ICIS 1987 Proceedings

International Conference on Information Systems (ICIS)

1987

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Recommended Citation

Blanning, Robert W., "EXPERT SYSTEMS AS AN ORGANIZATIONAL PARADIGM" (1987). *ICIS 1987 Proceedings*. 28.
http://aisel.aisnet.org/icis1987/28

EXPERT SYSTEMS AS AN ORGANIZATIONAL PARADIGM*

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ABSTRACT

During the past 75 years a number of paradigms have been put forward to explain the behavior of organizations. These include economic, behavioral, and information processing paradigms. We introduce here an extension of the latter: a paradigm drawn from the knowledge representation and processing procedures used in artificial intelligence.

*This research was supported by the Dean's Fund for Faculty Research of the Owen Graduate School of Management of Vanderbilt University.

1. INTRODUCTION

During the past 75 years a number of paradigms have been proposed to help managers and management researchers understand why organizations behave as they do. These include the scientific management paradigm pioneered by Taylor, the administrative theories of Fayol and others, the bureaucratic model pioneered by Weber, and other approaches arising from economics, behavioral science, management science, and systems theory (Kast and Rosenzweig 1979). These paradigms have their strengths, but as we will see, they also have weaknesses. Their collective weakness is that they do not explain in much detail how organizational subunits exchange information in an attempt to search for the solution to a problem -- such as the preparation of an annual budget, the decision to introduce a new product, or the answer to a "what if" question.

In order to solve problems of this type, organizations must call on the expertise of many of their subunits (i.e., people, departments, committees, etc.) and integrate this expertise to arrive at a decision or a judgment, such as a budget, a new product development decision, a profit prediction, etc. Although the process of integrating expertise is not well explained by the organizational paradigms currently recognized in the literature, it may be possible to construct a paradigm appropriate to this purpose. Such a paradigm might be based on the knowledge representation strategies used in expert systems. It is our purpose here to lay the foundation for a knowledge-based paradigm.

2. THE INFORMATION PROCESSING PARADIGM

It may be helpful at this juncture to describe the nature and use of paradigms in scientific research and, especially, in the study of organization behavior. The concept of a scientific paradigm was first put forth by Kuhn (1970) in his study of the history of science. A paradigm is a scientific world view -- consisting of theories (tested and untested), laws, solved and unsolved problems, etc. -- that guides scientists in their research and allows them to focus on a few problems and approaches to solving these problems that followers of the paradigm believe to be important. Kuhn describes scientific activity as a gradual process of paradigm development, punctuated by infrequent transitions to new paradigms. Examples of paradigm changes are the transitions from Ptolemaic to Copernican astronomy, from Aristotelian to Newtonian to relativistic dynamics, from corpuscular optics to wave optics, etc. A new paradigm has two essential characteristics: (1) it is "sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity," and (2) it is "sufficiently open-ended to leave all sorts of problems for the redefined group or practitioners to solve" (Kuhn 1970, p. 10). We also note that several paradigms may be employed at the same time, and that a paradigm that has been replaced by another paradigm is not necessarily wrong (i.e., a demonstrably false description of reality); rather, it may simply be inadequate to explain those aspects of reality that are of current interest to prominent scientists. Finally, we note that a paradigm may embrace several components, which we will call views or models.

Although a variety of paradigms have been proposed to describe the behavior of organizations, we are concerned with one of the most recent of these, which has been called the information processing paradigm. This is a collection of views or models that describes organizations in terms of the patterns of communication that take place among subunits as they coordinate to perform information processing tasks (e.g., preparing a budget, predicting the profit consequence of a price increase, etc.). One of these views derives from operations research and is based on mathematical programming. An organization is viewed as a purposeful collection of subunits that is attempting in an iterative fashion to converge on an optimal decision. The communication procedures described in the literature include the progressive policy refinement method of the Danzig decomposition method for linear programs (Baumol and Fabian 1964; Burton and Obel 1984) and the adaptive adjustment of Lagrange multipliers employed in nonlinear programming (Arrow 1959). This view differs from the established microeconomic view of organizations in that it not only describes equilibrium conditions for optimal organizational performance, but it also specifies the information processing and communication procedures needed to arrive at an optimum.

Another view, an information processing view with a strong behavioral emphasis, has largely supplanted the view just described of organizations as optimum seeking entities. In this view managers do not attempt to optimize the performance of the organizations or suborganizations for which they are responsible, rather they satisfice -- that is, they make decisions that meet a psychologically determined level of aspiration (March and Simon 1958; Simon 1972). In other words, managers are constrained by cognitive limits to economically rational behavior that induce them to engage in heuristic searches for satisfactory decisions, rather than comprehensive searches for optimal decisions. Attempts have been made to model the satisficing process by evaluating the use of various possible decision heuristics in a stochastic environment (Radner 1975; Radner and Rothschild 1975).

The satisficing view of organizations (also called the bounded rationality view) has inspired another view whose "purpose is to conceive of organizations as information processing networks and to explain why and through what mechanisms uncertainty and information relate to structure" (Galbraith 1973, p. 8). That is, it is assumed that organizations adopt various structures -- such as centralized structures, self-contained tasks, matrix forms, liaison roles, etc. -- in order to coordinate decision making so as to reduce the organizational impact of environmental uncertainty (e.g., market risk, financial risk, etc.). Thus, the purpose of interdivisional communication is uncertainty reduction.

The theoretical views described above have been supplemented with empirical research. The most significant studies are detailed investigations of how managers spend their time (Kotter 1982; Mintzberg 1973). This research, which is similar to the "time and motion" studies that have been performed on first-line supervisors in manufacturing and service operations, has disclosed that most managers spend most of their time communicating with other people both inside and outside of their organizations, and many of the insiders are outside of the managers' chains of command. The purpose of this communication is to gather information, disseminate information, monitor progress, look for problems, etc. Thus, managers rely on networks of formal and informal contacts, and they devote substantial effort to developing and making productive use of these networks.

In summary, adherents of the information processing paradigm view an organization as a collection of subunits that communicate with each other in order to perform information processing tasks. However, with the exception of those taking the operations research view and the early work of Cyert and March (1963), only recently have researchers interested in this paradigm begun to examine in detail what types of messages flow between the subunits as they attempt to solve a problem (Baligh and Burton 1984; Drenick 1986; Huber and McDaniel 1986). For example, we need to know more about the circumstances under which a subunit will request information from another subunit, or when it will provide information to another subunit.

Some researchers have begun to address this concern by incorporating into the information processing paradigm concepts from computer-based information processing. This includes the use of computer-based coordination methods for organizational coordination (Malone 1986), the impact of reduced communication costs on the relative merits of markets and hierarchies as methods of coordination (Malone, Yates, and Benjamin 1987), and the view of an organization as a parallel distributed information processing system (Cohen 1981; Fox 1981). We will focus here on a subset of these views, one that is based on the approaches to knowledge representation and processing developed during that past 25 years by computer scientists specializing in artificial intelligence -- and especially expert, or knowledge based, systems (Waterman 1986).

3. AN OVERVIEW OF THE EXPERT SYSTEM PARADIGM

We will regard an organization as an intelligent system that is attempting to make a decision or perform an analysis that may lead to a decision. Examples are pricing a product, deciding whether to expand production or distribution capacity, and forecasting market share. In many cases making decisions or performing analyses such as these will require the coordination of several units, which we will call organizational subunits (OSUs), such as production planning departments, market research departments, financial analysis departments, etc. We are concerned here with modeling the interactions between OSUs in the form of requests for information and responses to the requests.

Since there are several different knowledge representation schemes used in expert system (rules, frames, etc.), we may expect that there will be several paradigms that might be useful in describing the interactions between OSUs. In this section we will describe briefly five possible paradigms, and we will describe and illustrate one of them (the rule-based paradigm) in much more detail in Section 4.

3.1 Rule-Based Paradigms

In a rule-based expert system, the knowledge base is a set of rules, each of which contains an antecedent (sometimes called a situation) and a consequent (sometimes called an action) (Hayes-Roth 1985). For example, in an expert system for medical diagnosis an antecedent may be the presence or absence of a symptom or a set of symptoms, and the consequent may be a diagnosis and recommended treatment or a request for further information (such as a blood test or a biopsy). Whenever the antecedent is satisfied, the rule is said to fire, and the consequent may be invoked. (It may not be invoked if several rules have fired simultaneously, in which case a conflict resolution algorithm must be invoked in order to determine what to do.) In some expert systems a rule may be allowed to fire only once; in others it may fire many times. The set of executable rules is recursively executed until a halting condition has been reached (e.g., until the system has arrived at a diagnosis and a recommended treatment).

In a rule-based paradigm we view each OSU as a rule whose antecedent consists of information received by the OSU (e.g., it may be given an assumed inflation rate) and whose consequent consists of any information provided by the OSU (e.g., a unit cost of production that it has been asked to estimate). The firing of a rule represents an effort on the part of the OSU to produce information on the basis of information given to it, and the succession of rule firings represents an attempt by the collection of OSUs to perform an analysis or arrive at a decision. This is described in detail in Section 4.

3.2 Paradigms Based on Semantic Nets

A semantic net is a directed graph in which the nodes represent important entities (objects, classes of objects, transactions, concepts, etc.), and the arcs represent relationships between the nodes-- for example, that an object is a member of a class, that a class is contained within another class, that certain objects participate in a transaction, etc. (Barr and Feigenbaum 1981). An important purpose of a semantice net is to capture the notion of inheritance -- that is, an object inherits (possesses) the properties of the objects in the classes of which it is a member. This notion may be useful in describing the way in which common data is made available to many OSUs. For example, many OSUs may need to know the value of an assumed inflation rate to be used in preparing a plan or a budget, and it may be convenient to describe this by inheritance.

Another important relationship is the HAS-PART relationship, which describes the components of an object. For example, one might specify "automobile HAS-PART four wheels." This might be used not only to describe the components of the organization itself -- for example, "Finance-Department HAS-PART four wheels." This might be used not only to describe the components of products or services provided by an organization, but the components of the organization itself; for example, "Finance-Department HAS-PART Controller's-Office." Thus, the OSUs in an organization, the activities they perform, and any materials that they process would be represented by nodes in a semantic net, and the arcs would represent various relationships between them.

3.3 Frame-Based Paradigms

A frame describes an entity (such as an object, transaction, etc.) in terms of attribute names and values (Fikes and Kehler 1985). The expressive power of frames derives from the variety of values that an attribute can take on. The value may be a known value for the attribute, a default value to be used if the real value is unknown, an algorithm for calculating the value from the values of other known attributes, or a reference to another frame (from which it can inherit information). Frames are often useful in representing the variety of ways in which information may be obtained. For example, a price increase may be known, a default value may be available, it may be calculated as a function of the inflation rate, or it may be "inherited" by one OSU from another OSU. Thus, frames would perform functions similar to those performed by nodes in a semantic net -- they would represent OSUs and other important objects and activities and their interrelationships. In addition, such frame-like knowledge structures as schemes and scripts may also be useful.

3.4 Object-Oriented Paradigm

In object-oriented programming, a computational process is viewed as a collection of data objects, each of which consists of stored information and a set of information processing procedures (often called methods) which are invoked when messages are received from other data objects (Cox 1986). An object can access information contained in the other objects only sending the proper messages, which results in a high degree of modularity and encapsulation. By representing OSUs as data objects in an object-oriented system, it may be possible to represent the bureaucratic boundaries found in many large organizations. In addition, object-oriented systems support inheritance by allowing data objects to be represented by classes which are instantiated to produce individual objects. Thus, OSUs can be created and deleted dynamically, which may make it possible to represent changes in organization structure resulting from changing environmental pressures (Blanning 1987).

3.5 Logic-Based and Other Paradigms

A number of logics have been used in artificial intelligence research to describe inferential processes and the uncertainties and ambiguities associated with these processes (Turner 1984). These logics may also be useful in describing organizations; for example: (1) *first-order logic*, and especially logic programming (Clark and Tarnland 1982), may be helpful in describing logical reasoning within an OSU or among several OSUs; (2) *multivalued and fuzzy logics* may be helpful in quantifying ambiguities in decision processes; (3) *modal logic* separates information that is necessarily true from that which happens to be true but could equally well be false, which may be useful in distinguishing planning requirements from planning assumptions; and (4) *non-monotonic logics* allow one to state general principles and certain exceptions to these principles without creating contradictions, which may be useful in describing certain planning requirements and assumptions.

We have presented here an overview of certain knowledge structures that might be useful in modeling organizational structures and activities. Other knowledge structures might also be useful. For example, blackboard architectures may be useful in modeling planning and coordination (Hayes-Roth et al. 1979; Malone 1986), and neural nets may be useful in modeling organizational learning (Parunak, Kindrick, and Irish 1987). Rather than continue to examine the expert system paradigm in general, we now illustrate its application by examining one component of this paradigm.

4. AN EXAMPLE: A RULE-BASED PARADIGM

We now describe one of the paradigms outlined above -- the rule-based paradigm -- in more detail and illustrate its application.

4.1 The CORP World

We begin by describing in more detail the problem we hope to solve. We will do this by presenting the CORP world, a set of two toy problems that will be used in the following two subsections to illustrate the expert system paradigm. The notion of a world as a prototypical problem domain was first used in the development and presentation of SHRDLU, a system for natural language robotics in interaction, in which a "blocks world" was manipulated by the robot (Winograd 1972).

The CORP world consists of two components. In each component it is necessary to determine the profit that a corporation will earn in the following year. In order to do this, a set of organizational subunits (which we will denote OSUs) must communicate to estimate revenues, expenses, sales, volumes, etc., which are used in the estimation of profit. The OSUs common to the two components are as follows:

OSU-1: This OSU estimates the company's profit given estimates of revenue and expense.

OSU-2: This OSU estimates revenue given price and volume.

OSU-3: This OSU estimates expense given fixed cost and variable cost rate.

OSU-4: This OSU estimates volume given price.

OSU-5: This OSU estimates fixed cost and variable cost rate given inflation rate.

The sixth OSU is found in only the second component: OSU-6 estimates price given volume, expense, and markup.

The two components of the CORP world are illustrated in Figures 1 and 2. In the CORP-1 world, illustrated in Figure 1, the computational tasks, ordered by their input and output attributes, form a partially ordered set and, thus, are represented by a directed acyclic graph. In the CORP-2 world, the set is preordered (or quasi-ordered) and the graph is still directed but is not cyclic. The difference is important, as we shall see.

We note that the OSUs can be considered either line units (that make decisions) or staff units (that give advice). For example, OSU-3 may make decisions concerning production scheduling, inventory levels, routing of delivery vehicles, etc., or it may simply estimate expense using simple rules developed by the OSU or given to the OSU by a higher authority. From our point of view the impor-

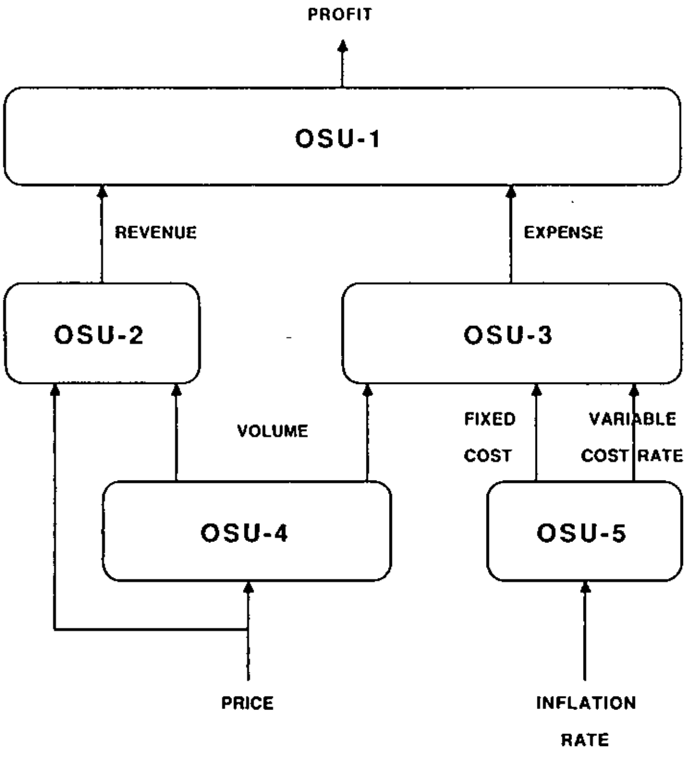

Figure 1. The CORP-1 World

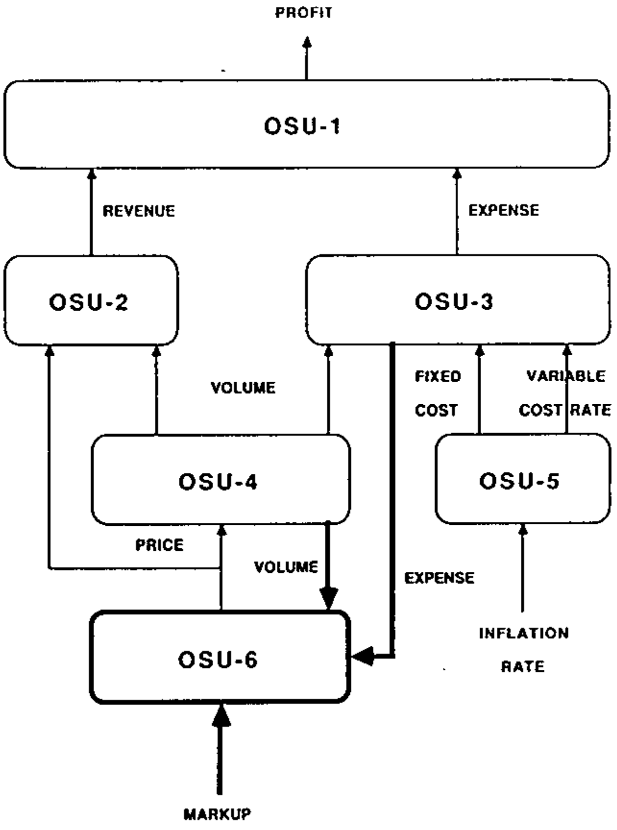

Figure 2. The CORP-2 World

important issue is not who decides what, but that OSUs be viewed as "black boxes" that are presented with information and that respond with additional information.

4.2 A Rule-Based View of the CORP-1 World

We will view an OSU performing an information processing task as a rule in which the antecedent is the information needed to perform that task and the consequent is the information produced by the OSU as a result of the task. For example, in OSU-1 the antecedent is revenue and expense and the consequent is profit; in OSU-2 the antecedent is price and volume and the consequent is revenue, etc.

There are several inference procedures used in rule-based systems, but the one that appears most useful here is backward chaining. If the goal is to determine the profit target for a particular price and inflation rate, then an attempt is made to fire the rule corresponding to OSU-1, because the goal is the consequent of OSU-1. Since revenue and expense appear in the antecedent of OSU-1, it is necessary to fire any rules with revenue and expense in their consequent. Therefore, messages are set to OSU-2 and OSU-3 asking for estimates of revenue and expense. OSU-2 needs to know the price (already given) and volume, so it sends a message to OSU-4 asking for a volume estimate. Similarly, OSU-3 requests a volume estimate from OSU-4 and also an estimate of fixed cost and variable cost rate from OSU-5. At this point the process reverses itself, and the information passes forward through the network until the goal (of determining profit) is attained.

The communication process described above is analogous to the search procedures used by an inference engine that implements backward chaining in rule-based systems. For example, OSU-1 must search through the available OSUs to find one that can provide an estimate of revenue. If no such OSU exists, then OSU-1 must provide its own estimate, and if more than one such OSU exists, then OSU-1 must either implement a tie-breaking metarule or combine the estimates. In some cases, such as the preparation of an annual budget, the search for appropriate OSUs and the action to be taken if a single OSU corresponding to each variable does not exist, will be straightforward and routine. In other cases, such as unanticipated internal (a strike) or external (a price war) crises, the search procedure would generally require more complex efforts at communication and negotiation (Davis and Smith 1983).

In addition, the backward-chaining strategy can be applied to intermediate variables. If the goal is to estimate expense (and not revenue or profit), then OSU-3 will send a message to OSU-4 asking for the volume and another message to OSU-5 asking for the fixed cost and variable cost rate. Once they have made these determinations (from the price and inflation rate, respectively), then the information is passed forward to OSU-3, which satisfies the goal of estimating expense.

The backward-chaining strategy can also be used to describe intraorganizational communication when some of the OSU's fail to perform their assigned tasks. For example, if OSU-4 is unable to estimate volume, then OSU-2 and OSU-3 must coordinate to arrive at a volume estimate. Similarly, if the inflation rate is unknown, then OSU-3 must attempt to estimate the fixed cost and variable cost rate directly, and the backward chaining will stop at OSU-3 (and never reach OSU-5). In summary, when the OSUs, ordered by their inputs and outputs, form a partially ordered set (i.e., when their graphical representation is a directed acyclic graph), then the communication process can be represented by a backward-chaining inference engine in which the quantity to be determined is the goal.

4.3 A Rule-Based View of the CORP-2 World

There is an important difference between the CORP-1 and CORP-2 worlds: in the CORP-2 world the OSUs do not form a partially ordered set and, thus, cannot be represented by an acyclic graph. Rather, they are represented by a directed cyclic graph. This is because of the existence of OSU-6, whose antecedents are volume, expense, and markup and whose consequent is price. The addition of this OSU creates two cycles: one involving OSU-4 and OSU-6 (through price and volume) and the other involving OSU-3, OSU-4, and OSU-6 (through price, volume, and expense). Thus, OSU-3, OSU-4, and OSU-6 must agree on a consistent set of values for price, volume, and expense for given values of markup and inflation rate.

Of course, they may not be able to agree. That is, the OSUs, using their procedures for determining their outputs as a function of their inputs, may not be able to find a single set of values of price, volume, and expense. Another possibility is that there may be more than one set of values of these three variables that meets the information processing criteria of the OSUs. This presumably would lead to more than one set of values for revenue, expense, and profit. Thus, for a particular set of values of markup and inflation rate, there may be no set of values for the variables to be determined, one set of variables, or two or more sets of variables. In other words, a solution may not exist, it may exist and be unique, or it may not be unique.

The backward-chaining strategy must be modified to accommodate the cyclic structure of the OSUs. In backward chaining, a rule normally only fires once. The reason is that the circularity found in the CORP-2 world is not generally found in expert systems. The simplest way to arrive at a solution (if one exists) is to invoke the rules cyclically until a solution is found or it appears that no solution exists. The process might be as follows:

1. OSU-3 assumes a value for price and, given the fixed cost and variable cost rate determined by OSU-5, calculates expense.

2. OSU-6 uses the same volume estimate, the expense determined by OSU-3, and the markup to estimate the price.

3. OSU-4 uses the price estimate to determine the resulting volume.

4. If the volume estimate prepared by OSU-4 is sufficiently close (e.g., within a few percent) to the estimate assumed by OSU-3 and OSU-6, then the process halts, and the values of revenue and profit are prepared by OSU-2 and OSU-1. Otherwise, OSU-3 assumes a new volume estimate and the process repeats.

We note a similarity between the procedures described above for acyclic and cyclic networks of OSUs and the method of constraint propagation used in artificial intelligence for finding one or more sets of variables that satisfy a set of constraints (Freuder 1978; Winston 1984). In constraint propagation a network of constraints is established and feasible values of the variables are identified by means of local searches (i.e., from node to node) through the network. In this case, the constraints are the relationships between the information inputs and outputs of the OSUs, and propagation is accomplished by inter-OSU communication.

5. CONCLUSION

Expert systems are beginning to be used not only for non-managerial tasks, such as diagnosis of equipment failure, but also for management support (Blanning 1984), which may lead to a proliferation of knowledge-based decision support systems (Dhar 1986). Thus, we may expect to see OSUs using expert systems for internal analysis and decision making and senior managers may use expert systems to assist them in coordinating the efforts of the OSUs. A theory of organizational information processing based on expert systems may be quite useful in helping them to effect this coordination.

One issue not addressed here is the degree of centralization or decentralization appropriate to an organization that structures itself along the lines of an expert system. In this paper there are no assumptions, explicit or implicit, concerning this. For example, OSU-1 may communicate with OSU-2 and OSU-3 because it has been told to do so, or it may do so because it needs information about revenue and expense and it knows that these are the OSUs that can provide it. The first (centralized) option is consistent with the view that post-industrial organizations will increasingly attempt to manage decision processes by structuring formal "decision projects" (Huber 1984). The second option is consistent with the view that organizations are best viewed as "organized anarchies," in which people, problems, and solution procedures interact to survive in a chaotic environment (Cohen, March, and Olsen 1972). Further development of the expert system paradigm may help to shed light on this issue.

Two other topics that may benefit from an extension of this work are (1) group decision support systems and (2) organizational simulation. The former are computer-based systems that formalize the interaction between participants in a decision project (DeSanctis and Gallupe 1987; Gallupe 1986). Expert systems models of the type suggested here may provide a useful foundation for structuring the interactions. The idea of constructing simulations of organizations using an information processing framework (i.e., a framework in which an organization is modeled as a network of interacting subunits) is represented in the literature

(Cohen 1981; Tuggle 1980), and this idea may be enhanced with an expert system paradigm.

Finally, we ask whether expert systems might be used directly by senior managers to help them to interact more effectively with their subordinates (e.g., by requesting information from them, evaluating their performance, etc.). This issue has been raised in both a theoretical (Demetrius 1986) and an empirical (Willmer 1986) context, with mixed reactions. However, it appears that the development of an expert system paradigm in the field of organization behavior may help to identify the capabilities and limitations of expert systems as top-level decision aids.

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