DSS FOR COOPERATIVE DECISION-MAKING

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Working Paper Series

CRIS #19

GBA #81-27(CR)

Presented at the **NATO Advanced Study Institute on Data Base and Decision Support Systems**, Estoril, Portugal, June 1-14, 1981.

Support for this paper was provided by the Center for Econometrics and Decision Sciences, College of Business Administration, University of Florida, Gainesville.

1. INTRODUCTION

'Two heads are better than one' - the old adage is a normative prescription for decision-making in unstructured environments. The combined insight and judgement of several people can sometimes bring sufficient 'structure' to a decision situation to enable a solution to be attained. Moreover motivations can be improved and subsequent implementation problems lessened by participation in the decision-making process (Mumford, [1980]). Often the group process of 'rationalizing' the problem reduces potential conflict; it also serves to make decision-making more consistent and facilitates the process of 'selling' the group choice to others if this is necessary.

Thus there are important reasons for considering group rather than individual decision-making in the context of Decision Support Systems (DSS). To what extent has this been recognized in existing DSS designs? There are a number of examples in the literature of groups of decision makers cooperatively solving problems using computer aids. One example is provided by the Geodata Analysis and Display System (GADS) which was used by groups of police officers to design police beats (Carlson and Sutton, [1974]) and a group of school officials to form a districting plan (Holloway and Mantey, [1976]). However in both of these cases the DSS could have been used by a single decision-makier and it is not clear whether the system design was altered in any way to facilitate group as opposed to individual decision-making. This seems to be true of most DSS's. Indeed a large part of the literature focuses on the problem of individual differences in cognitive style (Mason and Mitroff [1973]). The inference being that the system (or at least the user interface) would be tailored to each user-perhaps based on whether they are 'anaytics' or 'intuitives'.

In this paper we discuss some special problems and opportunities in providing computer support for cooperative decision-making. We use this term broadly meaning only that a number of individuals act jointly to make decisions as in a team, a committee, or across a bargaining table. The decision-making process may therefore have to resolve different perceptions of the underlying problem, different objectives on the part of the decision-makers, politics, personality clashes etc. Thus, depending in part on the degree of cooperation exhibited by the group, the DSS usage patterns are likely to be very different for the multiperson case. Even when a high degree of cooperation is present group decision-making can be markedly different. For example, Henderson and Ingraham [1981], found a change in information usage patterns when individual users of a DSS were brought together for joint decision-making sessions.

Group decision-making is likely to be relatively more 'unstructured' than individual decision-making for two reasons: (1) groups are often formed to bring collective judgement and intuition to bear on very 'wicked' problems; (2) the presence of more than one person will complicate the situation by introducing a need for communication and coordination to resolve perceptual and motivational differences. Thus the process by which judgements are found and decisions made is likely to be more important when designing a DSS for collective rather than individual decision-making.

In the next section we develop the notion of 'cognitive aid' as a conceptual approach to assisting the group decision-making. In Section 3 we discuss some general implications of joint decision-making for DSS design. An example of the design of a cognitive-aid based on Saaty's 'Analytic Hierarchy Process' (AHP) (Saaty, [1980]) is described in Section 4.

2. COMPUTER AIDS FOR UNSTRUCTURED DECISION MAKING

The traditional notion of DSS is that it is ueful in 'semi-structured' decision situations where it is not possible or not desirable to have an automated system perform the entire decision process (Keen and Scott-Morton, [1978], Ginzberg and Stohr, [1981]). In this section we attempt to clarify this idea and the propose that more attention be given by DSS resarchers to the construction of computerized aids that can help in the creative task of 'structuring' an initially unstructured situation. Specific examples of such aids will be given in later section of the paper.

Our viewpoint is shown in Figure 1. Computerized DSS operate on the 'structurable' part of the decision situation. They provide information that is combined with the judgement and intuition of the decision-makers to provide a solution.

What do we mean by the 'structured' and 'unstructured' parts of a decision situation? Adopting a decision theory framework, in order to structure a decision we must determine: (1) a set, S, of relevant states of the world (2) a probability measure, p, on S, (3) a set of alternative actions, A, (4) a logical-valued function, f, on SxA which

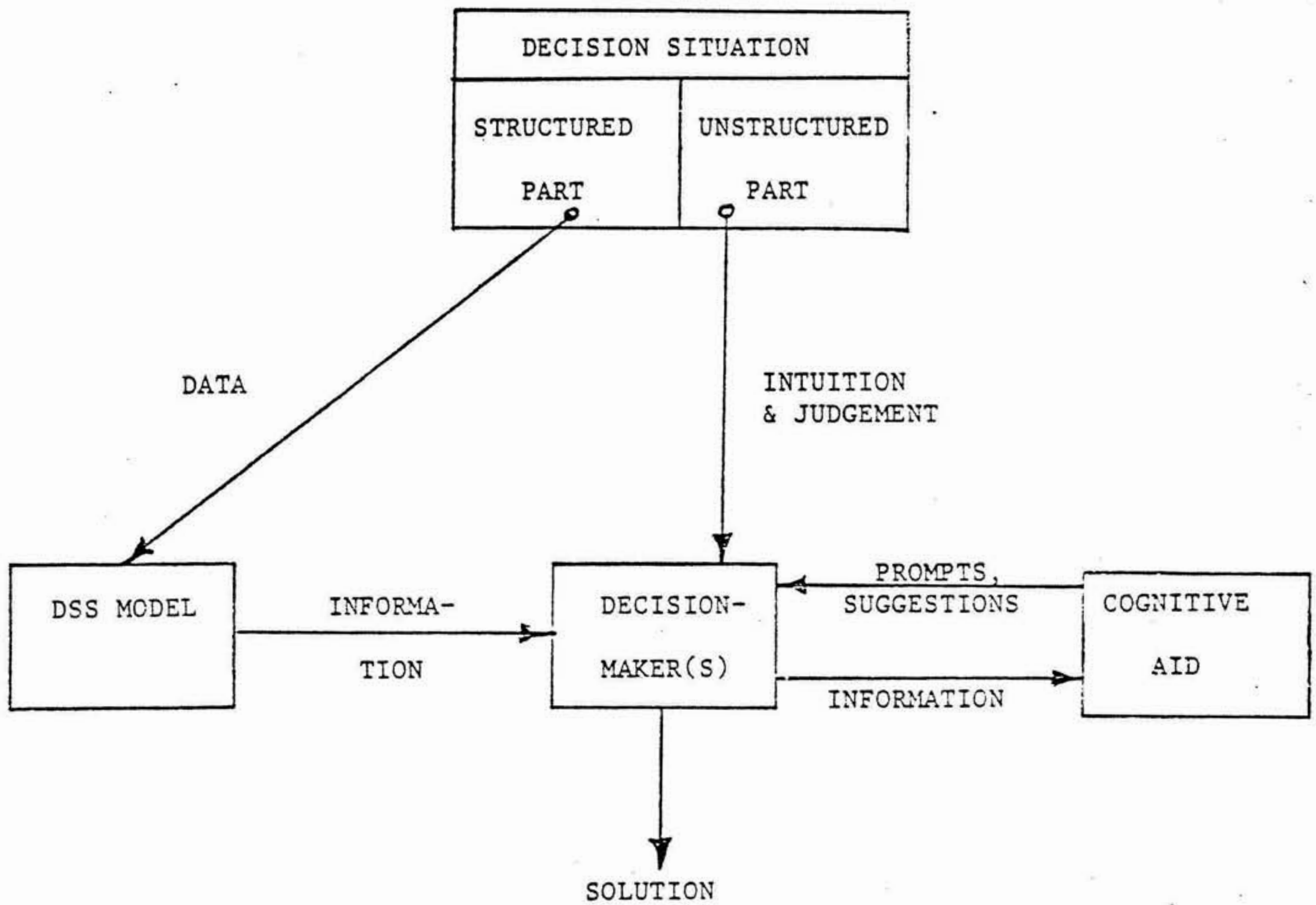

FIGURE 1

DSS ENVIRONMENT AND THE CONCEPT OF A COGNITIVE-AID determines whether or not an action-state pair is 'feasible'. (5) A set of consequences, C, (5) a mapping, r (called the 'result' function) from SxA into C and (7) a real-valued utility function, u, defined on C.

Under this framework a problem is unstructured to the extent that it is impossible to specify (either explicitly or implicitly via procedures) one or more of S,A,C,p,f,r or u. At a more general level of discourse a problem is unstructured if: (1) cause-effect relationships are unkown or partially unknown, (2) there is uncertainty (rather than risk), (3) variables are not measurable in any physical sense or are qualitative and not susceptible to numerical representation, (4) there are multiple conflicting goals and decision-makers can not express their trade-offs in terms of a higher level goal.

Implicit in this definition of the structured and unstructured parts of a decision situation is the question of computability. The 'structured part' can be (but is not necessarily) computerized, the 'unstructured part' can not be computerized. This still leaves open the question of whether the unstructured part can be organized (structured!) at a higher level of abstraction by human beings who sometimes seem quite capable of reasoning effectively with qualitative, 'fuzzy' concepts and relationships.

Turning now to a consideration of the DSS itself, there are three phases in its development and use:

(1) Recognizing that a part of a decision situation can be structured, organizing that structure and designing and implementing the DSS.

(2) Retrieving information by using the DSS - especially during sensitivity testing.

(3) Using the information from phase 2 in a judgement process involving the non-structured elements of the decision situation.

All three phases can severely test human capabilities. Note that Phase 1 (designing the DSS) is initially a semi-structured task which has caused a number of researchers to advocate a cooperative evolutionary building process involving iterations of all three phases (Keen, [1980]).

Hammond, [1975], has suggested the concept of a 'cognitive aid' as a means of helping decision-makers 'externalize' or structure their problems and facilitating goal congruence and conflict resolution. Arguing that 'wise decisions are in short supply because of the limited capacity c human cognition in relation to the complex problems that confront it' he illustrates the use of interactive computer graphics and multiple regression techniques as a means of revealing the parameters of human judgements in specific situations.

Borrowing Hammond's term can we build cognitive aids (supplementary to the DSS model itself) to assist in the three stages of DSS development and use?

The remainder of this paper will address this question-particularly with regard to the key phase 3. Our concept of a cognitive-aid is similar to Hammond's except that we emphasize on-line real-time support for the decision process (see Figure 2). Unlike DSS models which provide an analogue of the real world system under study, cognitive aids focus on the decision-making process itself. They may thus utilize concepts from decision theory, game theory and psychology.

There are three possible ways in which a computerized cognitive-aid may work:

(1) It might be used to help move the boundary between what is structured and unstructured - by, for example, helping users discover and quantify the components S,A,C,p,f,r and u of the underlying decision problem.

(2) It might be used to guide the use of the DSS model by organizing the process or sequence through which information is retrieved from the model and assimilated by the users. In this case it would operate in the interface between the structured and unstructured parts of the decision process.

(3) It might be used to help users manipulate intuitive and judgemental relationships ie. it would operate entirely in the unstructured part of the decision-making process. Note that this use is contradictory to our previous definitions unless we assume that the computer programs (or rather their designers) do not 'understand' the higher level concepts and issues that are being represented and manipulated.

At a more detailed level some objectives of a cognitive-aid might be:

(1) To aid the decision-making process by extending human memory and computational capabilities

(2) To 'externalize' the judgement process by making the structural

elements - goals and means to achieve them - explicit.

(3) To guide decision-making by encouraging a systematic approach and providing cues suggestive of new alternatives and goals to be considered by decision-makers

(4) To record the interaction process so that back-tracking and historic records are possible.

(5) To process and combine subjective evaluations made by different participants in the decision-making process.

Some cognitive aids can be used independently of any form of information retrieval or modelling support. However, as suggested later, data base and modeling facilities may enhance ther use. Other cognitive aids are designed specifically to support the use of DSS or management science models. Examples include data base aids and systematic protocols to help the user during sensitivity analysis. Note that these may be built into the modelling software itself (as in interactive multi-criteria decision-making (MCDM) packages - Ziont and Wallenius [1976]) instead of being separate sub-systems as depicted in Figure 2. Finally it is conceivable that the strategies for organizing systematic search where the sub-problems are quantitative algorithms (for testing feasibility or finding optimal solutions) can be used in unstructured situations where the sub-problems are qualitative and solved (for 'feasibility' and 'optimality') by subjective judgements.

It must be emphasized that the idea of cognitive-aids is already implicit in all DSS work. What is being emphasized here is merely the possibility of providing something more than just a user-friendly or

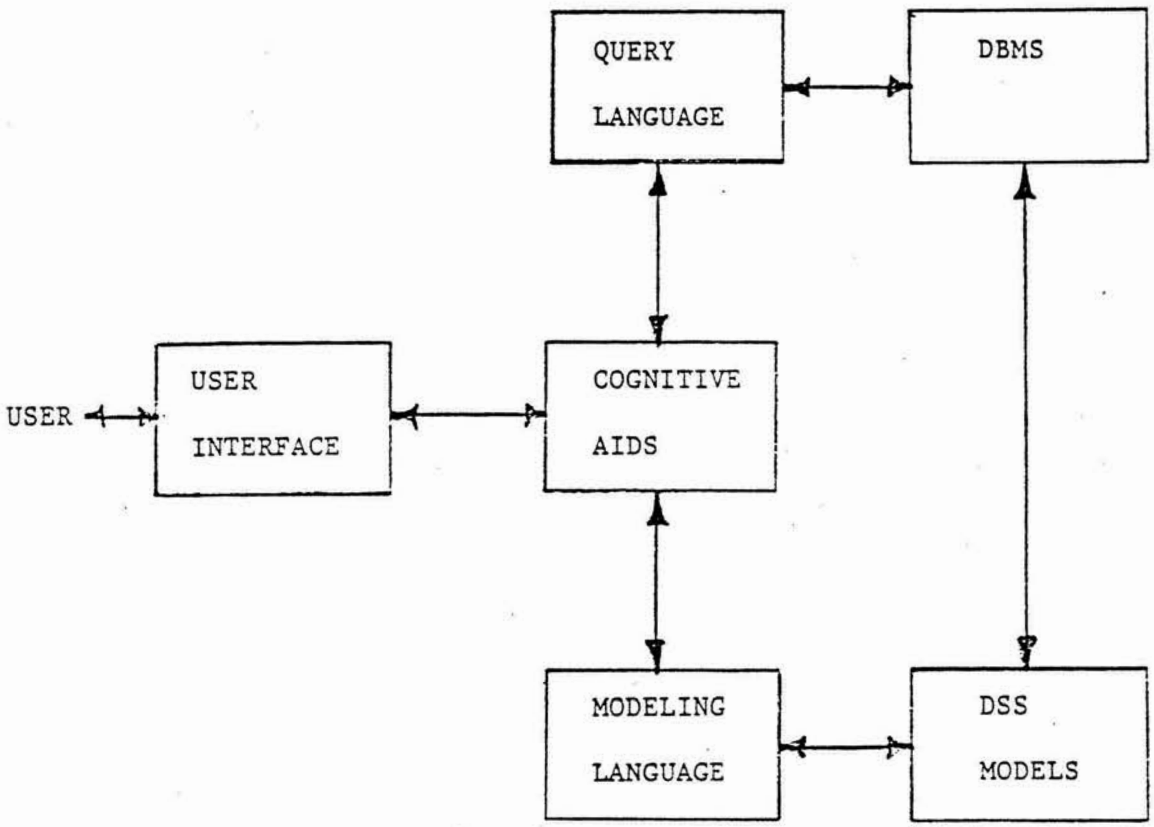

FIGURE 2

ARCHITECTURE OF A DSS INCORPORATING COGNITIVE AIDS individually-tailored user interface to the DSS. The extra dimension is the attempt to explicitly guide users during the judgemental, intuitive stages of decision-making.

3. COOPERATIVE DECISION MAKING

What are the implications for DSS of group rather than individual decision-making? In this section we discuss three sets of factors: organizational, motivational and cognitive. For each we deduce some general implications for cooperative DSS design and illustrate some possibilities for computer support. Some of these possibilities are cognitive aids as described in the previous section.

3.1 Organizational Factors

Organizational structure and processes impose a need for coordination of activities and of the decisions leading to these activities. Responsibilities are divided and role relationships complex. Each individual will have 'local' knowledge not available to others. The budgeting and planning processes of large organizations require cooperative decision-making by hundreds of individuals and are prime candidates for computer assistance. Similarly the control of scarce resources such as inventories between multiple locations often requires joint decsion-making. Depending on one's view-point one may or may not view computerized systems to support such activities as DSS (Keen, [1980]). But the similarities may be more important than the differences. An example of a DSS network of decision-centers each having some local autonomy but also engaging in joint decision-making is provided by the Hertz system for controlling the disposition of rental cars (Edelstein and Melnyk, [1981]). Such systems require efficient means for disseminating, and collecting and aggregating information. They also need a protocol or algorithm to coordinate the decision-making activity. Note that these algorithms are quite different to those developed by Marshak and Radner [1972] who also consider joint decision-making in organizations since their purpose was to provide 'rules' for optimal decision-making in the absence of the kinds of communication facilities being considered here.

3.2 Motivational Factors

Decision-making is often a collective endeavor; the final decision 'unfolds' through a process of definition, learning, understanding and re-assessment (Zeleny, [1975]). Managers consult with their subordinates, peers and supervisors before making a decision. Collective judgements are used to provide a 'consensus', compromises are made and bargains struck. This social process aids motivation and reduces the potential for conflict. Furthermore managers (as opposed to data processing professionals) have high social needs (Couger, 1980). To be accepted therefore the cooperative DSS user interface must support (or at least not impede) group interaction. Some technological advances such as large screen devices and voice recognizers obviously remove some technical barriers. However there has been little research or experience in this area.

The presence of more than one decision-maker will normally mean more than one view of the appropriate system or organizational goals. Often individual objectives and goals will complicate the issue giving rise to a difficult multiple criteria decision-making (MCDM) situation. There are theoretical problems associated with interpersonal comparisons of utilities and the aggregation of individual preferences to form a social preference function. Nevertheless, such problems do get solved in practice (see Keeney and Raiffa [1978] Chapter 10 for a discussion and proposed solution technique). Interactive MCDM techniques, such as those proposed by Zeleney, [1975] and Zionts and Wallenius [1976], in which decision-maker(s) reveal their preferences through interaction with a computer program are useful cognitive aids in group as well as in individual decision-making situations.

Group decision-making often involves bargaining and conflict resolution. An excellent example is provided by union contract negotiations where DSS models are often used by one or both parties to compute the costs and trade-offs involved with various contract provisions. Shakun, [1981], defines a conflict as a problem which initially has no feasible solution. He proposes a framework for generating new goals and means until a feasible solution is obtained. This, and many other concepts from game theory could provide the basis for cognitive aids in the sense of this paper.

3.3 Cognitive Factors

The limits of human cognitive ability provide a compelling reason for considering cooperative DSS. A simple model of the human mind is provided by Schneiderman, [1980]. There are three elements: long-term memory with virtually unlimited capacity, short-term memory which handles incoming information and has a strictly limited capacity and working memory which performs logical, computational and

(2) Retrieving information by using the DSS - especially during sensitivity testing.

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Borrowing Hammond's term can we build cognitive aids (supplementary to the DSS model itself) to assist in the three stages of DSS development and use?

The remainder of this paper will address this question-particularly with regard to the key phase 3. Our concept of a cognitive-aid is similar to Hammond's except that we emphasize on-line real-time support for the decision process (see Figure 2). Unlike DSS models which provide an analogue of the real world system 'brain-storming'. Computer support for this kind of activity can probably only be indirect; an information retrieval system and easy-to-use computational facility might be useful The second possible approach is to provide: (1) checklists to ensure that major aspects of the problem structure are covered and (2) prompts and cues for possible new search directions. Reitman, [1981] discusses the use of artificial intellignece techniques and a knowledge base to help structure problems and suggest decision alternatives.

There are a number of reasons why human decision-makers have difficulty in perceiving the structure of a decision situation: the size of the system to be analyzed is too great; relationships between decision elements are uncertain, ambiguous or confused; wishes are confused with facts and ends with means; important variables are immeasurable.

The first issue concerns size complexity. No one person can fully comprehend a modern business system. To cope with this systems are broken down into a number of interconnected parts. Usually a hierarchical structure is imposed (Simon [1969]) and a team approach is used. The latter induces a need for a language of communication (data administration function). Another useful computer aid which addresses the problem of size complexity is Structural Modelling (SM) (Hansen, et al, [1979]). Briefly stated SM accepts information from one or more users concerning relationships between pairs of system elements: what precedes what? What affects what? These inputs are analyzed to produce a graphical portrayal of precedence relationships and a break-down of the system into 'levels'.

The next issue involves perceptual confusion and might be termed the structural ambiguity of the decision task. Artificial intelligence techniques such as the means-ends analysis of the General Problem Solver(Ernstand Newell, [1969]) suggest useful heuristics but have not yet been applied to large scale practical systems. The AHP approach (Saaty, [1981]) copes with structural ambiguity by imposing a hierarchical view and is suggestive of some heuristics that may be useful as described later. It also attacks the immeasurability problem by providing a systematic means for incoporating subjective measures of importance and providing an automatic check for the consistency of the judgements.

The use of a group of experts is another approach to overcoming uncertainty and unstructuredness. An example is the Delphi forecasting technique (Linstone and Turoff, [1974]). Obviously a computer-based DSS utilizing electronic mail could facilitate the use of this method since the identity of the participants is not revealed during the process. There is a need here for a subsystem that can combine expert judgements (Winkler, [1981]).

Complexity and unstructuredness will remain an issue for resolution by human beings. Cooperative efforts probably provide the best available approach (see Churchman, [1971] for a discussion of a 'dialectic' approach to organizing the required interaction).

Summary

In this section we have surveyed some of the organizational, motivational and cognitive issues that may effect DSS design in cooperative situations. These factors and some suggested approaches to designing computer aids are summarized in Table 1. The list is meant to be suggestive but by no means exhaustive.

4. AN EXAMPLE OF A COOPERATIVE DSS

4.1 Introduction

In this section we bring together by means of an example the two main themes of this paper - group decision-making and computer support for unstructured decision-making.

4.2 The Analytic Hierarchy Process

AHP (Saaty,]1980]) is a method for structuring complex individual or group decision situations involving subjective qualitative elements and interrelationships. It is based on the premise that humans cope with such situations by grouping related factors into hierarchical levels. The top-level (root-node) is the overall objective to be achieved; each lower level consists of a number of elements that 'influence' the elements at the next higher level. The elements may be conrollable or uncontrollable. Usually, the elements in the lowest level represent the final decision - for example activities to which a resource must be allocated or discrete choices such as candidates that might be hired in a personnel selection problem. An example hierarchy adapted from Saaty, [1980] is shown in Figure 3.

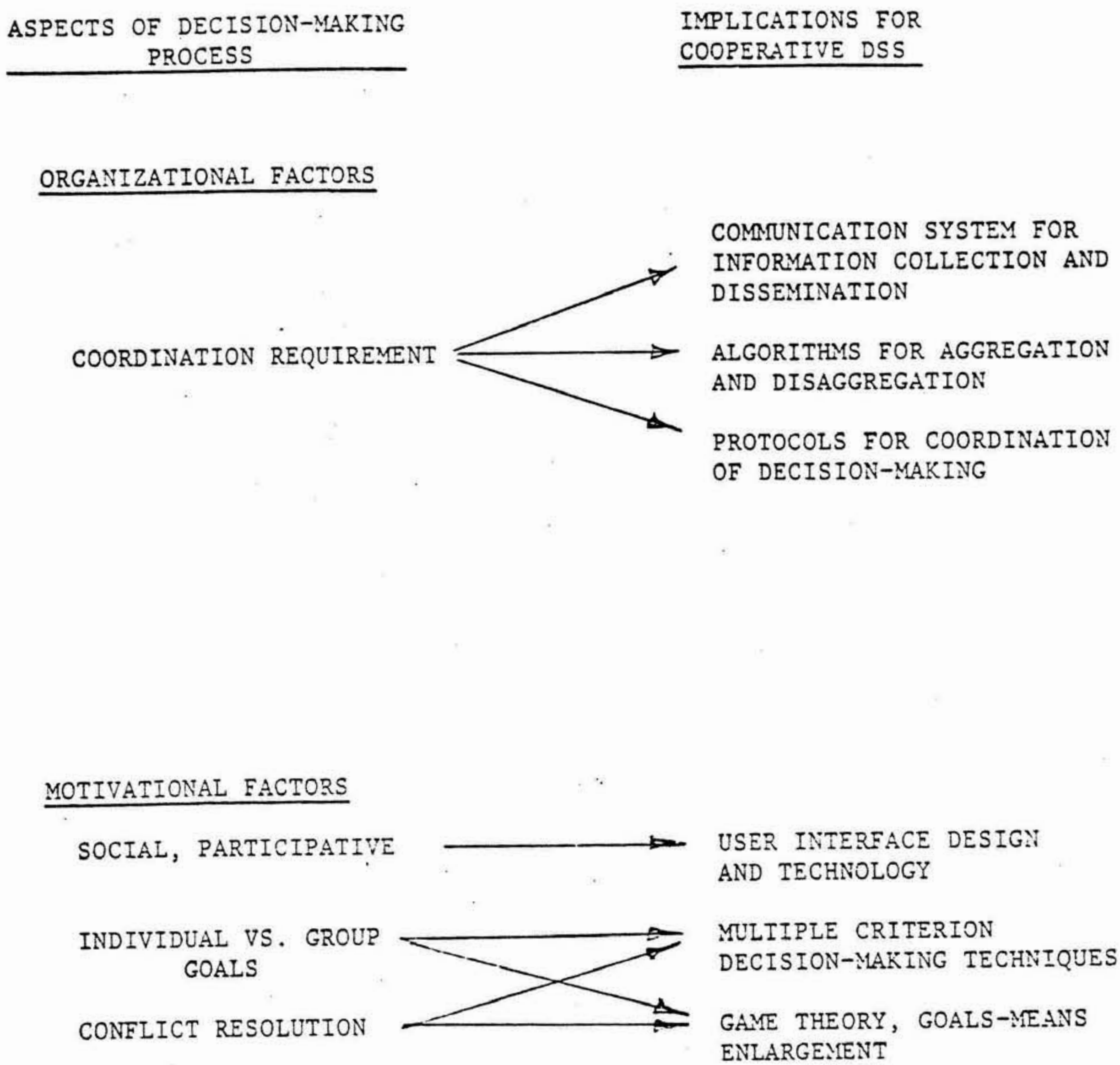

TABLE 1
IMPLICATIONS FOR COOPERATIVE DSS DESIGN

ASPECTS OF DECISION-MAKING PROCESS	IMPLICATIONS FOR COOPERATIVE DSS
COGNITIVE FACTORS	
HUMAN MEMORY LIMITATIONS	QUERY LANGUAGE, DBMS
	INTERFACE TO EXTEND SHORT-TERM MEMORY CAPACITY
LOGIC AND COMPUTATIONAL LIMITATIONS	MODELING LANGUAGE
CREATIVE PROCESSES	CHECK LISTS, PROMPTS AND CUES FOR ALTERNATIVE GENERATION
	AI TECHNIQUES
STRUCTURING	AI TECHNIQUES
	STRUCTURED MODELING
	ANALYTIC HIERARCHY PROCESS
JUDGEMENTAL	ANALYTIC HIERARCHY PROCESS
	COMBINE EXPERT OPINIONS

TABLE 1

IMPLICATIONS FOR COOPERATIVE DSS DESIGN (CONT'D)

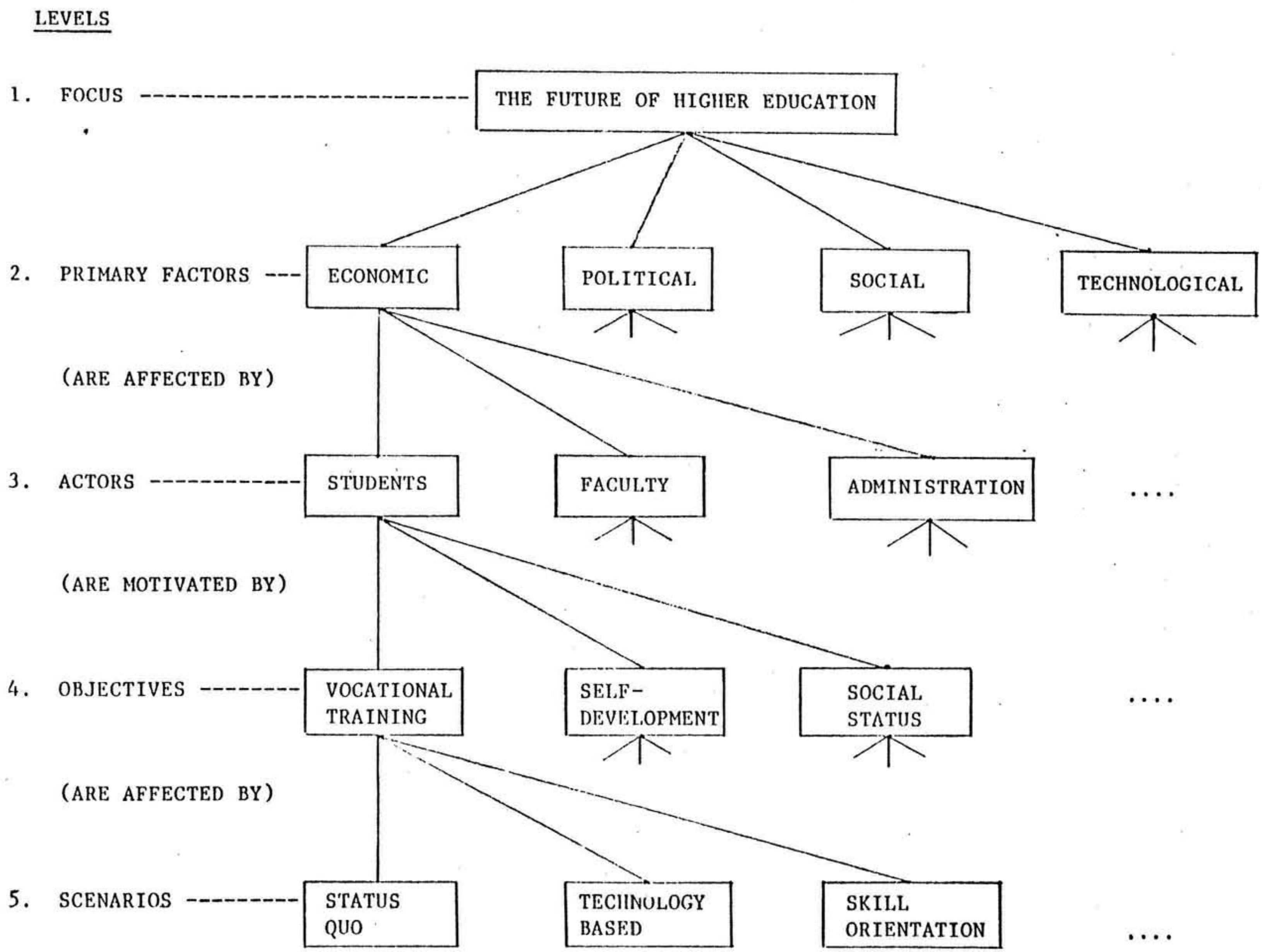

FIGURE 3
TYPICAL AHP HIERARCHY

Given an element, x, in the hierarchy the decision process proceeds by requesting each decision-maker to assign a numerical measure of importance (in the range 1 to 9) to the affect on x of each element in the next lower level. Thus the choice process is broken-down into a series of pairwise comparisons. The problem is solved numerically using an eigenvalue method based on the theory of positive reciprocal matrices. The 'solution' is in the form of a ratio scale of weights assigned by the computation process to the elements at the lowest level in the hierarchy.

The method involves some redundancy in information collection since, at each step n(n-1)/2 comparisons are made whereas only n-1 weights would be necessary to rank n elements. This redundancy improves the quality of the judgement process through an averaging effect; it also allows a consistency check to be computed thus providing a measure of the reliability of the final choice.

The application of the method in a group situation involves the formation of consensus judgements, concerning both the objectives and structure of the decision problem thus contributing to the 'externalization' of the problem and to final acceptance of the solution. Other advantages of the approach are:

(1) reduction in complexity of the choice process through disaggregation into a series of pairwise judgements,

(2) it can be used were the factors involved consist of preference and value judgements that can not be measured in any physical sense,

(3) it is easy to apply

Many examples of applications are discussed in Saaty, [1980]. It is used routinely by the RCA corporation for computer equipment and software package evaluation (Abbas, [1981]).

4.3 AHP as a Cognitive Aid

When AHP is applied in practice the computer is used in a passive sense - ie. to perform the computations off-line from the human judgement process. We now explore the possible use of AHP concepts in a cognitive aid used in real-time by a group of decision-makers. We assume: (1) the existence of suitable graphics input and output devices so that drawing the hierarchies is as easy as (say) using a black-board: (2) a DBMS with a query language interface, (3) a modeling facility and (4) statistical data analysis routines.

Structuring the Problem

The first step is to untangle the complicated web of goals, sub-goals, actors and their objectives, policies and scenarios that consitute the problem. Some ways in which the cognitive aid can assist are now discussed.

Experience has shown that the generic meanings of the various levels in actual hierarchies (eg. focus (overrall objective), primary factors, actors, objectives, scenarios in Figure 3) are consistent within a class of problem domains (Saaty, private conversation). For example in an equipment selection problem the levels are likely to be; focus (overall objective), criteria, sub-criteria, sub-sub-criteria,..., equipment purchase alternatives. Moreover the kinds of factors used at each level show consistency. Thus decision-makers could be aided by: (1) the ability to retrieve and display hierarchies used for similar problems (2) a man-machine dialogue in which the computer would suggest the factors that might apply at each level. Thus in an equipment selection problem the suggested second-level criteria list might include: user convenience, vendor support, technical quality, etc.

Alternatively the decision-makers might elect to develop their own structure. The various systems components could be input in a random piecemeal fashion as the group attempts to structure their problem. A combination of graphics and structural modelling techniques (see earlier) could be used keep the displayed system both current and internally consistent. A number of different versions could be constructed by each participant for later display and discussion until a consensus is formed. The definitions of each level and element in the hierarchy are discussed and recorded in the database.

The Judgement Process

During this 'prioritizationn' phase of AHP the pairwise comparisons are carried-out and subjective weights assigned. These can be arrived at either by discussion leading to a consensus or by each individual recording his/her evaluation independently in the database. In the latter case each user might be provided with a suitable hand-held input device. A Delphi-like iterative approach could be used with the computer acting as the central message-switching agent. Alternatively the individual assessments could be automatically aggregated to form the consensus result.

There are several advantages to the automation of this process: (1) the graphical display can be used to alternatively focus attention on the particular step being performed (by 'zooming-in' on a part of the hierarchy) or on the total picture.

(2) the previously recorded definitions can be displayed at appropriate times as an aid to memory.

(3) the participants could work through the heirarchy in any desired order with the computer prompting to ensure completeness

(4) the consistency measures for each group of evaluations could be displayed at the earliest possible times

(5) the computer could provide a warning if the imputed importance measures of any element or section of the hierarchy were less than some appropriate thresh-hold value.

(6) the structuring process could be reentered at any time to adjust the hierarcy if this is felt to be desirable - perhaps because of (5).

(7) the query-language facility could be invoked at any time to retrieve quantitative or descriptive information that might be relevant to a particular step in the judgement process.

(8) finally, the results of the analysis could be stored in the database as an historic record and also output in the form of a report.

5. CONCLUSION

In this paper we have surveyed some of the factors that should be taken into account when designing DSS for cooperative decision-making. We have suggested that the process of decision-making will be relatively more important in group as opposed to individual decision-making situations and have advocated the study of computer aids that address this issue.

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