition (e.g., Hawgood and Humphreys, 1988; Humphreys, Larichev, Vari and Vecsenyi, 1990).

Figure 3: Example of a general procedural schema for handling strategic decision problems



A3: construction of scenarios for options (i.e., decision alternatives);

A4: development of the conceptual model;

A5: gain information about the world of options;

A6: representation of options developed within the conceptual model;

A7: determine preferences among options.

Starting from the initial entry at activity A1, moving through the procedural schema is rather like playing a board game. The procedural schema is the board, the players are the stakeholders in the problem definition process. Progress through the schema is constrained to move sequentially through the seven major activities indicated in figure 3, but with considerable variation, according to the nature of the specific decision situation and of the decision maker concerning (i) the way the process is developed within each activity, (ii) the conditions which initiate the move from one activity to the next, and (iii) how the decision is made of whether or not to re-traverse a part of the cycle in the overall process of problem definition. A fundamental principle of effective support for problem owners is that assistance should be focused at the point within the overall decision making process where the problem owner is currently having difficulty in proceeding (Jungermann, 1980). These difficulties can be located and articulated at the appropriate activity within the general procedural schema which can be extended to indicate four major classes of support techniques and tools (R1 to R4), each with a qualitatively different support function, and each pointing to the activity within the schema where techniques and tools within that class may be able to render effective support[11]. These are:

Support class R1: techniques and tools facilitating problem owners' expression of issues of concern (providing support for activity A2, as indicated in figure 3).

Support class R2: techniques and tools aiding the generation of conceptual models (providing support for activity A4, as indicated in figure 3).

Support class R3: techniques and tools aiding exploration through a conceptual model (providing support for activity A6, as indicated in figure 3).

Support class R4: techniques and tools aiding preference structuring (providing support for activity A7, as indicated in figure 3).

Within this classification, MAUD, ZAPROS and ASTRIDA all belong to class R4. However, the process modelling capabilities of ASTRIDA allow it to be embedded within the general procedural schema for handling strategic decision problems in a more comprehensive way than is possible for other techniques and tools providing class R4 support. This is because ASTRIDA's module J (shown in figure 2) provides full support for comparison C3 within the general procedural schema shown in figure 3.

If an *actual best* alternative is chosen with the aid of ASTRIDA's module J, "to find O.K." is confirmed automatically as the chosen alternative has previously been

[11] Humphreys and Wisudha (1990) detail the nature of the support which can usefully be provided within each of these four classes and review the characteristics of some promising, currently available, support tools within each class.

assessed as realisable through activities A4 and A5 in the general procedural schema. However, when one or more *potentially best* alternatives are identified, these will not have been confirmed *a priori* as realisable, since they depend on "adjusted best" estimates on criteria, representing the precise improvements in levels on these criteria which each particular *potentially best* alternative would have to be able to achieve so that it can be chosen for implementation in reality.

Thus, ASTRIDA's module J provides precise proposals for improvement in terms of the objectives which would have to be met by each potentially best alternative so that it can be choosen. The issue of whether or not any *potentially best* alternative can actually meet the required objectives is addressed in ASTRIDA's module K (in figure 2), where the reality-testing of scenarios for improved alternatives is necessarily left to the decision maker.

Inspection of figure 3 reveals that an excellent way of accomplishing such reality-testing is through re-traversing activities A3 through A6 in the general procedural schema. This is exactly what ASTRIDA advises the decision maker to do. ASTRIDA's module K then completes comparison C2 within the general procedural schema. If *none* of the potential choices are thus found to be realisable, then the problem has to be re-developed from the point where key stakeholders are identified (see figure 3). If *just one* potential choice alternative is found to be realisable, then activity A7 is trivial: the decision is made. If, however, *more than one* potential choice alternative is found to be realisable, ASTRIDA assembles these as a new set of real alternatives and proceeds to help the decision maker choose between them.

ASTRIDA is currently under development and it is expected to be made commercially available by the end of 1991. ASTRIDA is designed as a stand-alone decision support system which can aid the decision maker in choosing between alternative courses of action. As was described in the previous sections of the paper, it places stress on the importance of modelling the decision making process and provides support for it throughout. However, it does not provide support of the nature that has been described within classes R1, R2 and R3 by Humphreys and Wisudha (1990). Thus, it is unable to support the earlier phases during the process of strategic decision making which are just as important. Hence, its greatest value in practical applications will be perhaps achieved as part of a *comprehensive* toolkit which can help for handling strategic decision problems (Larichev, 1984) comprising also techniques and tools providing class R1, R2 and R3 support.

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