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COMPARATIVE ANALYSIS OF USE OF DECISION SUPPORT SYSTEMS IN R & D DECISIONS

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Issues determining the success of applications of Decision Support Systems in ill-structured situations are examined through four case studies of R & D decision making. These concern (1) introduction of a new product where the R & D decision is taken at the company board level; (2) the determination of the product mix for a medium-sized manufacturing enterprise where more than one level of decision making is involved; (3) R & D decision making at the branch level within a three-level planning hierarchy; (4) the use of DSS in "top-level" decision making involving selection between proposals covering a wide range of R & D activities. In each case the context of each round in the decision making process is identified, together with the roles, motivation and responsibilities of the participants, and the level in the organizational process at which the DSS is implemented; factors which are shown to vitally influence the nature and success of the DSS usage. Pitfalls for DSS designers are uncovered through analysis and comparison of the cases, and ways of avoiding them are proposed.

INTRODUCTION

This paper examines through the use of case studies some factors which facilitate or limit the effectiveness of Decision Support Systems introduced into R & D decision making processes[1]. There is as yet no formal theory of exactly what constitutes decision support, and "Decision Support Systems" (DSS) is partly a rallying cry (Keen and Hackathorn, 1979). Here we adopt a very general view of a DSS. The system may involve the systematic use of tools, techniques, methods, etc., which support activities like the generation of decision alternatives, the elicitation and representation of information (values, premises, uncertainties) within decision models, the estimation of consequences of possible decisions, and the ranking of the alternatives in order of acceptability. However, while elements of these activities may be computer-based, in our view the system as a whole involves procedures carried out by individuals in interaction with others within an organizational context.

While successful implementations have been documented within R & D planning contexts (Boichenko et al, 1978; Mansfield, 1978; Souder, 1978), it is more common to find that the role actually occupied by the DSS in the overall decision making process was much more limited and quite often at variance with that anticipated by its designers or by the personnel who introduced the DSS into the decision making process (von Winterfeldt, 1982). One of the reasons

for this lies in the nature of the decision problems which have to be addressed: R & D planning problems tend to be relatively unstructured (McCosh & Scott Morton, 1978, Larichev, 1982). The decision problems faced in the four cases studied here were all of this type.

In Case 1, the directors of a medium sized company in Great Britain were quite uncertain about the structure of an R & D problem: should they replace an old, but currently successful product (a marine engine) with a new one involving a change to a more advanced technology in which they, as yet, have little experience. The new engine may be better able to meet as yet unspecified stricter environmental polution regulations, should they be introduced (and how should one estimate the likelihood of their being introduced in the next few years?)

In Case 2, the future of a Hungarian chemical works was uncertain. The works was producing plastic articles, pesticides, intermediaries used in the pharmaceutical industry and a variety of other organic and non-organic chemicals. Recently its rate of development had decreased, it had economic troubles and the ministry wanted to reduce its autonomy by fusing it with a larger enterprise. In what was seen as a last chance for the chemical works, new top managers were invited to help in solving the company's problems and to formulate a strategy for its development. But what should this strategy be - what criteria does it have to meet?

In Case 3, decision makers within a Hungarian State authority responsible for a sector of services at the national level were facing the problem of budget allocation among R & D projects. Because of the heterogenity of R & D activities in the field, the projects, as well as the phases in decision making were arranged in a three level hierarchical system comprising main areas (first level), programs (second level) and tasks (third level). However, each second level program comprised a set of tasks which were not rigidly defined, and each first level area comprised programs which were not rigidly pre-determined, and so decisions arrived at sequentially would not necessarily be consistent. How can harmony, rather than conflict, be ensured between the decisions taken at the three levels?

In Case 4, located at the highest level in an organizational hierarchy, a decision maker in the USSR had the task of evaluating approximately 1000 research and development projects. The decisions had to be made as the individual proposals came in. Yet the criteria for choice of projects had to be stable and set a priori. Moreover, these criteria, and values on them were all expressed in verbal terms. How can the decision maker decide how to structure them in the absence of a data base, that is, before the projects arrive?

In facing decision problems like these, there is likely to be confusion in the decision maker's mind at the outset concerning the nature of the problem domain. In some cases, parts of the decision problem may be well modelled a priori. For example, in Case 1 the company had a marketing department which felt confident that it could predict market share for a product with a given price and specification, defined in terms of advantages and disadvantages over its competitors. But other parts of the same problem may be less easy to structure on the basis of information already gained about the problem domain. In anticipation of the possible effects of changed environmental pollution regulations, does one have to consider the possibility of a change of

government in the next ten years and predict the changed policy that would go with it?

In providing decision support for ill-structured problems like these, it is our belief that the "knowledge system" incorporated in the DSS (Bonczek et al, 1983) must be of a fundamentally different character to that which can profitably be developed in supporting the analysis of well structured problems and repeated decisions. A corollary of a problem being ill-structured is that at the outset the domain of facts which may be relevant is potentially infinite. Given such a problem, and the severe time constraints which typify R & D decision making, we consider that it is usually better to leave the knowledge base in the minds of the participants. Computer-based resources can then be focussed on developing methods for (i) structuring the problem, (ii) accessing the knowledge base existing in the participants' minds, (iii) simulating alternatives under various assumptions and perspectives and (iv) performing interactive sensitivity analyses to provide an informed basis for choice.

DEVELOPING THE METHODOLOGY OF DESCRIPTION AND EVALUATION OF DSS USAGE IN R & D PLANNING

R & D planning in real life is a continuous process with sequential variety in the pattern of activities and participants involved. The conceptual framework used here requires that we first divide up the process into interconnected segments which can be separately modelled, together with the specification of linkages between these segments. This involves identifying a sequence of rounds, and stages within each round, in the planning process as well as specifying the level (or levels) of the decision making activities within each round.

ROUNDS AND STAGES

Our definition of a round within the decision making process follows that proposed by Kunreuther (1982) as

> "A round is simply a convenient device to illustrate a change in the focus of discussion either because (1) a key decision was taken (or a stalemate reached due to conflicts among parties) or (2) a change occurred in the context of the discussions due to an exogenous event, entrance of a new party or new evidence to the debate ... no matter how a round is initiated it is characterized by a unique problem formulation which is presented in the form of a set of attributes."

Within each of our case studies of R & D decision making we identify a set of stages within the rounds studied. Each stage is located in terms of those stages which precede and follow it. Its inputs and outputs are usually well defined. The outputs from a stage may serve as inputs to the immediately following stage in the round, or to any defined subsequent stage in the round. The converse holds for inputs to a stage. Inputs and outputs between rounds are generally less well defined as a boundary between rounds generally represents an untheorized discontinuity in the planning process. At the start of a new round outputs from previous rounds tend to be picked up and interpreted as inputs in ways unanticipated during the previous round.

At each stage within a round the "unique problem formulation" to which the round is addressed is represented in a different form. Where a DSS is employed, it will be important to examine whether the problem formulation to which the DSS is addressed is "requisite". Phillips describes the relevant requirements as follows:

> "To develop a requisite model, it is necessary to involve all those who are in some way responsible for aspects of the decision in the development of the requisite model. The process of building the model is iterative and consultative, and when no new intuitions emerge about the problem, the model is considered to be 'requisite'. In requisite modelling, it is expected that people will change their view of the problem during the development of the model; that is why the process has to be iterative." (1982, p.304)

This ideal way of constructing a requisite model is rarely achieved in practice but it gives us some clues about questions to ask in examining the degree of "requisiteness" extant in actual applications supported by DSS, viz: Are all those who are in some way responsible for currently modelled aspects of the decision involved in the development of the model? Are intuitions emerging about the decision in personnel currently involved or responsible for subsequent actions which are not incorporated in the model? Is the modelling process iterative in a way that can encompass changing or different views?

LEVELS

R & D policymaking usually progresses at several levels. These may be bureaucratically determined, where different strata within an organization are charged with policies with different scopes and time horizons. A particular R & D planning process may involve a departmental management stratum dealing with the evaluation of the characteristics of a particular product; a general enterprise management stratum dealing with problems of introduction of positively evaluated new products; a corporate or sector management stratum dealing with the future of the enterprise within a wider plan, and so forth. In general, the way in which a R & D planning problem is represented within a DSS will, if requisite, be specific to the organizational management stratum whose activities are being supported by the system (Jaques, 1976). Within any stage of the decision process "officially" located at the level of a defined stratum we may, however, find participants operating at different levels of problem conceptualization.

ROLES OF PARTICIPANTS IN THE ROUND

Within any stage in a round, individual participants can be classified as **decision makers** (defined as those who have the executive power to define the use of outputs from the round); **proposers** (those who have power only to make recommendations on this); **experts** (those whose primary function is to supply inputs to the currently modelled problem structure); **consultants** or decision analysts (those who advise on methods of problem representation) and **facilitators** (those who do not take any direct role in the decision making process, but who are in a position to facilitate the collaboration of experts, the transmission of the results within and/between rounds, and so on). A participant may act in different roles within rounds located at different levels, or even within different stages in a particular round. Therefore, in

categorizing participants, it is important that their roles be defined in relation to the state of problem representation and DSS in use at each stage in a round. Participants may also serve as links between stages or rounds, carrying certain information with them, but this is a process which can be studied separately.

MOTIVATION OF PARTICIPANTS IN THE ROUND

In the case studies outlined below we will be looking primarily at rounds in the R & D planning process where a new form of DSS was introduced. We shall see that it is very important to understand the differing motivations of the participants in the round, as this will affect the results they expect from the DSS, and how they view their significance (Berkeley & Humphreys, 1982).

A decision maker may be strongly motivated to apply decision analytic methods implementing DSS in situations involving many complex R & D proposals. In such cases a decision maker has practically no avenue of influence on decision processes except through the utilization of decision rules superimposed on expert evaluations. The support he is likely to seek from a DSS is that which will help him to increase the centralization of decision making through exercising influence in this way.

A proposer may wish to employ a DSS to get proof of support of experts, while already having some idea of what will make the project acceptable to those who will consider his or her recommendations. Some of the support which he is likely to seek from a DSS has to do with the possibilities of manipulation which can lead to a particular interest in a DSS having simulation capabilities under alternative scenarios (Humphreys & McFadden, 1980). It is often proposers who introduces consultants as this can serve their interest in increasing the probability of the acceptance of their proposals.

A consultant's principal motivation, as an outsider, is usually concerned with the acceptance of the procedures he or she introduces, which in the case studies discussed here were linked to DSS. However, doing this means penetrating an organizational culture (Handy,1981) and taking on a temporary role within that culture. The nature of this role sometimes attracts other motivations potentially in conflict with the principal motivation. These can sometimes reflect a desire for power ("behind the throne"), status ("consorting with the great"), social beliefs (promoting the "decision culture"; improving "organizational democracy") or self image (to be a "helping person")

The motivation of a participant in the round determines his or her view of the function of expected results of DSS usage. However, the extent to which this will lead to a positive orientation towards the DSS will depend upon how its effects are preceived at the outset of the round. Some of the relations involved here are shown in Figure 1.

RESPONSIBILITY

The relationship between motivation and perceived effects of DSS depends also on the responsibility a participant holds or wishes to assume. A high level decision maker with responsibility for implementation of policy may use the report from a decision analysis as justification for the policy. In effect

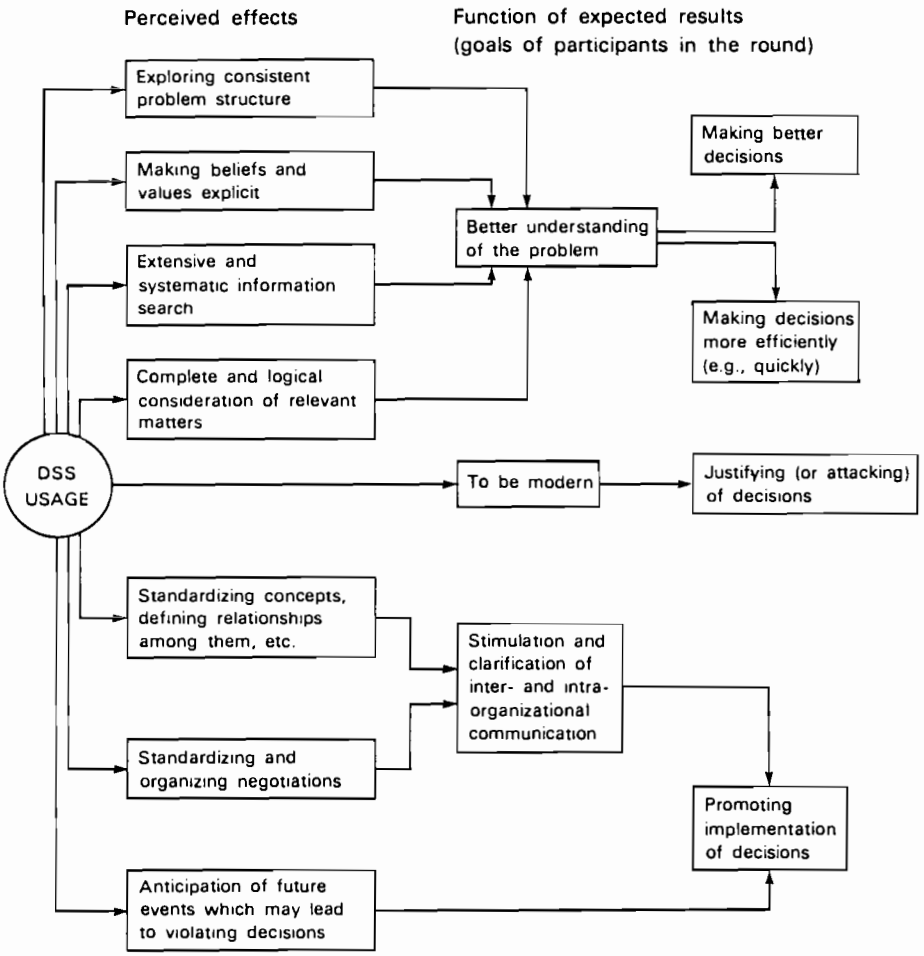

Figure 1 Some relations between perceived effects of DSS usage and goals of a participant in a round

this shifts responsibility in the case of failure onto the report and its creators and where a DSS has been explicitly involved it often ends up collecting a large share of the blame. Proposers may attempt to structure a problem to fit the preferences that they believe held by those with executive responsibility to whom they report. They may be more sensitive to their own position and career prospects than to an effective outcome, and it is with regard to these prospects that they may examine the adequacy of a problem representation constructed through the use of the DSS. In view of possibilities like these, we hypothesize that motivation and responsibility will interact in determining DSS acceptability in the way shown in Figure 2.

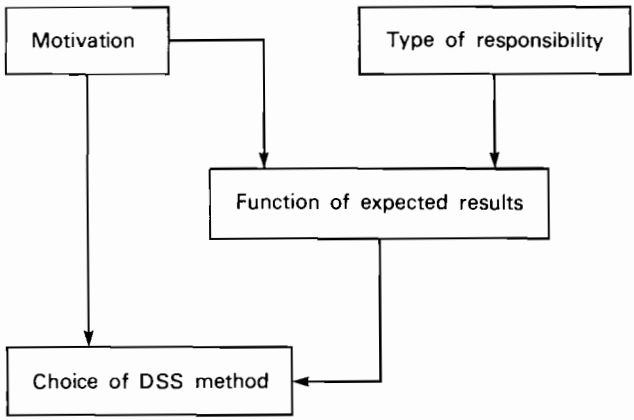

Figure 2 Hypothesized effects of motivation and responsibility on choice of DSS

A CHECK LIST FOR DEVELOPING CASE STUDIES

The issues raised in the previous section imply that, in comparing R & D/DSS case studies, one should develop a framework whose components are connected with:

(a) the organization and procedure of R & D planning.
(b) the goals that participants in the planning process hope will be achieved by using DSS within the context.
(c) the expected and the actual role of the consultants and of the other participants in stages of the decision process within the round.
(d) the expected and real function of inter- and intra-organizational communication within and across stages in the round (e.g., group negotiations).
(e) the requirements for information (e.g., the required number of alternatives, attributes, and scenarios regarded simultaneously), and its mode of availability.
(f) the way of handling uncertainties.
(g) the way divergent views are reconciled.

From this framework we developed a checklist of some items to be used in analysing the case studies described here. This check list, and details of its use, are published in Humphreys, Vari and Vecsenyi(1982). Here we will highlight some of the findings which were gained from applying the checklist retrospectively to four case studies, and provide references to the papers where the case analyses are described in detail. This will be followed by a review of findings from some comparisons we were able to make across the various case studies.

CASE 1: INTRODUCTION OF A NEW PRODUCT: MARITIME ENGINES AND MOTORS (MEM)

This study is located at the board level of MEM, a British company manufacturing outboard motors and small maritime engines (details are given in Phillips, 1982; the name of the firm and its product have been changed to maintain confidentiality). A single R & D decision had to be taken between continuing to manufacture an old product that might in the near future be banned by the government for failing to meet exhaust emission standards or introducing an improved product that would beat the ban but might lose market share to competing products using micro-chip technology. The company was unable to move directly to a chip-based product as it did not, as yet, have the required technology. Hence any product introducted in the next few years would have to rely on improvements in conventional technology.

MEM ROUND 1 (NO DSS)

The participants in the decision making process comprised MEM's board of directors. The managing director was the decision maker with executive power, but the board, meeting as a whole, had to agree on the action taken on the basis of the information participants have about the problem. The last time MEM considered introducing a new product, a report had been written recommending approval by the board of directors. Directors on the board took exception to certain assumptions made in the report and asked for it to be done over. The revised report was submitted to the board where participants now took exception to other assumptions, and so this process continued for eleven revisions over twelve months at the end of which no decision was taken.

MEM Round 2 (introduction of DSS)

After attending a university management programme course in which decision analysis was introduced, MEM's Managing Director sought the help of the Decision Analysis Unit at Brunel University to see if decision technology could be applied to the problem. This led to the start of a new round where a DSS was introduced in modelling the R & D problem outlined above. The stages and participants in this round are shown in Table 1.

Stage 1 defined the terms of reference for the subsequent stages. The decision makers who participated were MEM's managing director, business planning, finance and production managers and a consultant from the Decision Analysis Unit. Major uncertainties about act-event sequences were identified, company objectives were discussed, a time horizon (10 years) was set for evaluating possible effects of consequences when modelling the decision, and the major characteristics of the financial model to be employed were agreed.

A decision tree was developed in Stage 2 by the consultant through showing and discussing it in individual meetings with a variety of experts (e.g., sales, finance and production managers and some of their staff) and decision makers. In Stage 3, MEM's business planning manager, in the role of an expert, supplied the financial model which was married by the consultant to the decision tree. This formed the basis for a DSS generated by the Decision Analysis Unit, a process which included the use of generic software for building and analysing decision trees.

Stages in the Round \ Participants		Decision makers	Consultants	Experts	Computer
Stage 1: Define terms of reference		* (meeting together)	*		
Stage 2: Develop decision tree		* (meeting singly with consultant)	*	*	*
Stage 3: Develop DSS incorporating tree and functional model		* (meeting singly with consultant)	*	*	*
Stage 4: Decision making	Explicate model	* (meeting together)	*		*
	Conduct sensitivity analysis: final decision	* (meeting together)			*
Stage 5: Defining conditions for implementation of decision		* (acting alone)			

Table 1

Stages and participants in Round 1 of Case 1:
Introduction of new product: Maritime Engines and Motors

In Stage 4, the financial and decision models were presented to MEM's board of directors. Participants in this stage (MEM directors) expressed disagreements about assumptions in the model, and the DSS was used interactively by the decision makers themselves to test the sensitivity of the decision to their differing expressed views on assumptions (the IBM 5110 portable computer implementing the DSS had been brought to the meeting). This process continued iteratively until all participants in the stage were agreed that the patterns of assumptions which would be needed to overturn the

desirability of one of the policies modelled in the decision tree ("introduce improved product now") were unreasonable. The decision makers implicitly located their discussion of alternatives within the problem representation modelled in the DSS. Agreement was reached on policy without the requirement that the decision makers also reach agreement on assumptions about all the values in the model (although the general **structure** of the model had been accepted by consent in stages 1 and 2). The sensitivity analysis had demonstrated to them that each could agree the policy while maintaining his own set of assumptions.

At this point the consultants considered the round to be completed. However, the Managing Director subsequently initiated a further stage within the round. Noting that the R & D decision model accepted in stage 4 indicated that there was a considerable difference between the expected value of having a "clear introduction of the new product" as decided upon in stage 4 and "continuing with the old product", he decided that it would be well worth while trying to improve on the probability (0.6) which had been agreed by the Board as their estimate of getting a clear introduction. This involved spending money on improving the aesthetic design of the product and improving MEM's marketing methods before introducing it. The Managing Director took responsibility for deciding on this expenditure, justifying it as being considerably less (<10%) than that which would be saved through the resulting increase of the probability of a clear introduction to around 0.8.

REASONS FOR SUCCESS

This case study can be judged a success in that the introduction of DSS provided a framework for thinking about the problem which allowed the participants in Stage 4 of the round to reach a unanimous decision and to understand the nature of that decision in relation to their uncertainty about future events and conflicting assumptions. However, in comparing this result with the output of MEM Round one, one can see that nearly every aspect of the decision making process was ripe for improvement through the introduction of a DSS. We can identify some of the reasons which contribute to this success by contrasting this case with those described below, where improving on the previous (non DSS) baseline was generally not so straightforward a task.

CASE 2: DETERMINING A PRODUCT-MIX DEVELOPMENT STRATEGY MAKING BY A HUNGARIAN CHEMICAL WORKS (CW).

The context of this R & D is more complex than that for MEM in that (i) the decision concerned the product mix constituting the entire output of a medium size (3,000 employee) enterprise, rather than just a single product, (ii) while the rounds investigated here were located at top management level within the company, the resulting strategic decision making took place outside at a higher level.

CW ROUND 1

The first round we studied started with the introduction of new top managers at the chemical works to provide the 'last chance' for the works which we described in the introduction to this paper. One of these managers initiated

the analysis of the problem by decision analytic tools. He had been introduced to practical applications of multiattribute utility theory in a post-graduate management science course, and believed that this new method would be better than the traditional cost-effectiveness, market position evaluation. However, the actual method used for the decision analysis (and the supporting computer software) was developed during the round by a team of consultants from the Bureau for Systems Analysis of the Hungarian State Office for Technical Development and the Technical University, Budapest.

R & D strategy making is usually based on the assessment of proposals comprising ideas for new products together with the evaluation of previous R & D results. However, in the situation facing CW, R & D strategy had a different character, requiring pruning of the existing product mix rather than a consideration of possible new additions. The problem for analysis was defined at the outset of the round as the evaluation of the product currently being fabricated, revealing their weak points and requirements for development. This was seen as forming an important input to the overall R & D policy making, which was to determine the development and production strategy for the next one to five years.

Consequently the procedure used within the round did not focus on the assessment of alternative R & D proposals as such but on their components: preferences between products for development and production. This does not mean that assessment of the overall proposals should be omitted from strategy making, only that the DSS applied here was not required to support that activity.

CW ROUND 2

Two years later there was a second round in the process. The mode of initiation of the analysis, the definition of the problem and the method of use of DSS remained the same. However, at this time the situation of CW had improved. In the period between the rounds the firm had gradually started to develop, its economic state had stabilized, and its independence had been assured. Consequently, the motivation of the participants in the round for DSS had changed. In Round 1, decision makers perceived the use of DSS as one of the tools of survival but in Round 2 DSS was perceived by decision makers only as a useful aid in re-evaluating the R & D strategy based on the results of using the DSS in Round 1.

The participants in the round also changed. In Round 1 representatives of state authorities and of related organizations (foreign trade companies, association of chemical enterprises, etc.) were also involved in the analysis supported by the DSS. However, in Round 2 only internal experts were involved. In Round 1, securing the involvement of external representatives was one of the ways of getting their benevolent support in helping CW to survive.. In effect, they had played the role of facilitators in the decision making processes and in round 2 there was no longer a need for such explicit participation of external facilitators.

Here we shall concentrate on CW Round 1, making parallels and contrasts with the MEM study where appropriate. A detailed account of CW Rounds 1 and 2 is given in Vecsenyi (1982).

RESPONSIBILITY AND MOTIVATION OF DECISION MAKERS

As in the case of MEM, the board of top level managers were responsible for the determination of company strategy. However, they knew that they also had to "set an example" to decision makers at a higher level than their own if the company was to survive its independence. At this higher level, they acted as **proposers**, recommending their methods of analysing the problems of the company as the evidence of their own capacity for good strategic planning (as against the alternative of being fused into another strategic plan). Hence their motivation was more complex than that for MEM decision makers, being oriented towards three goals:

(i) rationalizing their decisions by basing them on more reliable information (as in MEM, see the discussion of MEM stages 4 and 5).
(ii) getting the collaboration of lower level managers in carrying out the strategy (this was hardly a problem in MEM, which was hierarchically organized with a board of established authority).
(iii) having a tool for convincing higher level authorities by setting an example to them to solve the problem of company by using up-to-date tools (this served the decision makers in their **proposer** role, which did not exist in the MEM case).

STAGES IN THE ANALYSIS

The DSS used in round 1 was seen by both decision makers and consultants (analysts) as a procedure generating multiattribute utilities of products in the mix on the basis of preferences expressed by individual participants grouped in various ways. This DSS supported the first four of the five stages shown in Table 2.

In the first stage in the analysis, a list of ten main criteria and 36 subcriteria, initially prepared for evaluating the products by postgraduate students in industrial engineering was discussed and modified by 30 leading executives of the company. This resulted in 70 subcriteria, and some changes in the interpretation of the main criteria. In the second stage CW managers determined company objectives and requirements related to criteria, so that attributes of products related to these criteria could be evaluated. In support of this, the consultants (the analysts who designed the DSS) organized a training course for the participants on the methods of weighting attributes and assessments of the products and on the procedure of DSS[5].

In weighting the attributes (stage 3), separate vectors of weights were provided for all 63 participants in this stage in the round (five top level executives, 38 medium level executives and 20 experts)[6]. The director of CW also asked 15 external "higher level" experts (members of the supervising committee and representatives of their respective supervisory committee at Ministry level) to determine importance weights for the principal criteria. The consultants used clustering techniques to compute pooled vectors of weights for three groups of participants in the round: (i) top decision makers within CW, (ii) CW company experts, and (iii) external (higher level) experts. The executives of the company discussed the similarities and

Stages in the Round \ Participants	Proposers	Decision makers	Consultants	Experts	Computer
Stage 1: Exploration of criteria	*	*	*	*	*
Stage 2: Weighting of attributes	*	*		*	
Stage 3: Assessment of alternative products	*	*		*	
Stage 4: Computation of multi-attributed utilities of products in the mix			*		
Stage 5: Strategy making		*			

Table 2

Stages and participants in Round 1 of Case 2:
Determining at product-mix development strategy by a chemical works

differences between the results for the various groups, and agreed that the model should be simulated using (separately) the vectors of weights from these three groups: (i) top executives of the company, (ii) the group whose individual weights demonstrated the highest degree of concordance, and (iii) the weights for the group of all 63 evaluators.

Assessments of 46 alternative CW products were made in stage 3 by the same 63 participants as in Stage 2 (no external experts were involved). The procedure was taught to them in the training course arranged by the consultants so that they could express both valuation and uncertainty on the attributes identified

in Stage 1 in a format appropriate for computing the multiattributed utilities of the products in the in the mix (stage 4). This computation was carried out by the consultants using a multicriteria simulation model developed by Kiss et al (Kiss, 1978; Kiss & Torok, 1979) from a procedure proposed by Kahne (1975). Three separate sets of rankings were computed for the products, one for each of the groups whose attribute weighting vectors were assessed in Stage 3. The consultants reported the evaluation of each product in terms of how each of the three groups viewed it according to the simulation model.

Strategy making (stage 5) was not covered by the DSS as the decision makers did not wish the support of the consultants in this stage and, on the other hand, consultants had no adequate method for strategy making in this case. Thus the problem defined at the start of the round by CW's director as that to be addressed by the DSS was complete at Stage 4, but it provided simulation outputs, not strategic prescriptions. In this sense the DSS supported **proposals**, rather than decisions. Vari and Vecsenyi (1982) discuss this as a pitfall for decision analysis: where the domain of the problem is greater than the domain of the decision analysis. In order to make decisions about the actual development strategies, additional criteria were used in stage 5 by the decisions makers, (e.g., those relating to governmental programs, costs required for development, capacity constraints, etc.). Excluding these from explicit consideration within the DSS meant that only part of the decision makers' values and preferences had to be made explicit and subjected to formal analysis while implicit values could be taken into consideration intuitively by the decision makers during the actual decision which was taken at this stage.

SUCCESS OF THE DSS AS A PROPOSAL SUPPORT SYSTEM (PSS)

Despite the apparent pitfall for DSS in Stage 5, two years later the director of CW initiated a second round in the R & D planning process with the introduction of similar DSS to that used in Round 1. Hence, in some sense the DSS had been found useful. But for supporting what? Von Winterfeldt (1980) has discussed how Multiattribute Utility Theory (MAUT) based systems like that underlying the DSS used here are inappropriate for **decision** analysis in resource allocation problems, like that facing CW. However, given the motivation of CW's managers, discussed in our account of Round 1, it appears that here the DSS met the goals of these decision makers through being perceived as a **proposal** support system (hence the emphasis on its simulation capability) rather than as a decision support system, which is, by contrast, the appropriate characterization for the DSS employed in the MEM case. Understanding the role of the DSS as a PSS sidesteps von Winterfeldt's criticism of the use of MAUT since here it is being used is a system with capabilities for proposal analysis rather than decision analysis. This in our opinion is what provided the key to its success.

CASE 3: R & D PLANNING AT THE BRANCH LEVEL

Case 2 illustrated how a decision maker's differing roles in a R & D decision making process in which he is involved at more than one level can affect his perception and use of DSS. We can explore the nature of differences between levels further by looking at a case of budget allocation among R & D programs.

In the Hungarian sector in which this case is located, programs - as well as the phases of the usual decision making process - are arranged in a 3-level hierarchy in the way that we outlined in the introduction to this paper.

The problem considered in Round 1 comprised budget allocation across ten 3rd level programs. Analysis of the problem by decision analytic tools was initiated by a lower-level decision maker responsible for making proposals for financing R & D programs in his field. The method for the decision analysis and the supporting computer software were developed by consultants (a team of decision analysts from the Bureau of Systems Analysis of the State Office for Technical Development and the Institute of Psychology).

In Round 2 the scope of the problem expanded to the consistent allocation of the budget on all the three levels, which means allocation across 4 areas, involving about 20 2nd level programs and about 50 3rd level programs. The analysis of the problem - by using the method and procedures developed in Round 1 - was initiated by higher level decision makers responsible for the whole R & D planning. Due to the greater complexity of the problem and the extended circle of experts involved some minor modifications were made in the method. The work is in progress, and so here we shall be mainly concerned with Round 1, and our preliminary experiences of Round 2.

RESPONSIBILITY AND MOTIVATION OF DECISION MAKERS AND PROPOSERS

Higher level decision makers were responsible in this case for the budget allocation among all candidate R & D programs. The programs covered all of the main areas of R & D activity and, of course, higher level decision makers cannot be competent in each of these areas. In using a DSS, decision makers were motivated by the opportunities it provided for (i) rationalizing their decisions by basing them on more reliable information, (ii) having a tool for explaining (justifying) their decisions to their subordinates (to the managers of the competing areas programs, etc.) and (iii) modernizing their decision making practice.

Proposers (in this case lower level decision makers within each of the main areas) were responsible for making suggestions to higher level decision makers as to which R & D program of their particular area should be supported. They were more competent in their area than higher level decision makers, although they needed the help of experts who were familiar with the details of the R & D programs. In using DSS proposers were motivated by the possibility of (i) influencing the decision makers by using more efficient tools, (ii) eliciting information from experts, and (iii) learning new methods for modernizing their own decision making practice.

FUNCTION OF RESULTS EXPECTED FROM THE DSS

Because of the difference in responsibilities and motivation between the decision makers and the proposers, we would expect from Figure 2 that the function of the results these two classes of users expected from the DSS used would be quite different. We found that decision makers expected to use the results for (i) prescriptions for action (e.g., rank order of R & D programs in terms of cost-effectiveness) which would at least partly transfer the responsibility for such actions from themselves to the DSS, and (ii) as rationalization for actions they might wish to take.

On the other hand, proposers expected to use the results for (i) gaining a better insight into the decision problem (e.g., simulation of the consequences of the possible choices, multiple criteria analysis of the options, etc.), and (ii) communication of information. Some of the reasons behind the differences between the expectations of the proposers and the decision makers were those we discussed for Case 2, above. Others will be examined when we consider some additional pitfalls below.

STAGES IN THE ROUND

At the outset of the round the consultants proposed that the problem should be conceptualized as one of budget allocation, and therefore the stages in the round would be those required to compute, as a basis for decision, the subjective expected utility (SEU) for each R & D project or, in the case of project-interdependencies, each project-combination. SEU was accepted as a basis for "decision making" by the proposers who were responsible for initiating the use of the DSS, but at the end of the round, they more or less neglected SEU in forming the final proposal.

The consultants (decision analysts) proposed direct optimization algorithms for budget allocation on the basis of the SEU of projects, but this was refused by the proposers (reasons why the proposers acted in this way will be discussed below). In view of this, the eight stages shown in Table 3 were agreed to constitute the round. The procedures used in the above stages are described in detail in Vari an David (1982). Table 3 also summarizes the involvement of the various types of participant across the stages in the round.

In round 1 the proposers played the following three roles: (i) they controlled the whole decision analysis process, determining the output of the crucial stages (e.g., alternatives, criteria, weights, probabilities, utilities) and they wrote the final report (including proposals and explanations, etc.), defining the output from the round; (ii) they mediated between decision makers and all other parties, thus determining the way that the outputs from Round 1 served as inputs to higher level decision making; (iii) they acted as experts, participating in the exploration of alternatives on criteria, evaluation of weights, probabilities and utilities. In Round 2 the role of the proposers was somewhat different. The overall decision analysis was controlled by the consultants and the formal proposal was formulated by the consultants as well. The participants who had played the role of proposers in round 1 acted only as experts throughout all the stages of round 2.

The experts' participation in the exploration of decision alternatives and criteria was focussed on determining criteria weights and those probabilities and utilities related to the projects within the field of their experience. The consultants (i) organised the decision analysis and the interactions between the participants involved in making this analysis, (ii) designed and implemented the computer programs supporting stages 2-7, and (iii) elicited data from participants and explained the results of the computer procedures to them. In round 2 they also formulated the final proposal for presentation to higher level decision makers.

Stages in the Round \ Participants		Proposers	Decision makers	Consultants	Experts	Computer
Stage 1: Definition of the set of projects to be evaluated		*			*	
Stage 2: Exploration of the evaluation criteria		*		*	*	*
Stage 3: Determination of weights of criteria		*		*	*	*
Stage 4: Definition of utility functions		*		*	*	*
Stage 5: Estimation of the uncertainties		*		*	*	*
Stage 6: Evaluation of the projects		*		*	*	*
Stage 7: Multi-criteria aggregation				*		*
Stage 8: Selection of the projects	Forming the proposal (reporting)	*		*		
	Final decision		*			

Table 3

Stages and participants in Round 1 of Case 3:
R & D planning at the Branch level

PITFALLS LIMITING THE SUCCESS AND SCOPE OF DSS FOR R & D PLANNING AT THE BRANCH LEVEL

In a general sense, the introduction of DSS into R & D planning at the Branch level in Round 1 of Case 3 was successful, as it led to Round 2 where higher level decision makers initiated the use of similar DSS in evaluating a much wider range of programs, located at three levels. However, when we examine **how** the DSS was used at the Branch level and compare this with the perspective and expectations of the consultants who designed the DSS at the start of the round (c.f. Czako and Vari, 1980), we can identify some pitfalls.

PITFALLS OF MISUNDERSTANDING THE ROLE OF THE PARTIES INVOLVED.

The first group of pitfalls the consultants had to face during the round was related to misunderstanding of the roles of the parties involved, which led to wrong definition for some of the communication interfaces:

Communication of the proposers with other parties. Proposers intended to play a more active role than the consultants originally expected. They wanted to participate in the analysis as experts as well as mediators of the, (supposed) preferences of the higher level decision makers. On the other hand, they wanted to influence the decision makers and to this end they wanted to have the freedom to manipulate the results. Therefore, they preferred having an insight into the consequences of the possible actions (choices) instead of receiving a direct prescription from the DSS. Thus, as in case 2, a system designed in support of **proposers'** activities was found to need to be centered on rather different capabilities than would be the case in supporting actual decision makers. Failure to recognise this distinction at the design stage constitutes a possible pitfall for DSS implementation. Note also in this respect that the proposers preferred to consider only a certain part of the whole problem structure (e.g., some criteria) in the course of the formal decision analysis process and to take the other components into consideration intuitively while making proposals (see the discussion of Case 2, above, and Vari & Vecsenyi, 1982). One way of limiting the extent of this problem is to make the formal analysis less public (as when, in subsequent rounds, proposers learn the method and replace the consultants). However, owing to the organizational character of decision analysis as a collective activity, publicity cannot be wholly eliminated.

Communication of the decision makers with other parties. Decision makers played a much more passive role than the consultants expected. Originally, the plan was to involve them in the analysis, particularly in determining and weighting the criteria, but they refused to participate. They required only a one-way channel which would serve to communicate to them the essence of the experts' views.

A conclusion to be drawn from this is that the DSS supported the proposers, rather than the decision makers. In other words, while implemented within a two-level organisational system, it was appropriate in providing support only at the **lower** level where it served as a proposal support system (PSS) in a way analogous to that described for the CW case. The lack of information available at the lower level about the real criteria and values of the decision makers also supports the advantages of simulation-type methods over direct optimization algorithms, and the importance of sensitivity analysis within PSS.

A comprehensive DSS supporting both levels would need to include a PSS at the lower level together with a system with rather different characteristics supporting the higher level where decisions are actually taken. Some of these characteristics are explored in the fourth case study which describes the development of a DSS for top-level decision making.

PITFALLS STEMMING FROM HIERARCHICAL DIVISIONS IN ROLES AND RESPONSIBILITIES IN R & D PLANNING.

The second group of the pitfalls is connected with the sequential character of decision making which, in this case, is the consequence of the hierarchical division of roles and responsibilities between participants.

Selection between programs on different levels. The usual practice in the context of Case 3, is for higher level decision makers to allocate resources between the main areas (1st level), and programs (2nd level), while lower level decision makers do so between tasks (3rd level). The result of this procedure is usually suboptimal: it may happen that an area which is declared to be "very important" does not include as many realistic R & D programs as do other, not so "important" areas. An optimal solution would require the simultaneous comparison of all 3rd level tasks and the selection of the tasks to receive support on the basis of this comparison.

Hence, in Round 2 of this case, the consultants carried out multiple criteria comparisons of the areas and programs at all three levels and put together the results gained on the different levels. The method employed (details of which are given in Vari & David, 1982) proved to be useful, although the consultants had to face serious methodological problems related to the comparability of the evaluations given by different experts. None of the experts could evaluate **all** the 3rd level projects. Each evaluated a subset, and so evaluations on different projects by different experts had to be compared.
Another potential pitfall stemmed from the decision makers' assumption that, given appropriate DSS methodology and experts, the large number of R & D themes which characterized the third level tasks could be analysed directly (using in effect an aggregated PSS as the DSS). This unrealistic assumption ignores the necessary discontuity between the requirements for top level DSS and lower level PSS.

Discounting for conditions of implementation. Another consequence of the division of roles is that decision on "what?" and "how?" are usually not considered simultaneously. The consultants in this case, motivated (i) to develop and test new methods in the field of R & D planning and (ii) to make the decision process more coherent, democratic and better organized, strived to ensure the use of an evaluation method which could take the conditions for successful research and implementation into consideration. For this reason they proposed calculating SEU of projects as the basis for choice between them since this took into account the probabilities of conditions permitting successful implementation, as well as the costs and benefits of the results.

However, on reaching the final stage (8) of Round 1, the proposers neglected the SEU of the R & D projects as a basis for choice. Post-hoc analysis of the choices actually proposed indicated that choice was governed by the **maximum feasible utility**, calculated for each project as that which could be

obtained in the case of total success in all aspects of research, implementation and application (Vari & Vecsenyi, 1982). In other words, probabilities of failure in implementation were discounted.

The consultants informed the proposers of the results of this analysis, the proposers utilized these results by putting forth suggestions designed to alter the social **context** of implementation of the programs in such a way that uncertainty about future events would be reduced. They alerted decision makers to the fact that in certain programs "great attention should be paid to promoting the implementation" **without any further analysis** of the possible alternatives to promotion.

CASE 4: USE OF DSS IN TOP LEVEL DECISION MAKING ON R & D PROPOSALS

Case 3, while situated in the context of multi-level R & D planning concentrated through force of circumstances on the use of DSS at the lower, branch level. In this final case study, we investigate the appropriate use of DSS at the top level, approaching the problem from the stand point of a large interdisciplinary research institute in the USSR and from the point of view of planning office heading a number of research institutes. Each situation had the same general features, notably:

(i) Individuals or organizations submitted proposals on R & D. These proposers were potential executants or clients, interested in gaining R & D results.
(ii) the decision maker reponsible for the choice of the best R & D alternatives was located at the top level: head of a planning office or the chief executive officer of an organization. The decision maker followed a policy in choosing among the R & D proposals realized through a set of **his** criteria (Zuev et al, 1979; Larichev, Zuev and Gnedenko, 1979).

A special feature of decision making at this level is that the decision rule had to be developed before any of the R & D proposals were submitted, so that the decision maker could assess the proposals as they reached him. Because of this, the decision maker had no opportunity to employ the characteristics of the R & D proposals which were actually submitted in formulating the structure of the R & D plan and thus determining the decision rule. Instead, he had to fix the concepts of his policy before the proposals started arriving and merely adjust it soon afterwards.

Another feature of the problem which had to be taken into account is that in this case there were **no** rigid limits on the resources necessary for conducting the R & D. This means that the problem studied here is not consistent with the general problems of portfolio optimization (Francis & Archer, 1971) or program selection within budget constraints (e.g., Buede & Peterson, 1977). The position here was that the authors of proposals would be able to secure the required resources (e.g., from state budget organizations) should the decision maker approve their R & D proposals. Rejection of a proposal was expected to force its proposers to formulate new approaches.

The decision maker's first task was to make a choice of a set of the best alternatives to be integrated into the R & D plan. His second task was to

compare both the accepted and rejected proposals in order to define the merits of the proposal developers. Hence, the decision maker was interested in ranking the R & D alternatives with respect to their utility. The introduction of DSS was a consequence of the desire of the decision makers to exert a stronger influence on the process of selecting the best R & D proposals.

STAGES IN THE ROUND

Each round in the decision making process involved the stages shown in Table 4. The proposers formulated the proposals so as to emphasize their merits (c.f. the discussions of cases 2 and 3, above). Inasmuch as the proposals were quite different and multidisciplinary by nature, they were too complex for the decision maker to be able to evaluate them directly. Consequently, in order to evaluate the alternatives he had to resort to the assistance of experts. These experts, however, were not required to make a general evaluation of the proposals but to answer explicit questions reflecting some or other aspects of the decision maker's scientific policy. So the need arose to develop a decision rule integrating the decision maker's scientific policy and the experts' judgements, and the method developed was supposed to be utilized by the decision maker.

The problem under study in each round constituted a choice of the best R & D alternatives to be included in the 3-5 year plan (one decision). The decision maker, the proposers, experts and consultants all contributed to the elaboration of this plan. The information concerning the set of criteria to be employed (see below) was available to everybody. The decision rule was developed by the consultants and the decision maker for the latter's use. The decision maker expected the consultants to submit explicit verifiable recommendations consistent with his policy. This placed specific constraints on the decision rule elaboration technique.

The traditional process of R & D formulation had previously involved the following three stages constituting a round:

Stage 1. R & D proposal formulation (by proposers)
Stage 2. Proposal evaluation (by experts)
Stage 3. Decision making (by the decision maker)

The new plan formulation procedure differed from the old one in that Stages 2 and 3 in the round were changed to the way shown in Table 4. The experts would now receive a special questionnaire and the decision maker would take decisions on the basis of the formulated decision rule.

As far as the proposers were concerned, the old and new procedures did not differ. The decision maker was the participant in the round who was most affected by the new procedure, as it qualitatively changed the entire style of his work. In practice the number of proposals considered in a single round ranged from several hundreds to several thousands. They comprised R & D alternatives largely representing applied research (i.e., they were oriented towards the solution of specific problems). The number of criteria employed by the decision maker did not exceed ten in any of the rounds and usually amounted to between five and seven.

It is important to emphasize the nature of these criteria. The choice among the R & D alternatives was considerably affected by hardly formalized factors such as "scale of R & D", "scientific backup", "versatility of expected results", "skill of potential researchers and developers", etc. In a word, the criteria were **qualitative** in nature.

Stages in the Round \ Participants	Proposers	Decision makers	Consultants	Experts	Computer
Stage 1: R & D proposal formulation	*				
Stage 2: Elaboration of set of criteria		*	*	*	
Stage 3: Estimation of projects				*	
Stage 4: Construction of decision rule		*	*		*
Stage 5: Construction of quasi-order of projects					*
Stage 6: Final decision		*			

Table 4
Stages and participants in rounds of Case 4 following the new procedure

(Note: Stage 1 is located at a lower level than stages 2 to 6, which constitute the top level decision making activities. Stage 1 activities continued at the lower level while the other stages were being implemented at top level.)

NECESSARY CHARACTERISTICS FOR DSS SUPPORTING TOP LEVEL R & D DECISION MAKING

The description given above of the requirements for a DSS in the rounds in this case indicates that the nature of this "top level" DSS must be qualitatively different from the lower level PSS's of Cases 2 and 3 or the single lower level DSS of Case 1 if we are to expect any success in its usage. Hence the consultants in this case developed a DSS for use by the decision maker which was distinguished by a specific way of describing the R & D choice situation in entirely qualitative terms on criteria, and a special way of obtaining a general estimate of the quality of R & D proposals through evaluating them on these multiple criteria. Details of this methodology are given in Larichev (1982). Here we present only a snynopsis of some principles underlying its design. These were:

(i) The description of the R & D choice problem was exercised in a language that allows one to structure many real-life problems through the use of verbal estimates of all degrees of quality on those scales on the criteria scales.
(ii) The DSS formulation could take account of the uncertainty brought about by the incomplete knowledge of decision implications at the time of decision making.
(iii) The description of the situation provided in the DSS through qualitative criteria constituted a verbal decision model reflecting the actual quality grades which the decision maker took account of in decision making and represented a language for communication between the decision maker and experts typical of that used in their work environment.
(iv) The set of criteria employed in the DSS was defined on the basis of the decision maker's desire to emphasize particular qualities which he considered substantial for a comprehensive evaluation of R & D projects. (The formulation of grades of quality on each of the criteria were developed by the consultants with the decision maker's assistance).

The description of a decision situation in the decision maker's usual language considerably increases his or her trust in the outcome of the decision analysis (Humphreys & McFadden, 1980). To maintain the trust, it is necessary to use this language throughout the decision rule formulation. Larichev (1982) describes how this was achieved in this case through treating the R & D general utility model as a rule according to which every combination of criteria estimates which might characterise a project is consistent with a certain class of quality which can be assigned to that project.

The resulting DSS procedures were designed to (i) provide for verification of the decision maker's preferences for stability and consistency, (ii) involve primarily those questions where the probability of obtaining reliable information was the greatest, and (iii) employ a method of preference elicitation from the decision maker which matched his "natural" way of making comparisons between characteristics of alternatives.

The principles outlined above are not in themselves a specific characteristic of DSS located at the "top" level of decision making. What is **specific** is the utilisation of the decision maker's language at every stage of the method, without any quantitive scales, scores, lotteries and so on; without any

transformation of the decision maker's preferences into numbers. What is also specific is how these principles are used to structure the DSS characteristics and interface with the decision maker in way that takes into account the language, motivation and responsibility of the decision maker, as well as the level of the organizational structure within which he works, and the way in which information relevant to R & D policymaking is communicated between levels.

EVALUATION OF DSS USAGE

In the rounds in Case 4 involving the DSS, decision makers trusted the results it provided in implementing their R & D policies. The two characteristics of the DSS which seemed especially important in generating this trust were: (i) all the resulting estimates were directly based on the decision maker's verbal information without any transformation thereof, and (ii) it was possible for the DSS to define a relative position of any pair of alternatives directly on the basis of data obtained from the decision maker.

We also have evidence from one of the rounds on the success of the system in terms of forecasting ability in proposal evaluation. At the end of this particular round, the recommendations obtained for a group of 700 proposals with the help of the DSS were, for a number of reasons, not implemented. Retrospective examination of the actual results of the R & D proposals which were subsequently chosen revealed that estimates provided by the DSS-based method were correct for 80% of the R & D proposals in the round.

SOME COMPARISONS

Table 5 summarizes some comparisons between the four case studies on the basis of the following major characteristic features:

- the number of alternatives taken into consideration in the DSS
- the number of criteria used in evaluating the alternatives
- the formal goals of the analysis, accepted by the decision maker
- the analytical tools used or constructed for solving the choice problem
- the participation, or otherwise, of decision maker in the analysis supported by the DSS
- whether there was identity between the criteria represented in the DSS and the real criteria controlling the decisions

The study of this table allows us to come to the following conclusions:

1. The choice of analytical tools used in the cases was related to the number of criteria and alternatives and to formal goals. In Case 1, use of decision tree methodology allowed the creation and evaluation of scenarios involving a small number of alternatives and the use of sensitivity analysis in selecting a best one. Cases 2 and 3 appear identical when viewed on these three factors and they are characterised by the same analytical tool - multiattribute utility assessment. In Case 4, the existence of a large number of alternatives defines an approach expressing the decision rule in terms of combinations of criteria estimates.

2. The last two factors in table 5 shed light on a major cause of success or failure of DSS implementation. Only the direct participation of the decision maker and precise correspondence of his expressed criteria with the real criteria controlling decision can provide a chance for the real implementation of a DSS aimed at supporting that decision maker's actual choice making. Systems supporting people who can hope only to influence these choices (as in cases 2 and 3) need to be aimed differently in order to ensure successful implementation.

Factors / Level	Number of alternatives	Number of Criteria	Formal Goal	Analytic tools	Did decision-maker participate in analysis?	Criteria in DSS = Criteria controlling decision?
Case 1:						
Corporate (UK)	small	small	Choice of best alternatives	Decision tree	Yes	Yes
Case 2:						
Corporate (Hungary)	medium	large	Select best projects	M.A.U. assessment	Yes	No
Case 3:						
Branch of industry (Hungary)	medium	large	Select best projects	M.A.U. assessment	No	No
Case 4:						
Planning for a number of research institutes (USSR)	large	large	order projects	Descriptive-normative multicriteria method	Yes	Yes

Table 5

Comparisons between four cases of R & D planning supported by DSS

DECISION SUPPORT SYSTEMS, ORGANIZATIONAL SYSTEMS AND DECISION METHODS

It is very important, in regard to the applicability of any particular DSS, that the users for whom it is intended be ready to apply it. Of course, a DSS comprising a more reliable and methodologically validated technique for comparison of decision alternatives has a greater chance of success in application. However, as we have seen above, reasons for succss or failure do not lie only in the merits or shortcomings of a procedure or a method.

At the outset, new DSS methods and procedures must be tuned to the existing organizational structure and to traditional ways of gathering and considering the inputs to the R & D planning system at the level at which the DSS is to be located. In penetrating such systems through successful long-term usage, DSS serve to change their essence sharply increasing the rationality and centralization of decision making.

There are also problems of a psychological nature in applying new methods and procedures involving DSS usage. R & D decision makers at all levels tend to share a number of old-fashioned views which hamper improvements to their traditional ways of working. One of them is a belief that a great number of R & D themes (up to several thousands) can well be analyzed directly. When faced with a variety of complex and different R & D proposals (as in Cases 3 and 4), such notions are far from realistic. Another notion is that having to choose can be avoided either through proportional allocation of resources to all the options, or by securing additional resources. Experience has shown that this unrealistic assumption can result in dissipation of resources. The third notion holds that the application of new methods and procedures must lead to a reduction of the decision makers' influence on decision making (see the discussions of proposers' expectations of DSS usage in Cases 2 and 3). Quite the reverse occurs where DSS methods adequately match the context within which they are employed.

R & D planning is characterized by complex problems which tolerate neither an approach which is too simple nor extreme formalization. The practical utility of DSS consists of its assistance to planners and only when we understand what is involved in providing such assistance will the new methods become a useful tool for improving existing systems of long range R & D planning.

Footnotes

1. These case studies formed part of a project of collaborate research coordinated through the International Institute of Applied Systems Analysis (IIASA), Laxenburg, Austria. Detailed descriptions of the cases, and of the methodology used in preparing the case studies were published by IIASA in 1982 as a collaborative paper series on Comparative analysis on application of Decision Support Systems in R & D decisions. Laslo David and Lawrence D. Phillips also contributed to the analysis of the cases described here.

2. These questions address **pre-requisites** for requisite modelling. Berkeley and Humphreys (1982) describe and discuss such types of uncertainty, all of which must be resolved in structuring a decision problem given that these pre-requisites are met. A 'requisite' DSS must also address these types of uncertainty in an adequate way.

3. In relatively unstructured situations like those typically found at the commencement of rounds in R & D planning, these typically determine the initial attitudes towards the DSS.

4. The development of the financial model was a stage in the round in itself, but conducted at a lower level than that examined here. Hence we cite only the output from this stage. Note that the business planning manager plays the role of expert at the higher level, but the role of proposer at the level of the team developing the financial model.

5. This followed from the consultants' goals from the round, which were quite different from the motivations of the decision makers, viz: (i) developing and testing new methods for real life problem solving, and (ii) proving that the information of the managers and experts can be effectively used in an organized communication process compatible with DSS.

6. This is in contrast with MEM where a single set of parameters was input to the model, and then varied interactively to take into account decision makers' expressed differences (MEM, Round 2, Stage 4).

7. Recall that at this higher level the director acted as **proposer**, rather than decision maker.

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