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A. P. Sage
[George Mason University, Fairfax, Virginia, USA]

Distributed Information and Organizational Decision-Making Models

The launch decision for the space shuttle is an organizational decision made in a distributed decision-making environment. Researchers and administrators at both NASA and outside contractors, such as Morton Thiokol, are involved. While the final launch decision is made by the mission management team, this decision is based on the decisions from readiness reviews conducted at multiple lower levels. The decisions of the lower levels, although not the information used to make those decisions, are communicated up to the next level; for example, the review decisions concerning the space shuttle main engine, solid rocket booster and external tank are all sent to the Marshall Space Flight Center for a flight readiness review decision. Researchers and administrators at each of these levels have access to different information, are concerned with different problems, have different goals and may be in different geographical locations. Today, many organizations operate in a distributed environment similar to that described above. Modelling organizational decision making when information, personnel and responsibility for parts of the decision are distributed makes it possible to explore the way in which the characteristics of the individuals involved, the information, the environment and the organization affect the timeliness and correctness of organizational decisions, and the efficiency with which they are made.

1. Distributed Decision Making

Distributed decision making refers to the process of organizational decision making that occurs when the information and responsibility for the decision are distributed across time, space and decision-making units (DMUs). A DMU can be an individual, group of individuals, a machine, or a collection of individuals and machines that is responsible for some component of the overall decision. Organizational decisions are a product of the information gathering, processing and decision making of multiple DMUs. In order to make correct, efficient, salient and timely decisions, the effort of the DMUs (which DMU collects what information and works on which aspect of the overall decision) must be coordinated. Each DMU may take part in the coordination process by attempting to negotiate its own role in the information gathering, processing and decision-making process. Each DMU has access to somewhat different information, has different criteria or goals for evaluating that information, has access to different technology for evaluating and gathering information, and so on. These differences affect both the ability of the DMUs to acquire new information, and their negotiation and decision-making behavior. Furthermore, these DMUs may be in different geographical locations and time zones.

From an organizational standpoint it is important that the decision be correct given the information available, and that the decision is efficiently made, salient and timely. From an information-processing perspective the factors affecting the decision-making capability of the organization can be roughly divided into three categories: the organizational structure, the event theater and the information gathering, processing and decision-making capabilities of the DMUs. The organizational structure is set of the modifiable characteristics that define the organization. These characteristics include size, the command, control and communication (C3) structure, distribution of information, procedures for making decisions and procedures for redistributing DMUs. DMUs can be redistributed by hiring, firing or redistributing personnel and by changing which DMUs have access to which computers or the power of those computers. The structure of an organization cannot be simply described as a hierarchy (Mintzberg 1979, 1983). While the command structure may be hierarchical, the communication structure may be uniform (everyone talks to everyone). Organizational procedures tend to be volatile. For example, for each decision, who makes the decision, the number of DMUs involved, the relation of information to the problems and decision, and the procedures to coordinate the DMUs may all be different. The event theater is the environment from which the organization draws information and which may dictate the schedule by which certain decisions must be made. Event theaters tend to be highly volatile. From day to day the flow of information, the number of problems faced by the organization, the number of decisions made and the rate at which decisions (at least certain decisions) must be made may all vary. Furthermore, the characteristics of the information available to the organization may continually change; for example, the level of completeness and reliability of the information relative to a problem change. The information gathering, processing and decision-making capabilities of the DMU depend on its composition. If the DMU is a single individual or machine then these capabilities are determined by the architecture (human cognitive or machine) and the information used to process other information. If the DMU is a collection of individuals or individuals and machines, then these capabilities are determined by the architecture, the information used to process other information, and the coordination and negotiation processes within the DMU. Characteristics of the architecture such as the way the DMU learns new information, stores information, plans and reasons about others are generally treated as similar across DMUs and constant over time. Characteristics of the information that the DMU uses to process other information (e.g., the goals or objectives, the salience which the DMU attributes to different problems, the DMU's level of expertise with this problem and heuristics used by the DMU to solve problems) are expected to differ across DMUs and to change over time for the DMU. Characteristics of the coordination and negotiation processes such as the degree of information loss and order of combining information are generally treated as similar across DMUs and constant over time. Thus, the organization is generally modelled as being composed of a set of DMUs which will function identically, provided they are given identical information and guidelines for processing information.

When the organization is faced with a crisis the factors affecting the decision-making capability of the organization become more volatile. Crises are characterized by increasing uncertainty about the procedures for making decisions, rapid event theaters and volatile information flows. As uncertainty about the decision procedures increases, the participation of the DMUs becomes volatile; as the number of DMUs decreases, coordination decreases and communication channels become unreliable. In a rapid event theater the number of problems increases and the time available to make decisions decreases. Furthermore, with a volatile information flow the amount of incoming information increases or decreases rapidly and the information becomes less reliable.

In an effort to understand how to increase the decision-making capability of the organization given the complexity of organizational decision making in a distributed environment, researchers have turned to model building and simulation. These models fall roughly into two categories—those emphasizing characteristics of the organizational structure and those based on models of individual cognition. In both cases, analyses tend to be done through simulation. Simulation is adopted since the nature of the problem involves feedback, effort allocation decisions, heuristic-based behavior, a large number of DMUs, vast amounts of information and large numbers of problems. Analytical results obtained when dealing with two or three DMUs and two or three problems are simply not generalizable to realistically sized organizations, in part because patterns of negotiation and coordination are qualitatively different for extremely small and simple organizations. Furthermore, in order to understand a crisis, the short-term consequences of changes in the event theater, rather than equilibrium or long-run behavior, must be observed (Carley 1986a).

2. Structure-Based Organizational Models

Predominant among the models that emphasize characteristics of the organizational structure are those following from the garbage-can theory of organizational choice (Cohen *et al.* 1972). According to the basic garbage-can model, organizations are anarchies characterized by severe ambiguity. There are three areas of ambiguity: problematic preferences (i.e., different DMUs have different goals and these goals change over time), unclear procedures for making decisions, and fluid participation (i.e., membership changes over time). People with their goals, problems and solutions flow through the organization and decisions happen by resolution (rationally solving a problem), by flight (ignoring the problem) and by oversight (owing to another related problem being solved). Public-sector organizations (e.g., city council and Red Cross), educational organizations (e.g., colleges) and any organization during crisis (e.g., joint task force) are typified by this model. Both educational (Cohen *et al.* 1972, Cohen and March 1974) and military (March and Weissinger-Baylon 1986) organizations have been analyzed using this model.

A variety of models based on the garbage-can concept have been proposed (Cohen *et al.* 1972, Padgett 1980, Anderson and Fischer 1986, Carley 1986a,b, for example). Using these models the researcher can explore the relationship between various characteristics of the organization's structure and its decision-making capability. Using their model, Cohen *et al.* (1972) found that regardless of organizational structure, as crisis approaches most decisions occur by flight and oversight, and that in organizations where the access structure is specialized (each DMU has access to different information and is responsible for different problems), more problems (50–65%) are solved by resolution. Alternatively, Padgett (1980) found that when the organization is modelled as a hierarchy with garbage-can properties, the chief executive officer (CEO) can most effectively get the organization to make decisions that meet the CEO's goals by exercising a hands-off policy and hiring liberal assistants for low-saliency programs and conservative assistants for high-saliency programs.

A very general model of this type is GARCORG (Carley 1986a,b). GARCORG is an interactive simulation model for exploring the relationship between organizational structure, the event theater and the decision-making capability of the organization. Unlike other models in the garbage-can tradition, GARCORG can be used to simulate organizations both with and without garbage-can-like features. The user specifies the organizational structure and some characteristics of the event theater. GARCORG then simulates the organization's behavior over time and reports on the results. The generic model used by GARCORG is portrayed in Fig. 1. In this model, the organization is set up as a four-level decision hierarchy (a) with four corresponding types of DMU: a CEO, an assistant executive officer (AEO), program chiefs (PC) and analysts (A). Each DMU occupies a particular slot in the organization (b). DMUs at higher levels may or may not have access to or consider salient the decisions that come out of slots at lower levels. Each time period, a certain amount of information comes into each slot (c), each piece of information having a different level of content (shown by different shading of the squares). Content can be thought of as the level of validity, reliability or completeness of the piece of information. Information in the form of decisions by DMUs from lower levels moves up the organizational hierarchy. For example, the decisions made by the analysts become the information available to the program chiefs.

In GARCORG, the user can describe the organizational structure by specifying the organization's size,

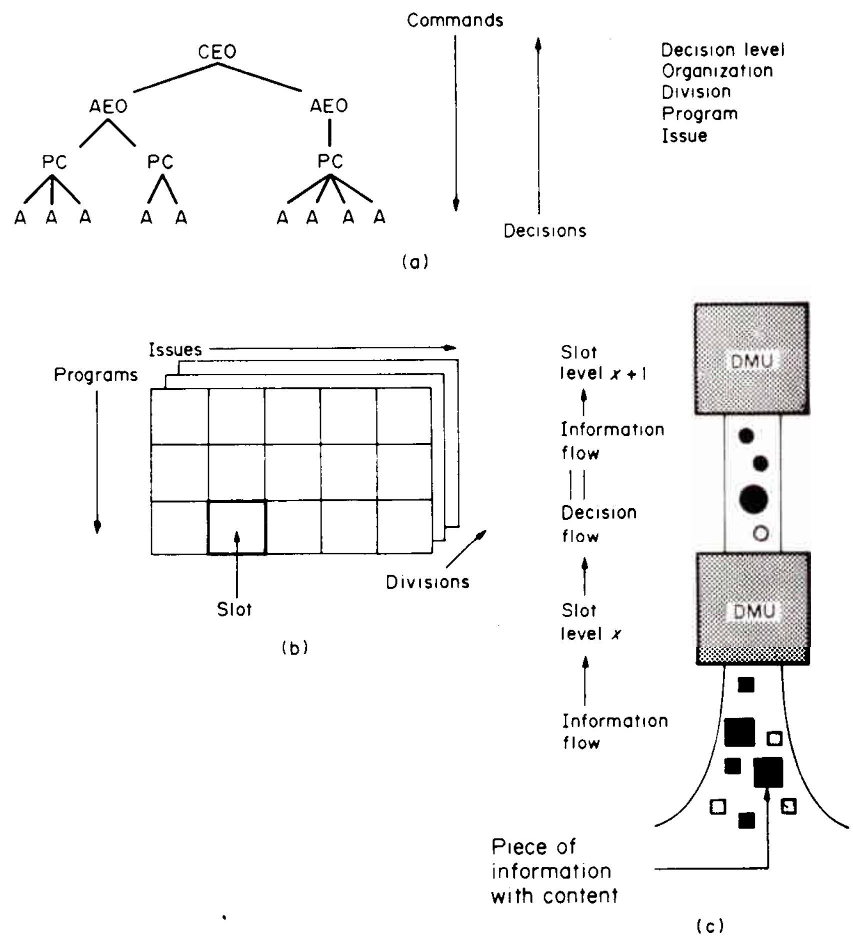

Figure 1
The generic model used by GARCORG

whether or not the organization is differentiated (the more differentiated, the larger the number of programs and the fewer people working on each program), the hiring and firing criteria (personnel transfer), the threshold for hiring or firing, the delay before hiring/firing decisions are made, who has access to what problems and hence information, the average level of saliency that the various problems have to the CEO and his assistants, and the level at which the CEO and assistants rubber-stamp the decisions of the lower echelons. The user can also characterize the event theater by specifying the amount and content (value or completeness) of new information per time period. Using this model the user can examine the impact of thousands of different organizational structures and nine event theaters on the organization's decision capability over time.

GARCORG can be used to simulate both crisis and normal operating conditions and response. Crisis can be simulated by setting up an event theater in which the amount of incoming information is high and the content low. Then, by observing the organization's behavior in the short run, the organization's response to crisis can be studied. In GARCORG the decision-making capability of the organization is measured in terms of the efficiency with which the decisions are made, and the percentage of decisions that are rubber-stamped by the CEO and assistants. Both structural and political efficiency are measured in terms of the fraction of bad slots in which analysts are working. A slot is a position in the organization. A slot is *structurally* bad if the CEO or assistants do not have access to the decisions made by the analyst in that slot. A slot is *politically* bad if the CEO or assistants do not consider salient the problem that the analyst in that slot is working on.

Using GARCORG, Carley (Carley 1986a) examined which organizational structures performed best during crisis. A total of 36 different organizational structures were simulated and the results statistically analyzed. It was found that: small organizations are more efficient than large organizations in the short run, especially structurally; differentiated organizations are more efficient overall; a hiring/firing criteria based on saliency does not guarantee political efficiency; and the criteria by which personnel are hired or fired has a more immediate and stronger impact on efficiency than do the other organizational structural features. This analysis also suggested that the organizations which must cope with crisis should be small and differentiated, with all managers having access to all problems, the hiring/firing criteria being based on information rather than saliency, and with the CEO not exerting direct control (high rubber-stamp level).

Collectively, the garbage-can models suggest that when information is distributed across DMUs, the best decisions (made by resolution) and the most efficiently made decisions occur when DMUs are responsible for making decsions about, and consider salient, those problems that need the information to which they have access. Thus, information, problem control and salience should be similarly distributed and segmented. Alternatively, all DMUs, should take part in all decisions or have access to all information; however, this distribution scheme may lower efficiency and the quality of the decisions. These conclusions are reached in part because these models do not allow communication of information (only decisions), negotiation or coordination among DMUs.

Recently, researchers have turned to models of parallel processing, rather than garbage-can models, to determine the impact of organizational structure and the event theater on the decision-making capability of an organization. For example, the petri net models (Hillion 1986, Remy and Levis 1986) and the effort allocation model (Carley *et al.* 1988) may be used. The effort allocation model is concerned with the impact of effort allocation schemes and coordination schemes on the timeliness and correctness of decisions. The effort allocation schemes are used to determine which DMU is responsible for working on which problem. The coordination schemes determine which DMU makes effort allocation decisions and what information it uses. Two effort allocation schemes have been explored: optimal allocation, determined analytically, and heuristic-based allocation. Coordination schemes explored include anarchy (each DMU acts independently, choosing which problems to attend to and making its decisions independently of the other DMUs in the organization), centralized (each DMU is arranged in a hierarchical structure and is coordinated by the CEO who makes all decisions) and decentralized (each DMU makes its own decisions, but these decisions are based on information received from other DMUs). These coordination schemes and resultant differences in information availability and the time it takes to make effort allocation decisions are shown in Fig. 2.

Using the effort allocation model it was found that any coordination scheme is better than none, heuristic-based allocation schemes are almost as effective in terms of number of correct decisions as optimal analytic schemes and they are less costly. In addition there is a trade-off between consistency and latency. This means the organizations with decentralized coordination schemes not only make more timely decisions, but also make incorrect decisions due to inconsistencies in the informaton available to them; centralized organizations make less timely but more correct decisions. In this model all information inconsistencies are due to lack of concurrency in the information.

Organizational decision making is not rational. Rather, because organizational decisions are the product, at least in part, of human decision making, such decisions are subject to limited rationality (March and Simon 1958). In the garbage-can models, limited rationality was achieved by affecting the infor-

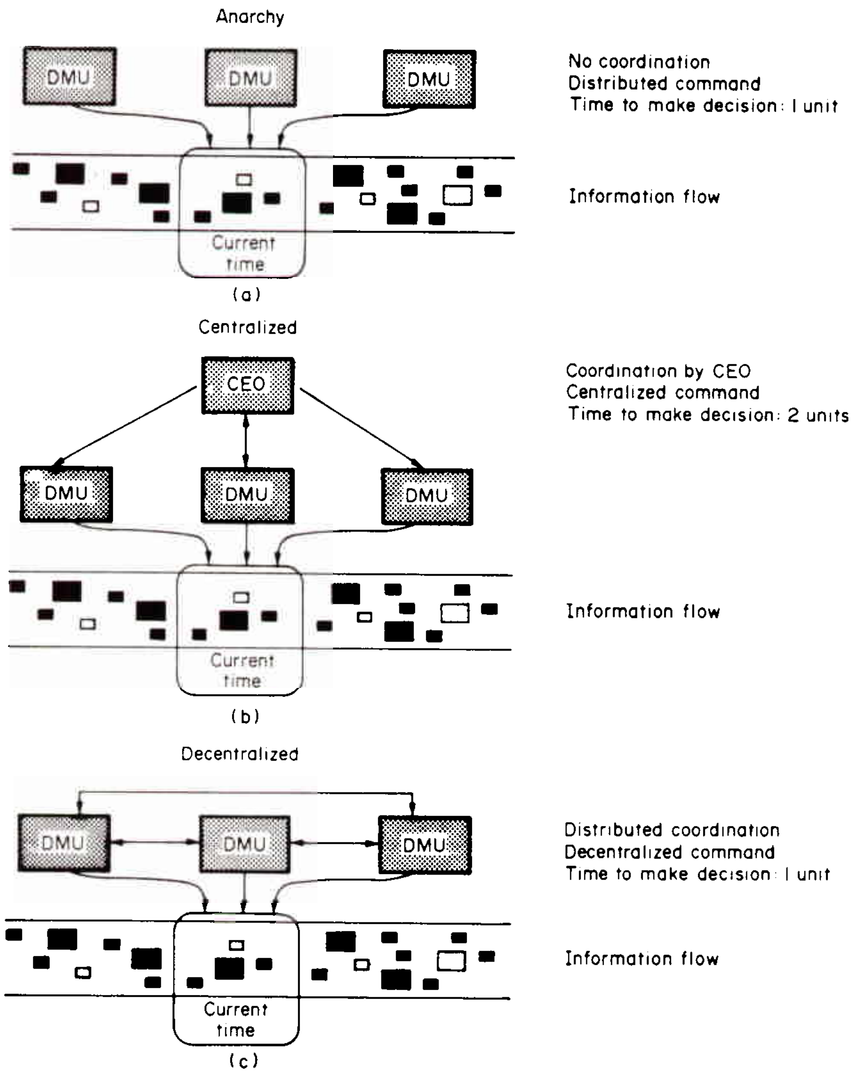

Figure 2
An illustration of three different coordination schemes: (a) anarchy, (b) centralized and (c) decentralized. In all three cases it is assumed that it takes one time unit for a DMU to acquire information from the external information flow and one time unit to communicate information to another DMU. In (a), as soon as the DMU acquires information (one time unit), it can make a decision. In (b), each DMU collects information (one time unit) and then communicates that information to the CEO (one time unit) who then makes a decision; hence it takes two time units before a decision can be made. In (c), each DMU can make a decision in one time unit after getting information from the external information flow and from the other DMUs. This decision, however, will rely on information about what the other DMUs are doing which is one time unit out of date

mation that the DMU used to process other information; for example, by giving the DMU goals that changed over time. In the effort allocation model, limited rationality was achieved by using heuristic-based allocation schemes. In neither case is there a model of the architecture of the DMU, nor of the coordination and negotiation processes within the DMU. It is expected that by basing the organizational model on more realistic models of the DMU it will be possible to explore how negotiation and planning are affected by different distributions of information and DMUs. It is further expected that such models will more accurately reflect organizational decision-making capability.

3. *Cognitively-Based Organizational Models*

Recently there has been growing interest in exploring the impact of the individual's cognitive architecture on organizational distributed decision making. In these models, the DMU is treated as a single individual. These models take into account features of the individual's cognitive architecture such as the information representation scheme, learning procedures, the ability to reason about others and planning procedures. Many of these models use techniques and ideas from artificial intelligence. Some of the organizational tasks that have been studied using this approach are tracking and surveillance (Drazovich *et al.* 1977–1979, Reid 1979, Lesser and Corkill 1981, Durfee *et al.* 1985), allocation of labor by bees (Reed and Lesser 1981), sensor data interpretation (Smith 1980), air traffic control (Steeb *et al.* 1980, Thorndyke *et al.* 1981) and general organizational management (Fox 1979, 1981).

A model of this type is CONSTRUCT (Carley 1987, 1988). CONSTRUCT is an interactive simulation model for exploring changes in the social or organizational structure that accrue as individuals communicate and gather information. CONSTRUCT, as a general social behavior simulator, can be used to simulate the learning and decision behavior of individuals in various group and organizational settings. CONSTRUCT utilizes a simplistic model of individual cognition based on a list-structured knowledge representation scheme and a series of learning mechanisms. CONSTRUCT is based on the premises that as individuals interact they acquire information, the more information that individuals share the more likely they are to interact given the opportunity to do so, and that the organizational structure is continually reconstructed as individuals acquire information and change their interaction patterns. Using CONSTRUCT, the researcher can explore the way in which different organizational structures are differentially useful for the storage and maintenance of information, development of shared knowledge and decisions consensus. CONSTRUCT can also be used to look at how different distributions of information and organizational structures alter as information flows through the organization. The use of CONSTRUCT suggests that when information is distributed across DMUs the organization's informal structure changes to become parallel to the information distribution scheme. Stability in the organization's structure can be maintained by segregating information across the DMUs according to the communication structure.

In CONSTRUCT the user can specify the organizational structure by specifying the size of the organization, the amount of information known to the organization, the rates at which DMUs enter and leave the organization, the initial command/communication structure (who interacts with whom) and the initial distribution of information across DMUs. The event theater is characterized by the rate of incoming information. To use CONSTRUCT the user first specifies the structure of the organization and the event theater, and then CONSTRUCT simulates the behavior of the organization for a series of time periods. CONSTRUCT can be used to simulate both crisis and normal operating conditions and response. Crises can be simulated by using a high rate of incoming information. As with GARCORG, crisis response can be studied by observing the behavior of the organization in the short run.

Organizational models which are cognitively based enable the exploration of issues such as the impact of information diffusion, planning and learning on organizational decision making. Currently, most of the cognitively-based models have only limited applications to organizational decision making as they do not allow the user to model the organizational structure. CONSTRUCT, on the other hand, can be used to model the organizational structure; however, the model of individual cognition and the facilities for modelling the event theater are limited.

4. *Future Work*

Organizational decision making when the information, DMUs and responsibility for parts of the decision are distributed is complex. Consequently, model building and simulation are viable approaches for studying this process. Among the factors affecting the decision-making capability of the organization are the organizational structure, the event theater and the information gathering, processing and decision-making capabilities of the DMUs. Future models of the organizational distributed decision-making process will combine these factors. The models discussed in this article indicate a variety of issues with which future models will need to contend. Three such issues are the impact of crisis, information characteristics, and the distribution and redistribution of DMUs on the decision-making capability of the organization.

A unique feature of the GARCORG and CONSTRUCT models is that they admit the study of organizational behavior during crisis. Crisis-related behavior can be studied by considering short-term behavior when the rate of incoming information increases. There are, however, many other characteristics of crisis. For example, during crisis it may become difficult for some DMUs to communicate with others and the number of decisions that need to be made may increase. Furthermore, crises last only a short time and the organization will then either recover, disintegrate or reorganize.

An important feature of all the models discussed in this article is that they deal with the relationship between various characteristics of information and the decision-making capabilities of the organization. The amount, content (completeness), distribution and the change over time in these information characteristics can all be explored. It is clear that information characteristics can affect organizational decision-making capabilities and that this relationship is complex. For example, the impact of the amount and content of the information may depend on the distribution of information across DMUs and the speed of communication between DMUs. Questions of information concurrency, information distortion, and the economics of transmission and storage still need to be explored.

Another important aspect of these models is that they begin to allow the user to study how policies which affect the role and placement of DMUs within the organization make impact on its decision-making capability. Policies which affect structural factors like the following can be studied: number of DMUs, movement of DMUs within the organization, coordination of DMUs, distribution of decision-making responsibility across DMUs and communication between the DMUs. In order to comprehend the impact of these policies on the organization's decision-making capability more fully, it will be necessary to examine issues such as the conditions under which useful heuristic strategies for coordination and communication evolve, changes in efficiency as DMUs enter, leave or move about in the organization, and information storage and loss as DMUs enter and leave the organization.

Even a brief consideration of organizational decision making shows that many organizational decisions are somewhat repetitive; for example, there were 25 shuttle launch decisions made between April 12, 1981 and January 28, 1986. It can also be seen that organizational decisions tend to be integrated decisions; that is, the final decision is the result of a plethora of previous decisions made by various DMUs. At a very primitive level, the models discussed in this article consider repeated and integrated decisions. There are, however, important aspects of repeated and integrated decisions that are not dealt with. For example, organizational learning from repeated decisions, and information loss and distortion when integrated decisions are made. Furthermore, it can also be seen that many DMUs are either a collection of individuals or a collection of individuals and machines. Up to the late 1980s, models of organizational decision making have not dealt with this complication, for example, the changes in communication speed, processing ability and storage capability when individuals can rely on machines are not explored in this framework.

Using models like those discussed here, it is possible to explore organizational decision making when information, personnel and responsibility for parts of the decision are distributed. As the concerns above illustrate, there are still many factors affecting organizational decision making that these models do not take into account. In order to understand and facilitate the decision-making capability of organizations such as joint task forces, NASA, Chrysler and the Red Cross, it will be necessary to develop not only new models but models which allow the user to examine empirical data drawn from studies of such organizations.

See also: Distributed Decision Making: Information Systems

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K. Carley
[Carnegie-Mellon University, Pittsburgh, Pennsylvania, USA]

Dynamic Decision Making

The tasks of process control in industry, treating a patient in an intensive-care ward, fighting a forest fire and managing a company are dynamic decision tasks in that they share the four following characteristics:

(a) a series of decisions are required;

(b) these decisions are interdependent;

(c) the decison problem changes, both autonomously and as a consequence of the decision maker's actions; and

(d) the decisions are made in real time.

Dynamic decision tasks differ from static tasks in that a series of interdependent decisions are required to reach the goal, and from sequential decision tasks in that the time aspect is important. Dynamic decision tasks require a different conception of decision making than the conception in terms of the resolution of discrete choice dilemmas prevalent in traditional research on decision making. They also require a new conception of decision tasks; the traditional conception, based on gambles, which sees a decision task in terms of a list of action alternatives connected to outcomes by means of probabilities is obviously unsatisfactory.

Brehmer and Allard (1988b) have suggested that decision making in dynamic tasks should be seen as an attempt to achieve control, instead of an attempt to resolve discrete choice dilemmas. They have also proposed a conceptualization of dynamic decision tasks in terms of six basic characteristics. We start with a discussion of these six characteristics, and move on to a brief review of results from empirical studies on dynamic decision making.

1. The Characteristics of Dynamic Decision Tasks

Brehmer and Allard (1988b) chose their six characteristics partly on the basis of systems theory in an attempt to capture what is needed to ascertain the possibilities for achieving control, and partly on the basis of psychological considerations to obtain a description that can be used to understand human performance in dynamic tasks.

1.1 Complexity

Although the meaning of the term complexity seems intuitively obvious, it is very hard to define. This is because complexity is a relative concept. Phenomena are not complex in general, they are complex in relation to something. In this article, we are interested in complexity in relation to control. We therefore follow Ashby (1956) and define the complexity of a system in relation to the capacity of the device that seeks to control the behavior of that system. Thus, a system is said to be too complex in relation to a given control structure if this structure cannot match the complexity of the system. The relative complexity of a task may then be defined as the extent to which it makes demands upon the resources of the control device.

In the present context, the control devices of interest are human decision makers. People are limited information processors in that they can only take a limited number of items into account at the same time. Hence, we may define complexity in terms of the number of elements and relations in the system that the decision maker seeks to control. However, from a psychological perspective, not all elements are the same, and we need to distinguish among at least four different kinds of elements:

(a) goals,

(b) control actions,

(c) processes that need to be controlled, and

(d) side effects.

Few, if any, dynamic decision tasks are so simple that the decision maker will have only one goal. Instead, there will often be many goals, with the attendant need to make trade-offs. In process control in a modern plant, for example, there is often a need to consider both productivity and safety, and to make a reasonable trade-off between them.

The number of control actions may vary in two different ways. First, there may simply be a number of different things that need to be done to acquire control. Second, there may be many alternative courses of action, and some of these may substitute for each other, so that there are different ways to achieve the same end. The former clearly increases the complexity