Gouvernement du Canada
Ministère des Communications

Government of Canada
Department of Communications

Le Centre canadien de recherche sur l'informatisation du travail
Canadian Workplace Automation Research Centre

INTELLIGENT DECISION SUPPORT SYSTEMS : A PRACTICAL APPROACH

by

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Canada

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This report is the result of research done at the Canadian Workplace Automation Research Centre

Communications Canada

Laval

November 1987

D) 10312496
DL12447200

No. cat. 28-1/69-1990F
ISBN 0-662-18235-9

SUMMARY

A review of the state of the art in intelligent decision support systems is discussed, in terms of what distinguishes them from other computer systems and in particular, how artificial intelligence techniques can be used to increase the power of decision support systems. Several taxonomies of decision support systems are also analyzed in order to develop a more comprehensive classification scheme.

The methodology of designing, developing and implementing a decision support system is outlined. This includes the various ways of representing the decision process, alternative methods for evaluating system perfomance and the different theories that may serve as a foundation for decision support technology. The initial system analysis and design phases included identifying the problem addressed, the needs of the users that will be met by the system and precise definition of who the approach currently used in creating artificial intelligence application systems, expert systems in particular.

Finally, the strengths and weaknesses of decision support systems will be pointed out and the use of artificial intelligence techniques, expert systems in particular, will be proposed as a good way of maintaining all the advantages while at the same time making up for the deficiencies of the traditional decision support systems. Some examples of intelligent decision support systems currently under development are included in order to provide some idea of the present status of this area of research.

1. Introduction

1.1 What is a DSS ?

A Decision Support System is a (computer-based) system aimed at supporting decision activities that are not fully structured by making sets of data and advice available to the user. DSS is exactly what the name implies : Decision (a problem to be addressed, an action to be taken), Support (i.e. not a replacement but an aid to enhance decision making) and System (not necessarily a computer, but the entire system that will be affected by the decision : man, machine, organization, environment, etc.) DSS are man-machine approaches to decision making, a systematic way of improving the effectiveness of decision making (and not necessarily efficiency, which refers to decreasing the time and cost required to carry out a task).

The requirements for a DSS consist of hardware (time-sharing, graphics, microcomputers, telecommunication networks), software (database management systems, simulation languages, application packages) and people (DSS analysts and designers, willing users). In addition, the right sort of problem should be addressed - namely, a semi-structured decision. Structure may be defined as follows: of the three major phases in any decision, intelligence (identify the problem), design (identity the alternatives); and choice (pick the best alternative); if all three are known, the decision is structured; if one is known, the decision is unstructured; all others are semi-structured. For example, reordering inventory when it falls below a certain threshold level is a structured decision, while hiring a manager relies almost entirely on subjective judgement and thus represents an unstructured decision. Deciding on the best location for a new plant, for example, would be a good semi-structured problem for a DSS (see figure 1).

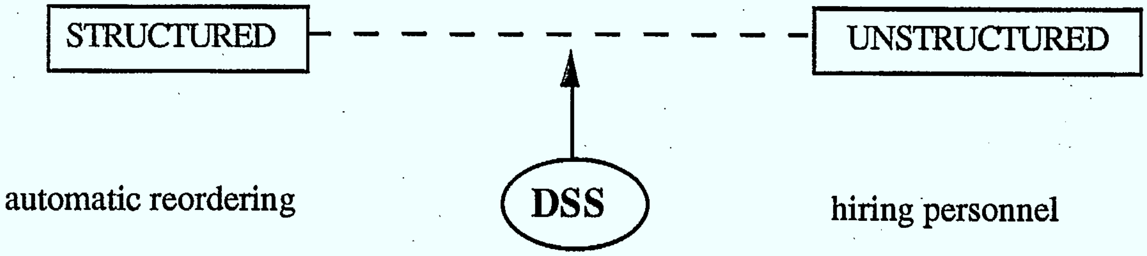


Figure 1. The Decision Spectrum

A DSS can be used in both a descriptive sense (how decisions are made) and a prescriptive one (how should they be made). Users of a DSS thus acquire information in order to make a decision as well as recommendations from the system. One can view a DSS as a provlem solving system or as an advanced inquiry system, where information is obtained and users make decisions manually. The simplest level of a DSS would be a spreadsheet while a complete, high-level DSS would have the following features : natural, English-like expressions, access to external databases, easy to use graphics to display results and computations of "what-if?" analyses (extrapolation, risk analysis).

A DSS is a means of creating, revising, checking and using a decision model, which is any type of quantitative or logical abstraction of reality, created to help someone make a decision (i.e. the quantities involved and the relationships between them) Traditional decision making has relied on optimization with a single measure being used to rank order preferences among alternatives. In DSS, we want instead to improve the quality of decisions made, to the satisfaction of the decision maker. One way of improving this quality is to provide more information, relevant information, th the decision maker. The DSS will contain facts, rules and also less tangible items such as opinions, judgments and educated guesses. The knowledge required may be explicit, logical or heuristical in nature. A DSS can support the decision maker dealing with ill-structured problems by enhancing their understanding and judgment, rather than providing a unique 'solution' to the problem.

1.2 How is DSS related to other areas ?

DSS is an interdisciplinary approach to problem solving that draws on a variety of fields : information economics (decision analysis, the value of information), management science (modeling, simulation, optimization, heuristics, decision theory), behavioural science (user resistance to implementation, user training, cognitive styles of decision makers), computer science (hardware, software, system analysis and design) and management (difference between information and data, who needs what information, when, where and why, information flows and control). Figure 2 illustrates the different disciplines that contribute to DSS.

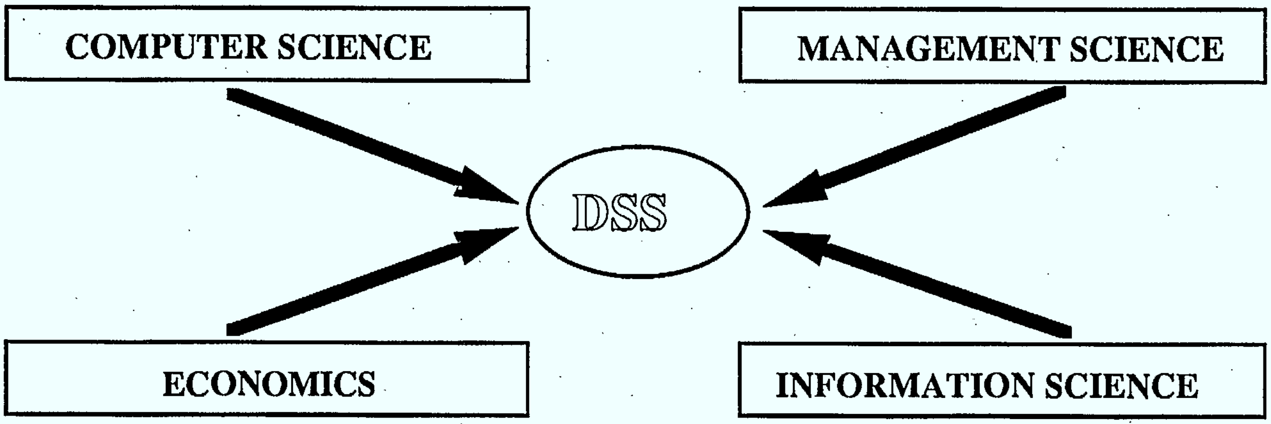


Figure 2. Interdisciplinary nature of DSS

DSS really has a wider context and more evolved nature than other, related disciplines. Management Information Systems (MIS), for example, deal with structured tasks with standard operating procedures, decision rules and reliable information flows. The goal is to increase efficiency. Operations Research (OR) and Management Science (MS) also deal with structured problems and aim to find better solutions through optimization techniques. DSS are distinguished by the fact that they address more judgmental decisions in an effort to increase effectiveness (see figure 3).

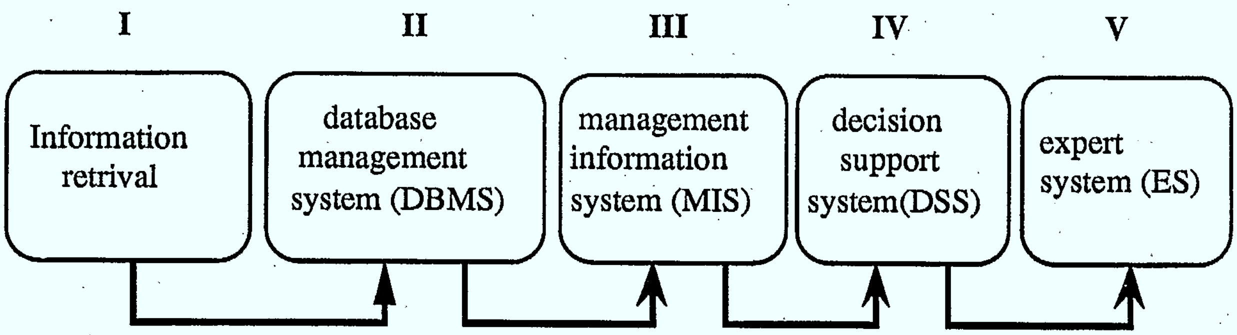


Figure 3. Evolutionary nature of DSS

The need to process information may be a continual one if decisions are made on a fairly regular basis. Periodic reports are need for such routine decisions, and Electronic Data Processing (EDP) systems serve this area well. However, some decisions are infrequent or arise only once. This necessitates special data analysis and greater decisional support, an area that is served well by DSS. EDP tends to provide technical solutions to technical problems by automatically generating standard reports. A DSS deals with unexpected, ad hoc problems and information demands. Intelligent MIS would thus represent a hybrid approach to decision making, combining some of the properties of a conventional MIS with artificial intelligence techniques (refer to figure 4).

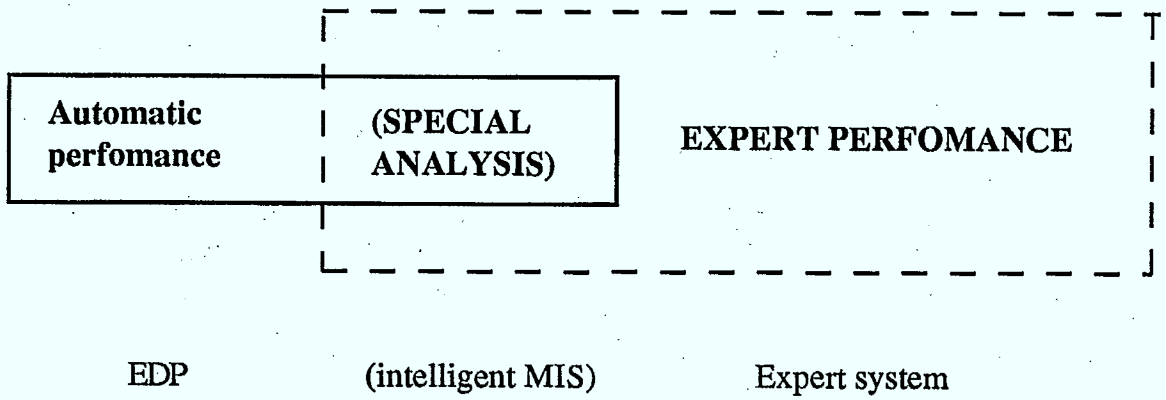


Figure 4. Overlap between expert systems and MIS

In summary, a DSS can be said to be a more evolved form of computer support that goes beyond simple information retrieval and manipulation to provide broader support and covers all aspects of a decision to provide more sophisticated output to the user (see figure 5).

MIS ------------------------Reports at regular intervals

↓

MANAGEMENT SCIENCE- -----------'Answer' to a problem (detailed advice)

↓

DSS-----------------------General guidance and help

Figure 5. Sophistication of output

2. Taxonomy

2.1 DSS Classification Schemes

DSS can be categorized according to a variety of factors. The major criteria are: the nature of the decision, the user of the system, the risk involved in the decision and the mode of usage. These are briefly outlined below.

2.1.1 Nature of the Decision

Decisions vary with respect to type, frequency, number, outcome (final result, input to another decision), where the decision is made, who makes it (individual, group), the organizational level, and the environmental setting (or context) of the decision. One possible taxonomy is a spectrum with programmed decisions at one end and nonprogrammed ones at the other. A programmed decision is routine, repetitive and more or less standardized, such as the processing of the payroll every two weeks. Nonprogrammed decisions are more risky, unique or arise very infrequently or only once, such as deciding on a merger with another company. DSS will best address 'semiprogrammed' decisions, with some structure but also with a substantial amount of uncertainty involved.

2.1.2 Risk

The risk inherent in the decision making process is another criterion. Decision making ususally occurs under certainty, risk or uncertainty. Certainty represents the situation where there is complete knowledge of all strategies and all possible outcomes. Risk is the case where all the alternatives, strategies and outcome probabilities are known. Uncertainty is the same situation with risk but with unknown probabilities as well.

2.1.3 End-Users

The actual user of a DSS may be one or more individuals and may be actual decision makers or intermediaries. At first it was thought there would be a terminal in every manager's office but because most thinking is off-line and most decisions are sporadic, involving only a brief analysis period, this has not happened. Typical DSS users are therefore computer specialists who communicate directly with the system (on or off-line) to receive and decode information. Other users are intermediaries who filter and interpret system outputs and explain the results to decision makers. Decision makers may be end-users of a DSS it they make decisions based directly on the system's output.

2.1.4 Mode of Usage

There is a basic dichotomy in the mode of usage of a DSS based on whether it is used on or off-line (interactive or batch technology). This can be further elaborated into four major modes of usage: the terminal mode, where the decision maker has direct, on-line access, the clerk mode, where the decision maker has direct but off-line access, the subscription mode, where the decision maker automatically receives periodic, standard reports, and the intermediary mode, where the decision maker receives information from intermediaries who analyse and report the system's output.

The most frequently used one is the subscription mode, despite its inflexibility and generation of unnecessary paper.

2.1.5 Other

Other DSS classification shcemes may be based on the nature of the input to the DSS (data, random numbers for simulation modesl), functional area of use (marketing, finances, etc.), the decision perspective (strategic planning, control) and the degree of specificity of the system (one specific application or used for general decision making).

2.2 Recommended DSS Taxonomy

The output of a DSS can vary from a single item of information to a complete decision analysis with recommendations, To this end, the proposed taxonomic scheme helps to visualize the spectrum that exists between a DataBase Management System (DBMS), a DSS and Expert System (ES). There appears to be a dichotomy between knowledge-based DSS, which can store and use large databases specific to a given problem area, and situation-based DSS, which are domain-independent and acquire knowledge, generate inferences and analyze decisions. Knowledge-based DSS provide factual information while situation-based systems provide advice on the decision to be made.

Another, parallel, dichotomy exists between a procedural DSS, which has to be 'told' each step to carry out, and a definitional system, which reads and in some sense understands the problem as an individual would. The latter is a situation-based DSS, with the ultimate system being one that mimics the behaviour of an experienced, "expert" decision maker. Both divisions occur between the third and fourth categories shown below.

Table 1. Decision Support System Taxonomy

CATEGORY	DESCRIPTION
I. Information retrieval	immediate access to data item on file (e.g. mechanized inventory system)
II. Selective retrieval	data manipulation and analysis (e.g. ad hoc budget analysis)
III. Computations	access and manipulation of databases, calculate consequences of planned actions (e.g. spreadsheet analysis of profitability)
IV. Models	accounting model, representational models optimization and recommendations (e.g. risk analysis, resource allocation)
V. Inferences	propose and/or make decisions (e.g. expert system to configure computers)

2.3 Some Existing DSS

Some representative DSS examples are shown below to illustrate the diversity of current applications. These range from advisors on textbook selection for course instructors, to advising on a career, managing a project, managing data and short term corporate planning systems. Research currently underway is geared toward the development of DSS tools to aid in the development of applications. One system, GODDESS is a computerized, domain-independent DSS that helps to structure and represent decision problems. This helps in problem perception by developing decision trees in order to formulate the problem at hand.

Table 2. Decision Support Systems

Portfolio Management System

- administer client portfolios, gives advice on investments
- helps analyse portfolios, extract information

CAUSE (Computer-Assisted Underwriting System at Equitable)

- helps insurers calculate renewal rates for group policies
- 500 to 1 000 calculations are necessary, helps choose the most appropriate ones
- decreases workforce mobility, decreases time and cost of training

BIS (Budget Information System)

- interactive reports on budget, status, profits and losses
- helps in planning, interrogating, analysing and modifying reports without imposing a structure

IMS (Interactive Management System)

- gives advice on the choice of publicity media
- identifies characteristics of target markets
- analyses market segmentation in order to determine the optimal media mix

CLC (Cost of Living Council)

- attempts to standardize salaries and prices in order to implement the ecomomic policy of the U.S. government
- gives advice on political matters and measures the degree of compliance with policies

3. DSS Development

3.1 Representation of the Decision Process

A quantitative decision model is simply a mathematical relationship between the variables involved in the decision. These variables may be decision variables, directly controlled by the decision maker, intermediate variables, linking decisions to outcomes, or outcome variables, which measure perfomance ('attributes'). A decision tree is used to initially model these variables. This is a graphical depiction of the relationship between variables, showing dependencies, decision nodes and all possible outcomes.

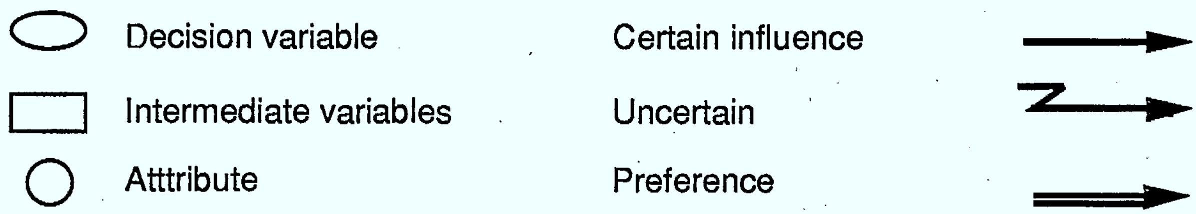
The DSS developer should ensure this tree is complete (all important factors have been included), minimal (non-redundant), comprehensive (no ambiguous variables) and measurable (effects of decision variables on attributes can be assessed). The next step is to transform the decision tree into an influence diagram which elucidates the exact nature of all the variables and all the relationships between them. The influence diagram displays the problem and frames the concept of the decision mode. Figure 6 shows sample representations of the decision process.

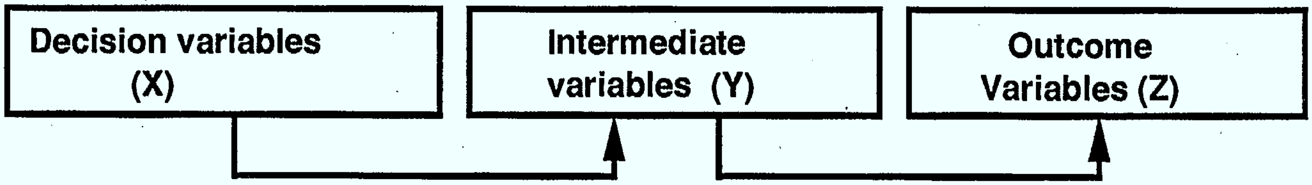
The influence diagram is a model, a representation, of the information that is available to the decision maker and is an invaluable first step in studying any type of decision process.

3.2 DSS Design and Implementation

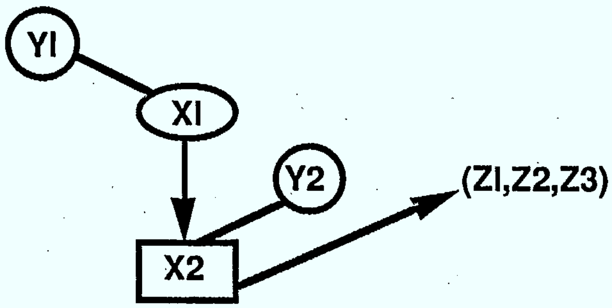
Once the DSS developer has understood the decision process, the potential ways of improving this process can be explored. Insight into how decision makers function is needed, in order to adapt to the particular context and thus effectively support decision making. In addition to describing the decision process, defining key decisions and identifying areas where DSS can be useful, the DSS developer must also identify risk factors and formulated possible strategies for dealing with them. The recommended approach is to divide the project into manageable portions, either through the use of prototypes or by using an evolutionary approach in system development. This serves to decrease both the complexity of the decision and the risk involved, especially in its implementation.

The following are some of the conventional symbols used :





A. DECISION MODEL



B. DECISION TREE

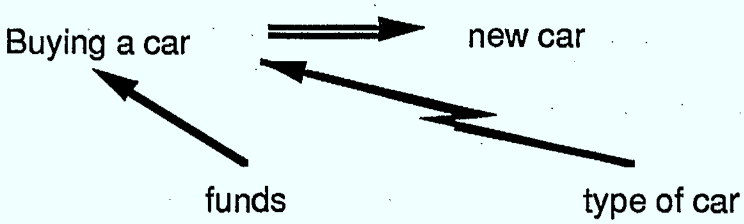


Figure 6. Sample Decision Representations

A satisfactory support base should be developed with user participation and committment in order to "sell' the DSS effectively. User needs must be met when it comes to institutionalizing the system, by providing training, ongoing support and tailoring the system to particular needs. An implementation risk analysis as well as the usual cost/benefit analysis should be carried out before any development work begins, in order to anticipate, and hopefully avoid, some of the potential implementation problems that may be encountered.

The initial DSS design will necessarily be incomplete given the nature of the problem. The problem is to first identify what is required and what the key decisions are, in order to define a normative model (what the decision process should be). The difference between the actual and normative models is a measure of both the potential payoff of the system and of the anticipated difficulty in implementating the DSS. This approach allows the generation of a range of alternatives and alternative designs in order to pick one (or synthesize some of all of the alternatives). The final choice will of course be judgmental to some degree. The DSS must then be validated, refined, updated and maintained in order to adapt to changes in needs, or in problem scope. The DSS development cycle is shown in Table 3.

Table 3. DSS Development

STAGE	DESCRIPTION
Formulate decision	Understand decision to be made identify needs, objectives constraints form value system to evaluate choices list all choices, options, outcomes
Analyze decision problem	determine impact and risk of all choices, identify all variables and relationships, identify their nature (certainty, preference), identify any bounds or weights

Model decision problem	structure (decision tree, influence graph), what-if analysis for each possible choice
Validate decision model	External numbers, data required, compare with individual perfomance, evaluate validity of decisions, variables, extend and refine model

The implementation of a DSS can turn out to be more complex than the design, especially if the system is intended to be used by managers. The DSS developper's role is therefore one of facilitator and manager of change rather than a technician. Human factors cannot be glossed over and much planning must go into the implementation of a successful DSS. Extensive training and support are required and the users should be actively involved in practically all aspects of the design stage as well. The more involved the potential end-users are the easier it will be to motivate them to use the system once it is in place.

4. Foundation of a DSS

4.1 Problems, Needs and Users Addressed

Situations where a DSS would prover useful are characterized by the following characteristics:

1. The existence of a large database that is difficult to access and to conceptualize,
2. The need to manipulate this or compute a solution based on this database,
3. Time pressure for the answer of for the process of arriving at an answer,
4. Judgment needed to recognize or decide what constitutes the problem, the alternatives and the solution.

A DSS assists the decision maker in visualizing the problem in its entirety (a more global view of the situation), in addition to keeping track of details and computations, taking into account more relevant facts, more long term factors and providing a methodology for trying out different assumptions (what-if queries).

The job of a DSS is to move the decision maker more toward the structured end of a decision spectrum. This makes the decision making more orderly and therefore easier to carry out. Semi-structured problems are the best candidates for a DSS. These can typically be solved with a 20 minutes consultation with the right person and usually involves a choice from among a few dozen alternatives. Problems addressed by a DSS are usually unanticipated ones, so that the information that will be required cannot be specified in advance. The data required typically comes from multiple sources and tends to be vague, imprecise, uncertain and even incomplete in nature, creating a problem that is wide in scope.

A DSS is often developed in order to improve effectiveness rather than efficiency per se. Improving personal efficiency (decreasing time and effort for clerical tasks) can help effectiveness but other factors include improving problem solving (decreasing time and increasing accuracy of results), facilitating interpersonal communication (persuasion and justification of choice using a DSS, providing common concepts and a common vocabulary), promoting learning and training (better understanding of the decision) and increasing organizational control (review of decisions and maintenance of their quality).

4.2 Underlying Decision Theory

DSS requires a detailed understanding of the decision-making process. A DSS must first have a descriptive framework of the problem before it can carry out its prescriptive functions (in other words, one must first analyze a system before embarking upon any improvements). There are two major factors to consider: the nature of the decision maker and the nature of the decision itself.

4.2.1 Decision-Maker

There are a variety of views concerning the decision maker which arise from differences in how people acquire and use information, how they reach decisions and how groups handle decisions. Five commonly encountered viws are :

1. *Rational man* - a completely informed individual that carries out a cost/benefit analysis and decides, based on decision analysis and game theory (this represents the ideal),

2. *Satisficier* - an individual who uses rules of thumb and operates within a bonded rationality to arrive at "good enough" decisions (a more realistic view of the decision-maker),

3. *Organizational procedures* - decisions are the output of standard operating procedures and the organization is seen as a string of decision centres linked through common communication networks,

4. *Political view* - the decision-makers are involved in a bargaining process and decisions are made within certain constraints.

It also appears that decision makers, regardless of cognitive style, all seem to prefer verbal information to documents and brief, face-to-face encounters as opposed to lengthy presentations, which should be taken into account when designing computerized decision aids for them.

4.2.2 Decisions

Decision-making typically involves three stages: listing all the alternative strategies, determining all the consequences that can result from each strategy and, comparing and evaluating each set of consequences. It is, of course, impossible for any one individual to know all the alternatives and consequences - thus a decision-maker cannot be entirely rational. There are simply too many alternatives and too much information in general to deal with in an entirely comprehensive and systematic fashion.

The traditional approach to decision-making has assumed that the decision-maker is a rational, fully informed person who will develop decisions in the best interests of the organization - namely, the best economic interests. However, many problems have non-economical considerations, such as political, social and personal issues that must be dealt with. Rationality becomes next to impossible which necessitates what is called a bounded rationality, constrained by individual experience, backgrounds and values. These constraints are defined by the decision structure.

Decision theories thus offer advice to human decision-makers by evaluating the problem to be adressed and by evaluating the proposed plans to deal with the situation, within these bounds of reality. A brief overview of the various decision methodologies appears below (in roughly increasing order of sophistication):

Heuristics

1. *Rule in rule out* - apply each rule in a stepwise fashion to each alternative, obtain a score for each, accept/reject them to varying degrees based on the scores obtained.

2. *Lexicographic rules* - rank all alternatives according to the most important rule; if there are ties, apply the second most important rule; continue.

3. *Mixed scanning* - (concordance analysis, pareto optimality): obtain a short list (first round elimination) by omitting all alternatives clearly dominated by another with respect to all criteria.

4. *Least committment principle* - to avoid premature and/or arbitrary decisions, avoid making them until there is enough information (but be careful of deadlock, when there are decisions to be made but no compelling reason to make them).

Mathematical

1. *Maximax* - optimize by selecting alternative with greatest expected value (probability times payoff)

2. *Maximin* - pessimistic approach, select the greatest payoff from the set of worst alternatives (best of the worst) to minimize potential loss

3. *Minimax* - regret approach, minimize post-decision regret (the amount of difference between actual and potential payoff) by selecting most likely payoff

4. *Laplace decision criterion* - the principle of insufficient reason; in the absence of information, assume all probabilities are equal for all alternatives and choose greatest payoff

5. *Optimization techniques* - linear programming, dynamic programming, etc. to choose the best alternative; identify what to maximize or minimize and what the alternatives, decision variables and constraints are.

6. *Decision tree (expeced value) analysis* - identify all outcomes, their probability of occurrence and the payoff or value, compute the expected value (payoff times probability) for each decision point and pick the branch with the highest resultant expected value (sum of all the nodes).

Note that numbers 1 to 5 represent mathematical approaches, using primarily matrical representations of the alternatives to generate evaluations of each alternative. The decision tree approach is a diagrammatic one, with mathematical computations perfomed at every decision node, to arrive at an overall value for all the branches.

Specialized

1. *Multiattribute decision theory (MAUT)*

This theory is applicable to a special kind of structured human problem solving that involves selecting a particular alternative based on a number of attributes, so as to satisfy the aims or goals of the decision-maker's environment. The problem is made complex due to identifying, obtaining and processing all the information required. Decomposing the problem into smaller, more manageable subproblems is one way to handle the complexity. The subproblems can be evaluated separately and independently with respect to the different dimensions and then a total, aggregate utility is obtained through a complex function of these performance variables. MAUT is well-suited for decision environments with multiple, conflicting and noncommensurate objectives.

2. *Group Decision Theories*

Many decisions are carried out by more than one decision maker. Common examples are elections and committees. This entails the additional problem of how to aggragate subjective evaluations into an overall decision (conflict resolution methodologies). Some approaches to group decision making are :

i. Majority vote - the simplest and most common way

ii. Borda rule - use strength of individual preferences to resolve conflicts

iii. Cardinal utility - score each alternative numerically by averaging all the individual scores given

iv. Bargaining - each individual strives to maximize their own gain in a collective bargaining methodology

v. Additivity - treat the group as an individual and maximize collective good by agreeing on the weighting scheme:
   - Delegation, where one decides (chairman),
   - Decision rules for a group utility function as a sum of individual ones,
   - Substitution to try each individual decision scheme and pick best to use.

3. *Fuzzy set theory* [15]

This is required for any complex, imprecisely defined problems and for decisions requiring inferences. Real world complexity can best be modelled using fuzzy sets, or variables, that are not defined as discrete functions. For example, in everyday usage, we tend to say 'around 50', 'very tall', 'not quite right' and so on. These are all fuzzy or linguistic variables but they can still be treated in a mathematical fashion. The only difficulty lies in defining membership of a fuzzy set. One way of thinking about this is by saying fuzzy concepts are adjectives for entities (nouns) or adverbs, for relationships (verbs).

4.3 Strengths and Limitations of DSS

The advantage of a DSS is that current information is available upon request. This serves to increase response time and the number of decisions that can be made. A DSS also allows the decision-maker to consider more alternatives which in turn improves the quality of the decision. DSS can therefore have a significant impact on decision-making by providing a better problem solving environment, one which focuses on the relevant items and one which separates facts from judgments. Data can be processed through more complex decision models using such systems and both data collection and data presentation can be more easily tailored according to the needs of the decision-maker.

The greatest benefit of a DSS, however, lies in its consistency and uniformity in applying decision criteria. After all, the reason why decision-makers cannot behave in an ideal manner is because they are not considering all the factors that are relevant to the decision, either due to limited memory or due to limited information. Decision-makers also find it difficult to weight all the factors appropriately and to account for any interactions between criteria (such as tradeoffs). To further cloud the issue, decision-makers often do not make consistent decisions as time goes on and they may also differ in the manner in which the decision is reached. Although it is not necessary for all decision-makers to use the same methodology for all decisions, they should behave in a systematic and comprehensive manner.

Despite the fact that DSS may help compensate for the limited capabilities of decision-makers, the computerized decision aids have their own limitations. Some of the major drawbacks are discussed below.

4.3.1 Fundamental Problems

A DSS should ideally be able to answer the following types of questions: What really happened in the past? What is happening right now? What will happen in the future? what can I do now to create the future I want? At present the DSS approach can only contribute to these questions and not answer them. There are four types of questions that may be asked: factual (direct access of a data item), factual inferential (interpretation required), causal inferential (why? - type questions) and predictive (What-if? questions). A DSS can handle factual questions and some forms of predictive questions but cannot carry out any inferencing on the knowledge that is required for the decision-making process. Also, as there is no real data on how any type of decision is actually made by human decision makers, it is difficult for any DSS to effectively support decision making.

4.3.2 Technical Problems

The more complex a DSS is, the more likely it is that technical problems will arise. Among these are the conventional hardware and software problems, such as exceeding the memory capacity and program bugs. There may also be more basic, conceptual design problems which will not be as readily apparent, such as inappropriate assumptions regarding the users, or having tackled the wrong problem in the first place. There will probably be a variety of user problems as a result of these difficulties, especially if the user interface has not been properly designed. In addition, the data required for the system may be problematic, either in its nature data (incorrect, ou of date) or in its quantity (too much, too little, nonexistent).

4.3.3 People Problems

User problems usually arise during the implementation stage of a DSS. One rule of thumb is that the more innovative the system is the more difficulties will be experienced in its implementation, especially in terms of user resistance. You can't simply plug in a DSS and leave it at that. Factors such as motivation, fear of replacement, and individual cognitive styles and work habits must be taken into consideration. A DSS will therefore require multiple perspectives on the decision process, which is not possible at present. For example, there are two major types of cognitive styles in decision making, analytical and intuitive. The analytical individual is systematic, algorithmic whereas the intuitive decision maker has a more global, heuristical perspective. Conventional DSS environments are most effective for the analytical decision maker and at paresent cannot fully accomodate intuitive cognitive styles.

4.3.4 Performance

Although many DSS applications exists and are currently in use, studies have shown that the average human decision-maker can outperform all of these. This was clearly shown in the case of evaluation and subsequent selection of research and development projects for funding decisions. Evaluation problems also play a role and these are discussed further below.

In order to be able to improve a decision making sequence, the following required of a DSS:

1. an a priori definition of improvement,

2. a process of monitoring progress beyond this goal,

3. a formal review process to determine when the system is complete (the DSS developer therefore requires a plan before beginning to keep the project to a manageable size).

We can attempt to evaluate a variety of facets of the DSS such as the decision outputs, the decision processes, the decision-maker's concept of the situation, a change in procedure, a cost/benefits analysis, service measures, the decision-maker's assessment of the DSS and anecdotal evidence. It is best to try more than one of these, keeping in mind that factors external to the DSS may also be held accountable for any improvements (e.g. a Hawthorne effect, when the control group tries to outperform the experimental group).

For each DSS to be evaluated, then, the following questions should be raised: What are we trying to accomplish? What criteria will determine success of failure? How will we know when the system is complete? and, How can we determine if the effort was worth the cost? (see Table 4).

Table 4. DSS Evaluation

I. The System	its technical configuration and how it functions
II. The problem	what problem is addressed and how does it affect the user
III. The User	who uses the system and in what manner
IV. The Implementation	how was the DSS installed, what problems arose (if any), and how they were handled
V. The Impact	what was the impact of the DSS and how was it measured
VI. The Evaluation	was the system a success of a failure and why
VIl. 20/20 Hindsight	what was learned, how does the system compare with others, what needs improving.

The two major stumbling blocks in DSS environments thus appear to be the lack of inferential capabilities and the inability of such systems to accomodate different types of users. Both of these can, however, be readily found in another emerging technology - expert systems. The possible synergy between expert system and DSS technologies is discussed in the next section.

5. Future Considerations

5.1 Technological Advances

Future trends in DSS indicate increased expectations, increased technological awareness and better quantitative skills on the part of decision-makers, in addition to tremendous advances in the basic technology (hardware and software). As familiarity with computer in general increases, the resistance to most computer systems will decrease. All this points to DSS environments becoming more and more commonplace.

These changes may improve the effectiveness of DSS and perhaps radically transform the manner in which we make decisions, By expanding the variety and volume of information available to the decision, the quality of decisions made is expected to improve. This will in turn accelerate the pace at which decisions are made, and will be <u>expected</u> to be made.

One possibility is that in the future, DSS developers will be able to build their systems in a modular fashion by choosing required blocks of functions from a library. For example, standard packages would include report generators, statistical analysis kits, electronic mail, etc. These can be selected and routed to the particular application system being developed through telephone networks.

Another trend is that of increased software costs with a concurrent decrease in hardware costs. One by-product of this will be greater decentralization of decision-making, improved quantitative analysis and therefore, better decisions. Unfortunately, these technological advances have not be matched by increased ability to monitor, filter and selectively analyze large volumes of information. Instead, a vast amount of information overload has resulted, with very inefficient use of DSS. What is needed now, more than ever, is intelligent processing of information - knowledge management system.

One approach is to look into the benefits of coupling DSS technology with that of expert systems, the most successful application of artificial intelligence technology to date. This will increase the sophistication of the support offered to the decision-makers by providing inferencing capabilities. Such intelligent decision support systems (IDSS) would act more as an expert consultant to the decision-maker in lieu of conventional DSS that act more as clerical assistants.

5.2 Intelligent DSS

The field of artificial intelligence has great potential for decision-making applications. Some overlap areas are: modelling and representation of knowledge, reasoning, deduction and problem solving, heuristic search, and expert systems. Knowledge-based expert systems are programs that can give advice or analyze complex information, much in the way a human expert would, for a specified domain. An expert system is in fact a model of one particular expert (or a compilation of many) and can be used as any other type of model (e.g. mathematical, physical, simulation, etc.) to solve relevant problems.

Most expert systems are based on a consultation paradigm with a diagnostic and/or prescriptive framework in which to consider various possibilities in order to recommend a course of action. These applications of AI have similar aims to those of operations research: there is a subjective assessment of probabilities in both decision analysis and knowledge engineering (the elicitation and representation of the expert's knowledge in the system). In fact, DSS developers and knowledge engineers perform almost identical tasks.

A synthesis of artificial intelligence and decision analysis would thus provide user-friendly assistance in problem perception and structuring in order to make recommendations. Such a joint approach to decision-making can provide many benefits. For example, an expert system is capable of explaining, and therefore justifying, its conclusions and recommendations. This will increase the liklihood that a decision-maker will, in the first place, use the system, and in the second place, consider its advice seriously, The decision-maker always has the option of accepting or rejecting any system outputs.

An intelligent DSS will likely increase the rationality, knowledge, expertise and reasoning powers of human decision makers, far beyond the capabilities of a DSS. As more intelligence is put into the decision support system, the system will become accessible to a greater number of people. This is because the more expertise is contained in the system, the less expertise is required of the user. The benefits here will spill over into the implementation stage. The more user friendly, easier to learn, intelligent DSS will probably induce less resistance on the part of the user. As more people begin to use the system, more decisions will be made, and the system will improve in both efficiency and effectiveness.

Expert systems have been used extensively and successfully in medical decision-making. MYCIN, the best known expert system that diagnoses bacterial infections and prescribes appropriate medication, is in fact a DSS in every sense of the word. MYCIN aids physicians in their decisions on what treatment to pursue, which test to order and what to prescribe. MYCIN consists of three subsystems: a consultation system, with approximately 200 decision rules, an explanation system, that can give reasons for all decisions, and a rule acquisition system, that allows new rules to be added to the system in a consistent manner. It is very probable that most expert systems are DSS, since human experts are usually consulted when a decision needs to be made; however, the reverse is far from true (most DSS are not 'intelligent' !)

In summary, the potential contribution of expert systems to DSS is to shift emphasis from decision theories, concerning the nature of the decision and of the decision-maker. to the actual problem to be solved. Intelligent DSS view decisions as problems of search in some specified domain of alternatives. Heuristics are used at each decision node to evaluate any consequences and arrive at a set of possible strategies for problem resolution. This becomes a process of bounded reality, in which choices are made by applying formal rules to partial information in ways that are precise but not based on a simple model of deduction and proof.

Decision analysis systems can use AI techniques to help management weigh options and plan strategies, help make decisions or analyze decisions already made. The intelligent DSS is thus best suited to the role of a checklist to supplement fallible and limited human memory and an expert consultant to help guide you through the steps of the decisional process. The effectiveness of such system, however, will only be as good as the input supplied by the user - the old 'garbage-in-garbage-out' maxim still applies. A DSS supports and analyzes decisions but does not make them for you. The best alternative can be suggested or the principles you applied in arriving at a decision can be deduces but the decision-maker has the final say.

At present, even intelligent DSS (IDSS) can only imitate the "psycho-logic" of a decision-maker's mind. This raises many issues, among them: who will be held responsible for a decision aided by an IDSS? Who will assume the risk inherent in almost all decisions? An intelligent DSS runs the risk of becoming everyone's favorite scapegoat. Other, more philosophical issues include defining the fundamental approach to an IDSS: to what extent can a rationally put together AI system take over the irrational, creative and often conflicting thinking of humans? Is this possible and should this be a goal?

Thus the MIS concept appears to be slowly evolving into the intelligent DSS concept which approximates reasoning in database query and problem solving. Intelligent DSS will be of particular importance in enhancing office productivity and management environments beyond the limited storage and retrieval functions of conventional databases. IDSS is expected to increase white collar productivity in much the same way CAD/CAM and robotics technologies are expected to increase blue-collar productivity. Knowledge-based systems will provide new tools for information management and decision support. By understanding the content of text, these systems will enable decision-makers to make more effective decisions. It is thought by some that expert systems will do for decision-making what the spreadsheet did for number crunching. However, people are rarely conscious of the nature of their decision making whereas spreadsheets support a process that is well understood.

5.3 Examples of IDSS

Besides the well-known medical decision making systems, intelligent DSS may be found for financial advice, investment aid, car buying help, tax advice, project management, plant site selection, long range corporate planning and legal liability decisions, among others. An intelligent DSS can be formulated for most types of decision, ranging from simple catalog selection decisions to complex, situational analyses with a large number of interacting factors. Again, the only significant limits to what these systems can do is how much information is available about the decision process. This is true even of the inductive expert systems, which induce the rules used from examples of 'good' decisions. Although this approach has the advantage of not requiring the decision-maker to be put his approach into words, a large number of precedents or case studies are required as input.

One can use a variety of approaches to IDSS: the simplest is to use a ready-made application system as is or modify it somewhat to tailor it to your needs. Another is to use expert system shells to develop the required type of IDSS so as to not have to worry about the programming code or interface design. It is also possible to develop the system from scratch, writing code in AI languages such as LISP or PROLOG, or in more conventional languages such as C, FORTRAN, etc. There is a tradeoff in that while the ready made system is the easiest approach it is also the least flexible one. Similarly, there is a tradeoff in the programming language used: while higher level languages are best for AI systems, they are not as adaptable nor as efficient as the more conventional ones. The strategy undertaken will very much depend on the nature of the decision and the overall goals of the organization. Table 5 shows some specific applications that have been developedto date.

Table 5. Intelligent Decision Support Systems

Forecasting [5]

- assists metereological analysis of observational data and past forecasts to predict severe storms

Programming Support Environment [6]

- assists in the design, coding, debugging and testing of programs
- database management system that accomodates queries and updates database
- tutors by explaining its reasoning and learns from examples and mistakes to enhance the knowledge base

Welfare Eligibility System [11]

- used to categorize welfare applications as to eligibility and amount of benefits entitled to (if eligible)
- collects data concerning eligibility, verifies this data, explains rights and responsibilities of applicants and calculates benefits

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