A Theoretical Study of Organizational Performance Under Information Distortion

Kathleen M. Carley • Zhiang Lin
Department of Social and Decision Sciences, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213
Department of Management of Organizations, The Hong Kong University of Science & Technology, Hong Kong

How should organizations of intelligent agents be designed so that they exhibit high performance despite information distortion? We present a formal information-based network model of organizational performance given a distributed decision making environment in which agents encounter a radar detection task. Using this model, we examine the performance of organizations with various designs in different task environments subject to various types of information distortion. We distinguish five sources of information distortion—missing information, incorrect information, agent unavailability, communication channel breakdowns, and agent turnover. This formal analysis suggests that: (1) regardless of information distortion, performance is enhanced if there is a match between the complexity of organizational design and task environment; (2) task environment characteristics have more effect on performance than information distortion and the organizational design; (3) the effects of information distortion can be combated by training, but only to a limited extent; and (4) technology based information distortion typically is more debilitating than personnel induced information distortion.
(*Simulation; Organizations; Performance; Stress*)

1. Introduction

It was July 3, 1988, the Persian Gulf. On board the most advanced Aegis warship, *U.S.S. Vincennes*, operators worked intensively at the radar defense system. Suddenly, they detected an attack signal by an "enemy F-14 fighter." The warning was immediately sent to Captain Will Rogers III, who without hesitation, gave the order to fire. Several minutes later, an Iranian civilian aircraft with nearly 300 passengers was shot down, no one survived (Cooper 1988).[1]

This tragedy prompted many to wonder: What went wrong? Investigations following the incident suggested many possible causes for the tragic mistake. Criticisms levied included: The Navy lacked training in real fighting, but had experience only with computer games and "canned exercises"; consequently, some crew members were unprepared and misinterpreted the radar data in this real and highly stressful situation (Cohen 1988). The Navy was not properly trained for low intensity conflict, but only for superpower confrontation; thus, their personnel as well as war machines were not suitable for the Persian Gulf situation (Duffy et al. 1988). The Navy used biased judgments (Watson et al. 1988). As Adm. William J. Crowe Jr., then Chairman of the Joint Chiefs of Staff, commented: "The rules of engagement are not neutral. They're biased in favor of saving American lives." The radar system received incorrect information regarding whether the aircraft was civilian or military (U.S. Congress 1988). And, the hierarchical command structure of the Navy warship led to insufficient cross-checking when information was passed to the captain (Watson et al. 1988).

This incident demonstrates that information distortion affects performance; but, the impact is mediated by design (such as organizational structure, resource access structure, and training) and the task environment.

[1] Though there have been other similar incidents, we use this incident to illustrate the main points in this paper.

0025-1909/97/4307/0976$05.00

Despite the often tacit acknowledgment that information distortion, organizational design, and task environment are intimately related, few studies have systematically and simultaneously explored the impact of these factors on organizational performance. Such a study should provide insight into how interactions among these factors impact performance. We engage in such an analysis using a formal model (analyzed via computer-assisted enumeration and computer simulation). The simulated organizations examined are engaged in a stylized radar detection task resembling that faced by the *Vincennes*.

2. Background

2.1. Information Distortion

Organizations often face information distortions. These distortions range in their potential to cause a crisis, inevitability (Perrow 1984), severity, and their novel or routine nature (March and Olsen 1976, March and Simon 1958). Information distortions are important to consider as they are pervasive (Cohen and Mach 1974) and yet potentially reducible, if not preventable. Information distortions, as we have seen, can be caused in numerous ways; e.g., turnover, personnel unavailability, incorrect information due to technology.

Answers to the question "How can organizations cope with information distortion?" have focused on the mediating role of organizational design. Two strategies have dominated the literature: "better technology" and "better training." The better technology strategy (Neuhauser 1971), an engineering approach, centers on the idea *if we can just design the procedure (and/or the associated equipment) right, then crises induced by information distortion can be avoided*. If Perrow (1984) is right, better technology may reduce information distortion but will not eliminate it. Indeed, the "better technology" may introduce new distortions. The better training strategy (Dunbar and Stumpf 1989, Green 1989), a personnel approach, centers on the idea *if we can just train people then they will respond more quickly and accurately given information errors thus minimizing the impact of information distortion*. But the value of training is indeterminate (Ganster et al. 1991, Hammond 1973). A third strategy, which has received less attention, is "better design." The better design approach (Burton and Obel 1984, Carley 1992, Carley and Lin 1995, Malone 1978), a structural approach, centers on the idea *if we can just design the organization right, the impact of information distortion can be mitigated*. Contingency theorists have suggested that the right design is situationally specific thus, general guidance and a simple theory of design cannot exist (Galbraith 1973, Lawrence and Lorsch 1967). However, as Scott (1987) points out "such a quest not only overlooks the vast diversity of existing organizational forms, but also fails to recognize the great variety of tasks undertaken by organizations" and also "fails to search for any underlying principles to guide their designs." Efforts at forging contingency theory and an understanding of tasks into a theory of design have gone the route of creating expert systems relying on highly situation specific knowledge (Baligh et al. 1990, 1994) or massive organizational engineering models geared toward specific organizations (Gasser et al. 1994).

We take the design approach, and consider training as the design feature that allows adaptation to the task environment. We search for systematic relationships among information distortion, organizational design, task environment, and performance. The expected relations are induced by examining multiple organizational designs under various types of distortions. We focus on the relative performance of various designs given different types of distortion. This is in contrast to research that, given a set of constraints, tries to locate the optimal design. This analysis will make it possible to determine systematically whether effects such as Staw et al.'s (1981) threat-rigidity effect will occur universally or only under certain conditions.

2.2. Organizational Design and Information Distortion

Organizations must deal with a predominantly exogenous task environment (Thompson 1967). However, the organizational design is more (or less) under the organization's control and is thus relatively adaptable to the task environment (Burton and Obel 1984, Lawrence and Lorsch 1969). Thompson (1967) and Mackenzie's (1978) suggest that it is useful conceptually to separate design from environment, thus focusing on their respective features and the connections between them, and that environment can impact design. Following their suggestion we separate design and environment and we separate the organizational structure (OS) from the resource access structure (RAS). This enables us to distinguish the connections between people (OS) and the connections between people and task information or resources (RAS). In our model, part of the linkage between design and environment is through the RAS (Mackenzie's task process structure).

It is generally assumed, often implicitly, that organizational performance is tied intimately to design. This relation is expected to hold as organizations are composed of intelligent agents who can, and do, learn from experience which affects their decision making (Carley 1991, 1992; Carley et al. 1992; Levitt and March 1988; March and Simon 1958; Simon 1947). The organization's performance depends on the members' performance (Hastie 1986). However, the organization's design constrains the agents and thereby affects their performance. We observe individual-based organizational performance under different types of distortion, design, and environment.

Most agree that design should affect performance; but, as to how the literature is replete with contradictions. For example, Mackenzie (1978) argues that the degree of hierarchy is linked to the organization's efficiency. Roberts (1989) suggests that "hierarchical structures should increase the reliability of performance." In contrast, others claim that hierarchies may exhibit lower performance due to information loss because of condensation (Jablin et al. 1986) and uncertainty absorption (March and Simon 1958). Davis and Lawrence (1977) suggest that a matrix will exhibit high performance only in complex environments; however, Houskisson and Galbraith (1985) show that matrix structures can improve performance even in simple task environments. Staw et al.'s (1981) threat-rigidity hypothesis suggests that when faced with distortions organizational designs become rigid, i.e., restricted or simplified "in information processing and constriction of control." An illustrative rigid structure is the team with manager. Whereas, Krackhardt and Stern (1988) suggest that "adaptation to crisis requires increased coordination," and that more complex structures exhibit higher performance in the face of information distortion. Another aspect of design, training, is also expected to affect performance. Though the common wisdom is that training improves organizational performance and prevents performance degradation under information distortion (Perrow 1984, Roberts 1989, Shrivastava 1987), some research suggests that training can adversely affect performance (Ganster et al. 1991, Hammond et al. 1973).

Organizational design has been characterized as: formal structure and task decomposition structure (Burton and Obel 1984, Mintzburgh 1983); degree of hierarchy (Mackenzie 1978); informal network structure (Krackhardt 1994); organizational coordination process (Pfeffer 1978); information combining and decision making procedures (Panning 1986, Radner 1987); and information processing characteristics or cost (Carley 1990, Galbraith 1973, Malone 1986, March and Simon 1958). Nevertheless, important aspects of design are frequently neglected; e.g., the employee's skill or expertise level. Herein, organizational design is viewed as a combination of OS, RAS, and procedures (such as training).

2.3. Task Environment and Information Distortion

Open system theory (Scott 1987) and population ecology (Hannan and Freeman 1977) have refocused attention on the environment as a set of problems that are externally posed for the organization. Researchers in artificial intelligence and distributed artificial intelligence (Bond and Gasser 1988, Carley et al. 1992, Dreznick 1986), have clearly demonstrated that environmental features constrain what organizations are most effective, and even possible (Demael and Levis 1991, Levis 1988). We take the view that the environment poses a set of problems for the organization and note that the environment can limit the organization's performance; i.e., some tasks are easier than others. Despite agreement that environment constrains organizational action there is little agreement as to what are the salient environmental features.[2]

Task environments vary on many dimensions, not the least of which is complexity. Numerous studies have examined the effect of task or environmental complexity on organizational performance (Wood et al. 1990). These studies demonstrate that increases in complexity correspond to decreases in performance (Carley 1990). Further, in simple task environments, centralized or-

[2] In this paper, the task environments we study all have only nine task components as will be described later. The changes of task environments are limited to the relationships among these task components.

ganizations (such as hierarchy) make fewer errors than decentralized organizations (such as team with voting) (Cohen 1962, Shaw 1981); whereas, when the environment is complex, the opposite is true (Shaw 1981). Multiple factors may affect task environment complexity; e.g., decomposability and bias. Decomposability has received extensive attention. The common wisdom is "divide and conquer" (Babbage 1832, Tausky 1970). Decomposability is related to the interdependence of the task components (Roberts 1989, 1990). Coordination problems occur if the organizational design does not consider environmental decomposability. Bias, operation within a niche, has received less attention. The niche defines what types of problems the organization sees. Specialized organizations operating within a highly specialized niche (Hannan and Freeman 1977) are expected to perform well, whereas generalists are expected to perform well in coarse-grained or unbiased environments.

3. Model

3.1. Stylized Radar Task

We use a stylized radar detection task similar to that used by Hollenbeck, Ilgen and associates (1991, 1993, 1995).[3] There is an air space that is being scanned by the agents. Within this airspace, during any specific time period, there is a single aircraft. This aircraft may be Friendly (F), Neutral (N), or Hostile (H). Each aircraft has nine characteristics such as speed and direction (see Figure 1). For an aircraft each characteristic takes on one of three values, e.g., the speed may be low, medium, or high. The indication of a specific characteristic may not reflect the "true state" of the whole aircraft. The number of possible unique aircraft or problems is 19,683 (3^9).

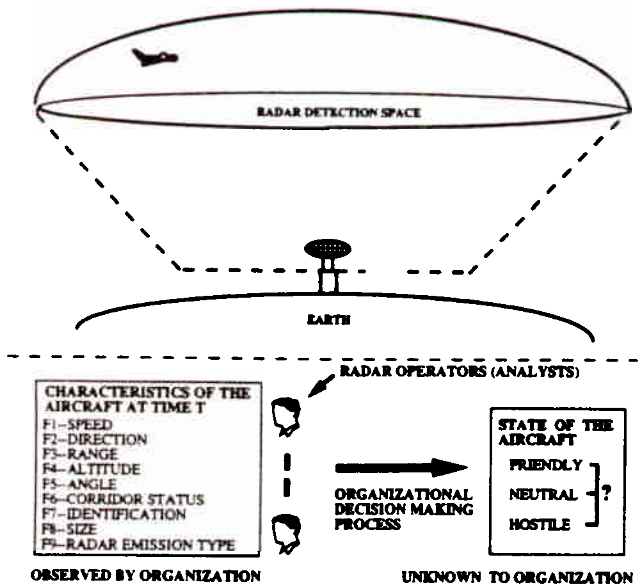
Each time period, the organization must scan the air space and make a decision as to the aircraft's nature. The organization goes through this process 19,683 times, once for each unique aircraft.[4] Some agents (the radar analysts) access information on the aircraft, develop a recommendation (their opinion as to whether the aircraft is F (=1), N (=2), or H (=3)), and communicate this recommendation. How the organization processes or combines these recommendations depends on the organizational structure (OS) (see next section). Regardless of the OS, the processed (or combined) recommendations form the organization's final decision on that aircraft (whether the organization thinks the aircraft is F, N, or H).

The aircraft has a true state—F, N, or H. The organization is not omniscient and the world's true state is not known a priori but must be determined by examining the aircraft's characteristics. Organizations are guided by history and their knowledge of technology, and so have a vague understanding of the world's true state. The organization's understanding resides both in the agents and in the pattern of relationships among agents (Carley 1992). Agents are modeled as intelligent (i.e., they make decisions on the basis of all the task-based information available to them); but boundedly rational (i.e., information availability depends on the current problem, the agent's position, and the agent's training).

[3] We chose this stylized task for the following reasons: First, it is based on a real world problem and has been widely examined in military and civilian (e.g., air-traffic control) contexts. Second, it is a very general task, not a specific or narrowly defined task. Although we interpret this task as radar control, it is a ternary choice task, and any classification task where the agents can choose between three options is comparable. Third, issues of training can be addressed as the true decision can be known and feedback can be provided. Fourth, it is ideal for a distributed environment as the task is sufficiently complex that multiple agents can be used to work on different task aspects. Fifth, the task has a limited number of cases (19,683 = 3^9) and so computer assisted enumeration can be used to exactly calculate performance under the no information distortion condition. Sixth, this task is a ternary version of the binary choice task used by Carley (1990, 1991, 1992), so admits replication and extension of earlier work. While binary choice tasks have received a great deal of attention (Pete, Pattipati, and Kleinman 1993), ternary choice tasks have received less attention. Thus, this study will extend our understanding of performance for choice tasks. Finally, this task is sufficiently interesting and can be easily expanded to include other factors, such as communication of different types of information, different process rules or learning rules or training orientations. This makes possible a wide variety of studies using the same task and so enhances the prospect of cumulative research.

[4] One could relax this assumption to make it a non-uniform distribution by assuming that certain problems appear more than others. Adding bias in that fashion would not change the results but it would affect the rate of learning with which we are not concerned in this study.

Figure 1 **Stylized Radar Task**



3.2. Information Distortion

Information distortions create ambiguity within organizations (March and Simon 1958). The literature is replete with discussions of different types of and sources of information distortion (Cohen and March 1974, Perrow 1984). While there are many sources, we limit ourselves to those that directly affect the design-environment link. Specifically the following five types of distortion are examined—missing information, incorrect information, agent unavailability, agent turnover, and communication channel breakdown. These were chosen because they are prevalent in real organizations and vary in whether the ambiguity is technology based (missing information and incorrect information), agent based (agent unavailability and agent turnover) or due to the technology-agent interlink (communication channel breakdown). In addition, we examine three levels of severity—low (1 distortion), medium (2 distortions), and high (3 distortions). In reality, multiple distortions of different types simultaneously occur. In this paper, in order to examine the differential impact of distortion types, only a single type is examined at a time and multiple distortions are all of the same type. For each organization, the locations of the distortions are chosen randomly before each decision cycle. Thus, a technology based distortion is equally likely to occur for each of the nine task characteristics. An agent based distortion (or the communication breakdown) is equally likely to occur for each analyst.

Missing Information occurs when one or more of pieces of incoming information for a particular problem is not available. For example, in real organizations aircraft altitude may be unknown as certain surveillance equipment is broken.

Incorrect Information occurs when incoming information is erroneous; e.g., the aircraft's speed may be reported as being fast when it is slow. In reality, this can happen when equipment does not work properly.

Agent Unavailability occurs when one or more radar analysts are not available to help the organization solve the problem and so do not report their decisions to their manager. In real organizations personnel unavailability can occur when personnel are sick or unable to be on duty.

Communication Channel Breakdown occurs when one or more radar analysts are unable to report to a superior because the communication channel is unavailable. This can be thought of as communication technology failure, or, as ignorance of the necessity of communication.

Agent Turnover occurs when one or more radar analysts leave the organization and are replaced by new analysts. Herein, in experiential[5] organizations new radar analysts enter untrained, do not learn, and proceed simply by guessing. In real organizations turnover can occur when analysts are transferred, quit, or become war casualties, and new analysts take over.

3.3. Organizational Design

As previously noted, the concept of organizational design has taken on a variety of meanings and aspects in the organizational theory literature (e.g., Mintzburgh 1983, Mackenzie 1978, Pfeffer 1978). We will characterize organizational design by three factors—the OS, the Resource Access Structure (RAS), and the organizational procedure for providing training. While this overlooks many important elements of organizational design, such as informal structure and accounting practices, it does focus on three elements that have

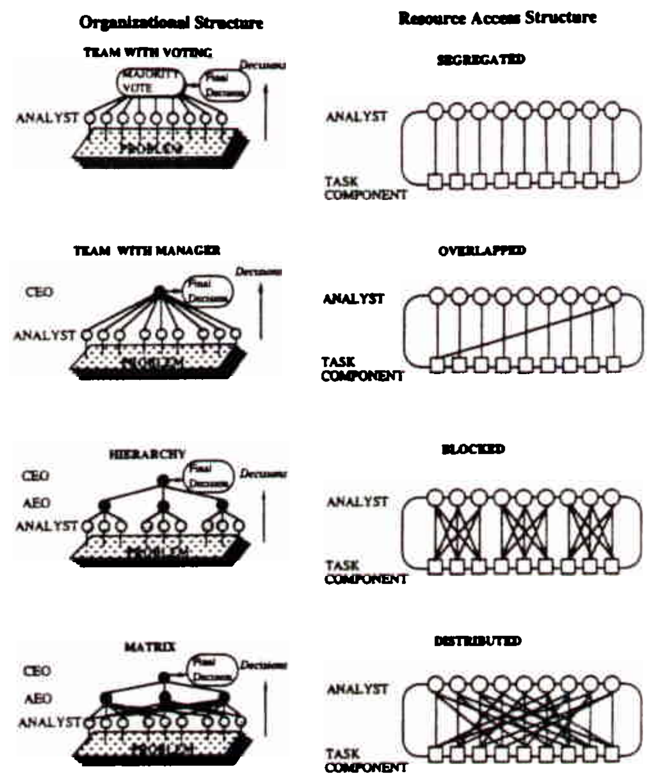
[5] Experientially trained organizations are also more discretionary.

repeatedly been demonstrated to be critical to organizational behavior.

Organizational Structure (OS). Organizational structure has typically been characterized as the formal reporting, decision making, communication, and authority structure. We focus on the reporting/decision making/communication aspect and distinguish four structures: team with voting, team with manager, hierarchy, and matrix[6] (see Figure 2). We assume that the communication and reporting structures are identical and that the authority to make the organizational decision rests in the "top" organizational level. Each structure consists of nine radar analysts. Additionally, some structures employ middle and/or top-level managers (CEO). The complexity of the OS has been viewed in a number of ways (Etzioni 1961, Galbraith 1973, Perrow 1979). Herein, we use complexity in an information processing sense to mean a system in which the number of communication/reporting links is higher. Thus the team with voting is less complex than the matrix as the organization's decision for the team is based on the addition of the agents' decisions (9 links) and in the matrix the organization's decision is based on the collapsing of decisions through links to managers and from them to the CEO (22 links, 18 from analysts, 3 from managers, 1 from CEO). This notion of complexity is similar to, but not identical with, the definition used for task complexity; i.e., a system is more complex if the input variables make a multiplicative, rather than an additive, contribution to the system's output.

These structures are examined because they represent stylized versions of real organizational reporting structures. The performance of these structures has been examined but rarely contrasted.[7] Each structure has features which have been touted as enabling it to perform well under some circumstance; however, they vary in the level of hierarchy and the presence centralization.

Figure 2 Organizational Structures and Resource Access Structures



Hierarchies have been characterized in many ways in the literature (Hummon and Fararo 1995); herein, we focus on the hierarchy as a multilevel structure with a nonunitary span of control and role specialization by level (i.e., managers do not access task information only reports by their subordinates). We use the term centralized to mean that the ability to make the organizational decision rests in a single individual. The team with manager, or "wheel" structure (Mackenzie 1978), for example, as we have modeled it is virtually a flat hierarchy such that while each analyst examines information and makes a recommendation, the organizational decision is made by the manager (or team leader). Such teams are common in settings such as software design projects. They are the simplest of centralized structures and arguably are good in simpler task environments. The team with voting, or "all channel" structure (Mackenzie 1978), is a collection of equals, not subject to any supervisor, who together make the final

[6] We have also examined an alternative matrix structure, in which only six of the nine baseline analysts report to two managers, while the 3 remaining analysts report to a single manager. The performance of organizations with this structure is between that reported for the hierarchy and matrix.

[7] Malone (1986) and Carley (1991) contrasted the performance of various organizations.

organizational decision by majority vote.[8] Such teams are common in settings such as congress and judiciary systems. They are the simplest of the decentralized structures, and though quick to learn new information are rarely resilient in the face of information distortions such as turnover (Carley 1991, 1992). The hierarchy is multileveled such that each analyst submits a recommendation to his or her immediate supervisor who in turn makes a recommendation to the top-level manager who makes the organizational decision. Hierarchies have been extensively studied (Malone 1987, Simon 1973) and are expected to absorb uncertainty (Simon 1973). An important contrast is the matrix organization; which, like the hierarchy, has been characterized along a variety of dimensions including dual reporting and dual authority (Davis and Lawrence 1977, Jagner 1979); herein, we focus on the dual reporting aspect. The matrix, like the hierarchy, is multi-leveled, but unlike the hierarchy has cross-links between the divisions in the organization. Thus the matrix has "redundant" communication links as analysts report to multiple managers. Matrix organizations should sustain uncertainty and do well in complex environments. By examining these typical, albeit stylized, structures we will gain insight into the impact of structure on performance.

Resource Access Structure (RAS). The resource access structure[9] determines the distribution of raw (unfiltered) information to organizational members. It connects the organization to the task environment. In our model, the RAS determines which analyst has access to which type of surveillance equipment. Each type of equipment allows that analyst to garner information on a particular (or a particular set of) characteristics. We examine four structures (see Figure 2): segregated, overlapped, blocked, and distributed.[10] These are ordered from least to most complex. In this case, we are measuring complexity from a cognitive information processing perspective such that a task is more complex if it requires the individual to do more work (handle more pieces of information or more different types of information). Thus, overlapped structures are more complex than segregated as they require individuals to process more information, and distributed are more complex than blocked as the similarity of what the manager sees is potentially lower.

As with OS, the RAS schemes were chosen as they represent unique, albeit stylized, patterns of distributing task information across analysts. These structures vary on two features—the amount and location of information overlap. The segregated structure employs a divide and conquer scheme. Cohen et al. (1972) found that the segregated structure is fragile under information distortion and suggested that information overlap reduces reliance on a particular employee and increases the ability to cope with distortions such as communication breakdowns. The overlapped, blocked, and distributed differ in how information overlap affects the overall distribution of information within the organization. The blocked structure provides complete redundancy within a division and none across divisions; the overlapped structure provides for some information sharing between divisions; and the distributed structure guarantees that all information is available to all divisions. Teams do not have divisions, so the impact of the RAS may be less. By considering these variations we are able to see how RAS impacts performance.

[8] In dealing with ternary choices, the simple majority rule has to be slightly modified.

[9] The resource access structure has also been referred to as the task decomposition scheme or the information access structure (e.g., Carley 1991, 1992). We use the term resource access structure to (1) emphasize the role of resources in organizational performance, and (2) to clearly differentiate ties between people and data (the resource access structure) and ties between people and people (the organizational structure).

[10] We also examined two other task decomposition schemes, segregated-2 and overlapped-2. The segregated-2 case differed from the segregated structure shown only in which analyst saw which specific characteristic. Examining this scheme enabled us to determine whether the exact pattern of which analyst sees which piece of information matters. The results, however, are close to the segregated scheme examined in this paper and so suggest that the exact order of information is not highly critical. In the overlapped-2 case, each analyst has access to three pieces of information, such that two pieces of information are shared (overlapped) with the next analyst. The result for this scheme are similar to the simple overlap pattern examined in this paper.

3.4. Organizational Procedures

While the relationship between training, decision making, and performance has been examined from a variety of perspectives (Ganster et al. 1991, Ilgen et al. 1991); we focus on training only to the extent to which it alters what rules fully trained agents use in making a decision given a specific input. We consider the effect of two training procedures—experiential training and procedural training (use of standard operating procedures, SOPs).[11] These training scenarios are stylized but reflect types of training prevalent in real organizations and so help to illuminate the effect of training on performance. When we measure organizational performance we are dealing with organizations composed of essentially fully trained agents. To fully appreciate why organizations behave as they do it is necessary to understand how fully trained agents make decisions. Further, within an organization, all agents (managers and subordinates) are either experientially trained or procedurally trained (other than under turnover conditions where untrained agents become mixed with experientially trained agents). In all organizations, agents receive accurate and immediate feedback as to the correct organizational decision during their training phase.

Experientially Trained Procedure. In the experiential condition, agents base their recommendation on historical information. Agents are fully trained in that they have previously encountered and received feedback on all possible aircraft. The experientially trained agents follow the decision procedure identified below but no longer alter their memory. Their expectations remain fixed. This condition represents agents who are empowered to act on the basis of their own assessment. Agents proceed as though following a historical dominance rule; i.e., the agent classifies the aircraft and then makes the decision that has been correct most often in the past. This corresponds to a situation where agents with extensive prior experience are placed in front of surveillance systems and are told, *OK tell me is that aircraft out there F, N or H?* The experientially trained agent will say, *well, in my experience, when this particular pattern appeared on my equipment, the aircraft out there was typically . . .*

Agent's Knowledge: Each agent's memory contains a record of the types of aircraft seen during the training period and the number of aircraft of each type that were truly F, N, or H. Aircraft types are defined by the pattern of observed characteristics. For example, for one agent, a type of aircraft might be high speed, long range, and radar emission of type weapons. The number of aircraft types seen by an agent observing is 3^N, such that N is the number of pieces of information accessed by the agent. Agents do not have perfect recall: they cannot recall specific events but they can recall (perfectly) the frequency of events.

Training Procedure: During training, each agent sees each of the 19683 possible aircraft, is asked to provide a recommendation, and is given feedback. The feedback provided to the agent is the true state of the aircraft (based on the objective definition). This feedback is the same for all agents in the organization regardless of their position and does not depend on what the agent has done or should have done. The agent begins as an untrained agent and starts out guessing. As agents see each possible aircraft type they augment their memory. After seeing all possible aircraft each agent knows the frequency of each outcome for each pattern.[12] The result of this procedure is that each agent acts as a majority classifier in an unbiased decomposable task.

Decision Procedure: Each agent makes decisions only on the basis of his or her historical experience. The decision procedure followed during and after training is identical. The procedure varies slightly depending on whether or not the agent has complete information.

[11] We also examined the no-training scenario. In this condition, the agents given a problem simply make a random guess. This condition provides a baseline against which we can address the question, *to what extent does training improve performance over and above guessing?* The guessing procedure is followed whether the agent has complete or incomplete information. The agent proceeds as though simply following hunches. Returning to the radar scenario, this corresponds to a situation where all the agents are simply placed in front of surveillance systems, with no prior experience and told, *OK tell me is that aircraft out there F, N or H.* The untrained agents in this situation will simply throw up their hands and guess or toss a three-sided coin.

[12] Since different agents observe different characteristics, their memories will be slightly different. This is the same procedure followed in the experiential learning model employed by, and described in detail by, Carley (1990, 1991, 1992). Analysts who see an unbiased decomposable task essentially learn to be majority classifiers.

Decision Procedure Under Complete Information: When the agent has complete information, the agent first classifies the aircraft on the basis of the observed characteristics. The agent looks up in his or her historical record, how often for that type the true decision was a F, N, or H. Let us call the number of times that, for a particular type, the true decision was x, the expectation of x represented by $E(x)$. The decision procedure is described as follows:

If $E(\mathrm{F})$ is greater than $E(\mathrm{N})$ or $E(\mathrm{H})$, then the agent reports that the aircraft is F.

If $E(\mathrm{N})$ is greater than $E(\mathrm{F})$ or $E(\mathrm{H})$, then the agent reports that the aircraft is N.

If $E(\mathrm{H})$ is greater than $E(\mathrm{F})$ or $E(\mathrm{N})$, then the agent reports that the aircraft is H.

If $E(\mathrm{N}) = E(\mathrm{H}) > E(\mathrm{F})$, then the agent randomly reports that the aircraft is either N or H.

If $E(\mathrm{F}) = E(\mathrm{H}) > E(\mathrm{N})$, then the agent randomly reports that the aircraft is either F or H.

If $E(\mathrm{N}) = E(\mathrm{H}) > E(\mathrm{F})$, then the agent randomly reports that the aircraft is either N or H.

If $E(\mathrm{F}) = E(\mathrm{N}) = E(\mathrm{H})$ and H are equally likely and both greater than F, then the agent randomly reports that the aircraft is either F, or N, or H.

By following this procedure the agent is acting as though it has an accurate recall of the distribution of events.[13] As the agent has no way to determine the "correctness" of the information, this procedure is followed whether or not the information acquired is correct. Since the agent cannot discriminate between correct and incorrect information, if the information is incorrect then the agent will misclassify the aircraft. For example, the agent might think it is looking at an aircraft of type a when it is looking at an aircraft of type b and so will recall the expectations for aircraft of type a and not b, and acts on these.

Decision Procedure Under Incomplete Information: When information is incomplete, the agent cannot uniquely classify an aircraft. Instead, the agent matches only that information available (partial pattern matching). This may result in the selection of three or more types. For the selected types, the agent sums up the expectations for F, N, and H and acts on the basis of the combined expectations following the procedure previously dictated.

Procedurally Trained Scenario. In the procedural condition, agents employ standard operating procedures (SOPs) to make recommendations. Agents are considered fully trained as they have perfect knowledge of the SOP and employ it without error. This condition represents agents who are expected to mechanically follow accepted procedure. The SOP chosen is such that agents act purely on the basis of the criticality of their local current information. History, has no effect. This corresponds to a situation where all of the agents are placed in front of surveillance systems, and told, *OK report whether that aircraft out there is F, N, or H*. Unlike the experientially trained agent, the procedurally trained agent will say, *well, let's plug this data in to the SOP and the answer will pop out*. Agents act as though they are blindly following orders with no apparent concern for the consequences.

Agent's Knowledge: This consists of current information and the SOP. This procedure is equivalent to acting as a majority classifier in an unbiased decomposable task.

Training Procedure: All agents in the organization are told the SOP which they perfectly memorize. They then follow the procedure automatically.

Decision Procedure: The standard operating procedure is:

1) Sum up the information available to you on the current aircraft.

2) Categorize this sum. The categorization procedure requires that the total number of cases be equally divided into three parts. For example, for three pieces of

[13] As a further exploration, we also tried a probabilistic approach in the simulation of experientially trained organizations. The probabilistic approach differs in that the agent does not simply report the choice with the highest frequency, but can report any of the three choices but with a probability equal to the frequency of their occurrence. For example, if the distribution of decisions as truly "friendly," "neutral," and "hostile" is 10, 30, and 20, then the agent reports "friendly" 10/60 of the time, "neutral" 30/60 of the time, and "hostile" 20/60 of the time. The results showed that the performance of experientially trained organizations using this probabilistic approach was lower than that when the agents using a fixed choice. The particular performance of organizations with different structures and task decomposition schemes was essentially just scaled down. The relative standing of the probabilistic approach and the SOP approach varies with structure.

information, the sum of information available to the agent ranges from 3 to 9. If the sum is between 3 and 5 the agent is to classify the aircraft as F, if 6 as N, and if between 7 and 9 it is to be classified as H.

3) Recommend the classification determined in the previous step.

In practice, the SOP differs slightly if the agent has complete or incomplete information.

Decision Procedure Under Complete Information: The agent, given information on an aircraft, adds the values of all information, and reports the category into which the sum falls.

Decision Procedure Under Incomplete Information: When information is not complete the agent adds the remaining known information and reports the modified category in which the sum value falls. The category is modified by taking the total number of cases of the remaining information and dividing it equally into three parts. When there is no information known, the agent simply guesses (the three possible decisions are equally likely).

3.5. Task Environment Characteristics

Task environment has been characterized in a variety of ways (Thompson 1967, Hannan and Freeman 1977, Scott 1987, Bond and Gasser 1988). Herein, we characterize the task environment as the problem space in which the organization operates; i.e., a set of problems about which the organization can make decisions. The true state of the world is an environmental feature external to, and not manipulatable by (at least in the short run), the organization. Such true states are often a product of the technology; e.g., aircraft that are carrying weapons, moving fast within the corridor and have an unknown identification typically are hostile (H). We can manipulate the "true state of the world" faced by our organizations, by altering the definition of what constitutes a truly F, N, or H aircraft. Two such manipulations are particularly interesting: decomposability and bias.

A task environment is decomposable if there are no complex component interactions that need to be understood in order to solve a problem. In a decomposable environment each component has a separable, identifiable and additive effect in determining the problem solution. Each piece of information contributes equally to the final decision. No agent has greater "power" simply by virtue of having access to more (or the right) information. In contrast, in the non-decomposable environment the pieces of information do not contribute equally to the final decision, and portions of the information interact to determine the aircraft's true state. Some agents may have greater "power" simply by having access to more (or the right) information. Decomposable environments are less complex than nondecomposable environments due to the absence of interactions.

A task environment is biased if the possible outcomes are not equally likely. In reality, biased environments are quite common; e.g., during war time one might see many more H than F aircraft. Biased environments are less complex and more certain than unbiased environments due to the preponderance of a particular solution.

Based on these manipulations, we examine four different environments[14] which are ordered from least to most complex in Figure 3.[15] Given a particular environment, the 19,683 problems can be classified as being "truly" F, N, or H. Classification involves categorizing the aircraft as F, N, or H on the basis of the sum of the nine characteristics' values. As seen in Figure 3, in decomposable environments the sum is an unweighted linear combination of the characteristics; whereas, in nondecomposable environments a weighted sum is used. In an unbiased environment the possible outcomes are equally likely; whereas, in a biased environment one outcome (e.g., H) is more likely. The number of aircraft that are "truly" F, N, or H depends on the environment.

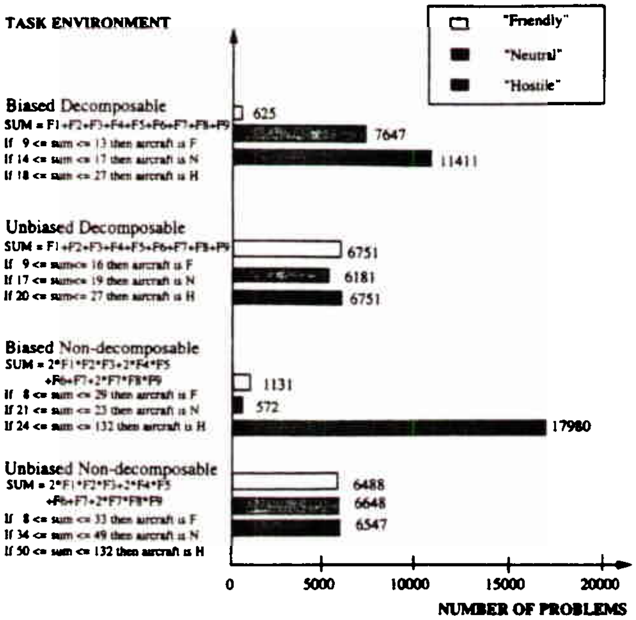
3.6. Performance Measures

There are many indicators of performance, with little agreement as to which is the best indicator. We use a

[14] We also examined a non-decomposable rule where Sum = F1*F2*F3 + F3 + F4*F5*F6 + F6 + F7*F8*F9 + F9. This rule generates results similar to that of the nondecomposable rule described. The fact that the results are similar suggests that decomposability in general is more of a problem than the specific type of decomposability.

[15] For the unbiased decomposable task the categorization scheme shown in Figure 4 is only an approximation. We further categorized those problems whose sum equals 17, such that some are friendly, and others are neutral. Similarly, for those problems whose sum is 19, we categorize them such that some are hostile and others are neutral. This categorization kept the number of problems in each category closer to one third of the total problems.

Figure 3 Task Environments



single indicator and define organizational performance as the percentage of correct decisions made by the organization given all 19,683 cases. Recall, an organization's decision is correct if the final organizational decision as to whether the observed aircraft was F, N, and H matches the aircraft's true state.

4. Experimental Design

A series of simulation experiments are run. We examine 192 types of organizations across 20 different conditions. The 192 types of organizations are obtained by varying organizational structure (4), resource access structure (4), training scenario (3), and task environment (4). The performance of each organizational type was calculated under optimal operating conditions (no information distortions) and each of the information distortions. The 20 conditions are obtained by varying the levels of severity (4, including "no" distortions), and the type of distortions (5). The combination of 192 organizational types by 20 conditions results in a total of 3840 cases. We consider all possible problem scenarios (all aircraft) in each case. For the no information distortion case computer assisted enumeration is used. For the information distortion cases, the location of each distortion is randomly chosen each time period using standard Monte Carlo techniques.

5. Properties of the Model

5.1. Bias Toward the Extreme

A major performance difference attributable to training can be seen by considering the unbiased decomposable task environment. Under this task, analysts act as majority classifiers regardless of whether they are experientially or procedurally trained. The team with voting/segregated organizations exhibit perfect performance regardless of training. The impact of training on performance emerges when there is a management structure. In procedural organizations managers act as majority classifiers; thus, performance is reasonably high. In experiential organizations mid-level managers learn a "conservative" bias; thus, performance is lower.

What is the basis of this conservative bias? In experiential organizations in biased environments, agent's memories contain more information about H than F or N situations. Consequently, agents have a conservative bias, i.e., a tendency to think of borderline aircraft as H. In an unbiased environment, the number of F, N, and H problems is approximately the same (33.33%). Agents are not automatically biased by the task; however, the midlevel managers can exhibit a conservative bias if the analysts face a nonsegregated RAS. Consider a hierarchy faced with a distributed RAS in a decomposable unbiased environment. In an unbiased task environment, all experientially trained analysts become majority classifiers and suggest that they think an aircraft is H/N/F if the majority of the incoming data is 3/2/1. Given information overlap due to the RAS, a N decision by one analyst often masks a truly overall H aircraft. If the structure is non-segregated, as in the distributed case, and if all analysts under one manager report that the aircraft is N (or H), then the experiential manager actually learns to respond that the plane is H (see Table 1). This is because the chance of the sum of the remaining features of the aircraft being close enough for the plane to be called H is slightly higher than the chance for the sum to be low enough for the plane to be labeled F. In a nonsegregated RAS, the distribution of information makes it appear as though the chance of the "whole" aircraft being H is higher than the chance of it

Table 1 **A Partial Illustration of Experientially Trained Agents' Memories in a Hierarchical Structure with a Distributed Resource Access Structure Faced with an Unbiased Decomposable Task Environment**

Information Received	Agent Level	Memory of Previous Feedback		
		"F" (or 1)	"N" (or 2)	"H" (or 3)
	CEO	279	201	24
1, 2, 2	Midlevel manager	28	310	97
	Analyst	314	322	93
	CEO	31	58	10
1, 2, 3	Midlevel manager	10	116	241
	Analyst	228	273	228
	CEO	25	39	10
1, 3, 2	Midlevel manager	8	106	217
	Analyst	228	273	228
	CEO	16	34	4
3, 2, 2	Midlevel manager	13	133	250
	Analyst	228	273	228
	CEO	26	46	6
3, 2, 1	Midlevel manager	12	124	227
	Analyst	228	273	228
	CEO	38	378	116
3, 1, 2	Midlevel manager	0	32	427
	Analyst	93	322	324

Note: The agents' memories of feedback are averaged at each level.

being F or N. Midlevel managers develop a "conservative" bias—"better safe than sorry."

If the true state of the aircraft were not determined by a sum, but symbolically, this might not happen. Further, this midlevel bias is also present in the biased task environments, but there the environmental bias outweighs this consideration. Partial redundancy at the analyst level results in bias at the next level up in the hierarchy. This result is an argument for either extreme specialization or complete generalization. Either extreme may eliminate the conservatism or bias in the midlevel managers. Future research might further investigate this "conservatism of the middle."

5.2. Baseline

The baseline case is when all agents are untrained (act only on their hunches) and face optimal operating conditions (no information distortion). In this case, all organizations make the correct decision 33.33% of the time.[16] When guessing, an agent is equally likely to decide that the aircraft is F, N, or H and so the chance of a correct decision is 1/3. In the team with voting, for example, the probability that the overall vote will be correct is 1/3, because a) majority rule is used, b) there are nine analysts voting, c) the probability of each one giving the correct answer is 1/3, and d) all agents are independent. In all other organizations, there is a CEO. For the untrained CEO, subordinates' responses are irrelevant as the CEO will simply guess no matter what he or she is told. For untrained organizations information distortion does not affect performance.

6. Results

6.1. The Effect of Information Distortion

Information distortion is expected to produce ambiguity and thereby degrade performance. Training may reduce this degradation and improve performance. However, as Scott (1987: 247) argues, a critical organizational design issue is whether agents should be professional (and so trained to follow experience) or trained to follow procedures. Rarely does the literature discriminate between training styles, and few have looked at the interplay between the training, distortion, and environment. The following propositions summarize this literature.

PROPOSITION 1. *Information distortion degrades organizational performance* (*March and Olsen* 1976, *March and Simon* 1958).

PROPOSITION 2. *Training improves organizational performance and prevents degradation of performance given information distortion* (*Perrow* 1984, *Roberts* 1989, *Shrivastava* 1987).

PROPOSITION 3. *Training impedes organizational performance* (*Ganster et al.* 1991, *Hammond et al.* 1973).

[16] Had there been only two choices, as in the experimental learning model examined by Carley (1990, 1991, 1992), the baseline performance would have been 50.00%. When the organization must choose between a set of options, the minimum acceptable performance is simply 1 over the number of options. Any performance, if less than this baseline of 33.33%, is unacceptable as organizational performance could be improved by simply guessing.

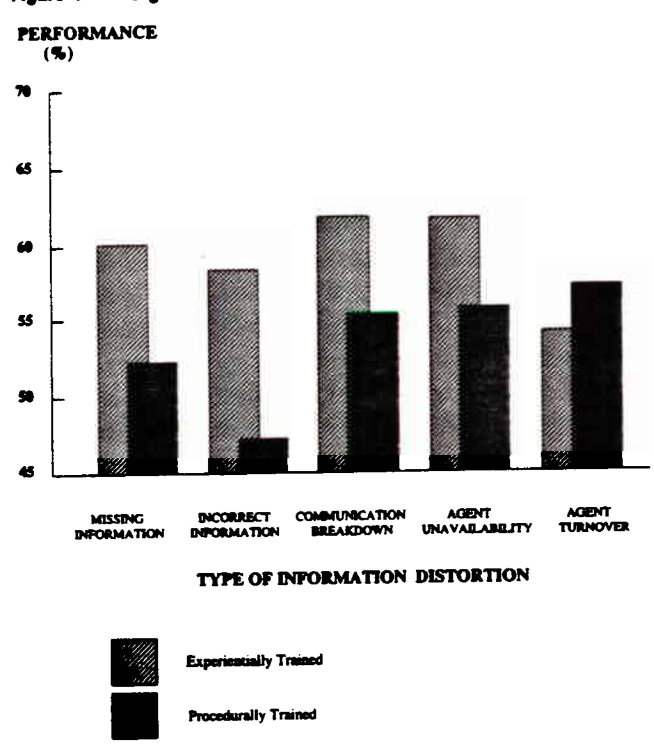
We find support for Proposition 1: As the number of simultaneous distortions increases, performance degrades.[17] For experiential organizations, information distortions degrade performance (optimal conditions mean = 62.18, standard error = 0.96, $n = 320$, and suboptimal conditions mean = 59.18, standard error = 0.55, $n = 960$). This difference is significant ($t = 2.71$, $df = 319$, $p < 0.005$). Similarly, for procedural organizations, information distortions degrade performance (optimal conditions mean = 57.29, standard error = 0.75, $n = 320$, and suboptimal conditions mean = 53.66, standard error = 0.33, $n = 960$). This difference, too, is significant ($t = 4.43$, $df = 319$, $p < 0.0005$).

We also find that both experiential and procedural training improve performance over the 33.33% baseline.[18] The effect of training depends on the style. Overall, organizations employing experientially trained agents (mean = 59.93) tend to outperform those employing agents trained to follow SOPs (mean = 54.56). This difference is significant ($t = 9.4$, $df = 1279$, $p < 0.001$) and both are significantly higher than the baseline. This supports Proposition 2, but not Proposition 3. This result holds only on average and is largely attributable to the advantage of experiential training in biased task environments and to the experientially trained managers' ability to effectively ignore error-prone personnel. As previously noted, in an unbiased decomposable task, for the team with voting/segregated structure performance is 100% regardless of training. Further, in the unbiased decomposable task the procedural organization tends to outperform the experiential due to the conservative middle in the experiential hierarchies and matrices.

Consider the interrelationship among training, distortion, and environment. We find that the type of information distortion determines its effect. In general, misinformation related distortions (such as missing information and incorrect information) are more debilitating than personnel-based distortions (such as agent unavailability, communication channel breakdown, and agent turnover) (see Figure 4). However, in experiential organizations agent turnover results in the highest level of degradation from optimal performance (mean = 56.10, standard error = 1.09, $n = 256$). In procedural organizations turnover has less effect, whereas incorrect information has the most effect (mean = 49.80, standard error = 0.60, $n = 256$). Further, while the degree of performance degradation due to distortion is a function of the task environment, the relative impact of different types of information distortion, other than agent turnover, remains basically the same under different environments (Table 2). Generally, environment has more impact on performance than distortion.

Finally, we find that experiential organizations do best in biased task environments; whereas procedural organizations do better under unbiased task environ-

Figure 4 Organizational Performance by Distortion Type



[17] This degradation is nonlinear. Also, when the organization is procedurally trained and the task environment is biased then the occurrence of a single information distortion may actually improve performance.

[18] We also examined the case where organizational members are trained experientially on a task where most events are friendly and then are faced with a series of hostile events. The results demonstrated that training can degrade performance below guessing. Organizations whose members were trained in this way can perform even worse than an organization of untrained agents.

Table 2 Average Performance of Organizations by Training, Task Environment, and Type of Information Distortion

Training / Task Environment	Information Distortion: Missing Information	Incorrect Information	Agent Unavailability	Communication Breakdown	Agent Turnover
			Experiential		
Biased Decomposable	61.04 (0.38)	60.84 (0.33)	61.81 (0.50)	61.64 (0.50)	55.49 (1.04)
Unbiased Decomposable	50.79 (1.47)	47.38 (1.36)	52.16 (1.53)	52.13 (1.54)	48.93 (1.64)
Biased Nondecomposable	85.04 (0.14)	84.67 (0.15)	85.39 (0.21)	85.39 (0.21)	78.06 (1.44)
Unbiased Nondecomposable	45.74 (1.17)	44.31 (1.04)	47.97 (1.16)	47.86 (1.18)	41.90 (1.31)
Training					
			Procedural		
Biased Decomposable	47.45 (0.18)	45.03 (0.35)	48.33 (0.15)	48.52 (0.15)	47.80 (0.20)
Unbiased Decomposable	68.15 (1.05)	60.49 (1.51)	71.34 (0.83)	71.93 (0.78)	77.81 (1.14)
Biased Nondecomposable	46.84 (0.47)	46.23 (0.47)	48.59 (0.37)	48.60 (0.37)	47.33 (0.49)
Unbiased Nondecomposable	51.93 (0.57)	47.43 (0.85)	55.50 (0.34)	55.75 (0.35)	56.22 (0.31)

Note: There are 64 types of organizations in each cell. Standard errors are in parentheses.

ments (Figure 5). Experience serves agents best when most of the experience is in the same area (a biased environment), thus promoting an interaction between training style and task environment.

6.2. Organizational Design

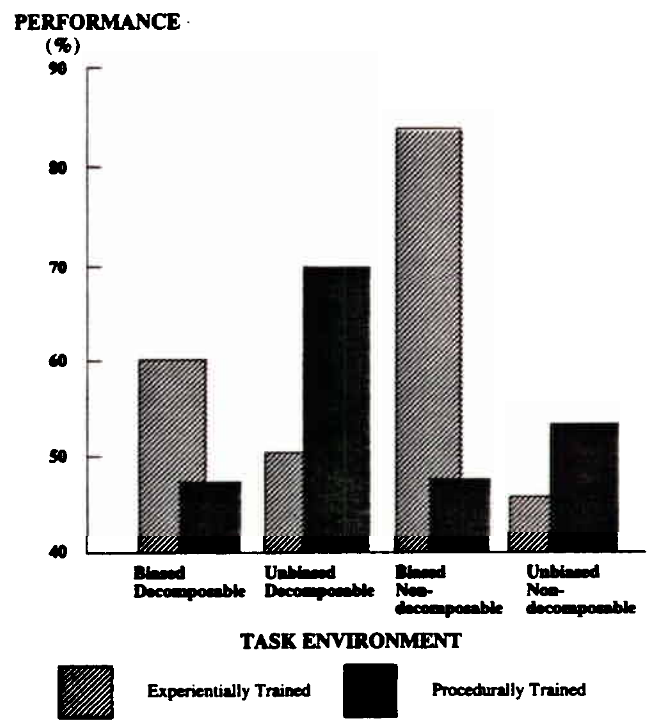
The question remains, how should organizations be designed to obtain high performance? The overriding argument is that there is no one best design, and that design is contingent. Further, the literature is replete with contradictory expectations as to which organizational designs will exhibit high performance. This can be shown through the following assertions.

PROPOSITION 4. *Organizations with a high degree of hierarchy will perform better than organizations with a low degree of hierarchy* (*Mackenzie* 1978, *Roberts* 1989).

PROPOSITION 5. *A high level of hierarchy will degrade organizational performance* (*Jablin et al.* 1986).

PROPOSITION 6. *Under information distortions, nonhierarchical organizations will outperform hierarchical organizations* (*March and Simon* 1958).

Figure 5 Organizational Performance by Task Environment



PROPOSITION 7. *Matrix organizations perform better than purely hierarchical organizations (Houskisson and Galbraith* 1985).

PROPOSITION 8. *Complex structures (with more communication ties, such as matrix) perform better in the presence of information distortions (Krackhardt and Stern* 1988).

We find that, on average, the top performing experiential organization is the team with voting/segregated structure, and the bottom performing organization is the team with manager/overlapped structure. On average, the top performing procedural organization is the hierarchy/distributed structure, and the bottom performing organization is the hierarchy/segregated structure (Table 3). In contrast to experiential organizations, for procedural organizations the organizational design is largely irrelevant (notice the greater equivalence of values in Table 3). Propositions 4, 5, and 6 receive mixed support when organizations are procedurally trained. On average, Propositions 7 and 8 do not receive support.

6.3. The Role of Organizational Design and Task Environment

Now consider how organizations with different designs perform under different types of information distortion and tasks. Contingency theorists argue that there is a relationship among organizational form, task environment, and performance. One such argument centers on the matrix structure. Unlike Proposition 7 by Houskisson and Galbraith (1985), the following proposition suggests that whether a matrix exhibits high performance depends on the task.

PROPOSITION 9. *Matrix organizations only perform well under complex task environments (Davis and Lawrence* 1977).

First consider experiential organizations under different levels of information distortion. The no information distortion case is shown in Table 4. When there is no distortion, and the task environment is biased decomposable (a simple environment), the team with voting/segregated structure, and the matrix/distributed struc-

Table 3 **Average Performance of Organizations by Training, Organizational Structure, and Resource Access Structure**

Training / Organizational Structure	Resource Access Structure: Segregated	Overlapped	Blocked	Distributed
	Experiential			
Team with Voting	66.760 (1.794)	65.918 (1.309)	66.790 (1.352)	66.444 (1.346)
Team with Manger	55.214 (2.066)	54.650 (2.096)	59.269 (1.932)	57.614 (1.928)
Hierarchy	56.601 (1.980)	57.010 (2.000)	60.247 (1.912)	60.150 (1.929)
Matrix	55.986 (1.988)	54.932 (2.129)	60.899 (1.876)	60.372 (1.881)
Training	*Procedural*			
Team with Voting	54.658 (1.947)	54.258 (1.254)	53.653 (1.202)	55.795 (1.139)
Team with Manger	54.658 (1.947)	54.258 (1.254)	53.653 (1.202)	55.795 (1.139)
Hierarchy	52.160 (1.196)	53.106 (1.072)	53.678 (1.339)	56.277 (1.053)
Matrix	54.196 (0.894)	55.942 (0.902)	54.856 (0.804)	56.071 (0.839)

Note: There are 80 types of organizations in each cell. Standard errors are in parentheses.

Table 4 Average Performance of Experiential Organizations by Task Environment, Organizational Structure, and Resource Access Structure

Task Environment / Organizational Structure	Resource Access Structure: Segregated	Overlapped	Blocked	Distributed
Biased, Decomposable				
Team with Voting	57.97	58.02	60.72	60.61
Team with Manger	61.76	61.90	60.72	65.36
Hierarchy	57.97	60.09	60.72	65.85
Matrix	58.03	59.23	60.72	70.06
Unbiased, Decomposable				
Team with Voting	100.00	68.97	72.93	72.87
Team with Manger	51.13	37.38	43.16	45.21
Hierarchy	53.68	42.03	39.02	46.93
Matrix	52.12	38.80	43.16	48.34
Biased, Nondecomposable				
Team with Voting	84.58	84.58	84.72	84.58
Team with Manger	84.58	84.58	88.83	84.58
Hierarchy	84.58	84.58	88.83	84.58
Matrix	84.58	84.58	88.83	84.58
Unbiased, Nondecomposable				
Team with Voting	58.22	62.48	59.95	57.18
Team with Manger	34.50	42.04	61.00	44.36
Hierarchy	35.31	41.61	61.00	40.93
Matrix	35.87	40.43	61.00	44.80

ture outperform other organizational forms. However, in the unbiased decomposable environment, the team with voting is the sole best performer. In nondecomposable task environments, which are more complex, more complex RASs (such as the blocked structure) help organizations to achieve high performance. This suggests that, when the environment requires information integration, redundancy in information access helps. In this sense, individuals are better than the organization as a whole at integrating information. In general, in a biased environment there is less impact due to organizational design than in an unbiased environment. Information distortions not only result in lower average performance; but they also increase the impact of organizational design, particularly when the environment is biased.

Now consider the procedural organization (Table 5). When there is no information distortion, the performance across organizational forms is relatively flat,

Table 5 Average Performance of Procedural Organizations by Task Environment, Organizational Structure, and Resource Access Structure

Task Environment / Organizational Structure	Resource Access Structure: Segregated	Overlapped	Blocked	Distributed
Biased, Decomposable				
Team with voting	45.20	46.85	46.85	48.37
Team with Manger	45.20	46.85	46.85	48.37
Hierarchy	46.85	47.90	46.85	49.27
Matrix	49.67	50.23	48.87	50.58
Unbiased, Decomposable				
Team with Voting	100.00	78.24	76.95	77.14
Team with Manger	100.00	78.24	76.95	77.14
Hierarchy	76.95	73.30	76.95	75.19
Matrix	70.91	71.22	66.04	69.66
Biased, Nondecomposable				
Team with Voting	41.30	44.69	44.81	49.26
Team with Manger	41.30	44.69	44.81	49.26
Hierarchy	44.81	46.58	44.81	51.50
Matrix	50.74	52.08	53.62	53.04
Unbiased, Nondecomposable				
Team with Voting	52.80	55.40	54.20	57.96
Team with Manger	52.80	55.40	54.20	57.96
Hierarchy	54.20	54.66	54.20	59.61
Matrix	57.75	59.99	58.46	59.90

except in the unbiased decomposable environment, in which a team with voting/segregated structure is the best performer. Under information distortions the level of performance is lower but the pattern is similar to that observed when the organization is operating free of information distortion, particularly when the task environment is biased. Further, in contrast to experiential organizations, in procedural organizations such distortions decrease the impact of design.

In an unbiased decomposable task environment, while more complex organizational designs help performance, the team with voting is still one of the better performing organizations. Further, procedural organizations generally exhibit lower performance than experiential organizations. Training personnel to follow SOPs reduces the impact of structure and so the reliance of the organization on its structure. This is particularly important for organizations that might expect to have rapidly changing designs such as might occur in response to rapid turnover. Procedural training, unlike experiential training, allows the organization to switch designs with relative impunity vis performance degradation. By the same token, organizations where personnel follow SOPs are less likely to see performance benefits to redesign efforts unless the SOPs are part of the redesign. These analyses support Propositions 1, 2, and 3. The results also support Propositions 7 and 8 when organizations are procedurally trained. Proposition 9 receives only limited support, and only for average behavior across all task environments.

Under optimal operating conditions (no distortions) teams with voting outperform other structures as long as the task environment is unbiased and decomposable, which suggests such an organization may better balance all factors and may make less biased decisions. This supports the result reported by Carley (1991, 1992). Further, this is true whether the organization is employing experiential or procedural decision makers. However, teams with voting are not better in all circumstances. In fact, in what one might consider the most common real world situation, a biased nondecomposable task environment, teams with voting exhibit the worst performance. These findings suggest that there may be a relationship between complexity and performance.

6.4. Complexity Matching

Contingency theorists argue that organizations should design for the task environment. We now examine whether matching the complexity of the organizational form and the environment actually improves performance.

PROPOSITION 10. *Overall, more centralized organizations (hierarchy and matrix) perform better than decentralized organizations (team with voting and team with manager) when facing simple task environments, but perform worse than decentralized organizations when facing complex task environments* (*Cohen* 1962, *Shaw* 1981).

PROPOSITION 11. *Under information distortion, rigidity (in terms of fewer communication links) helps organizations when facing simple, but not complex, environments* (*Staw et al.* 1981).

Given the OS and the RAS, we can define a measure of organizational complexity. This measure is useful as it will allow us to examine whether more complex organizations are needed to deal with more complex task environments. We define organizational complexity as: (a) simple—an organization with either a team with voting or a team with manager OS and a segregated or an overlapped RAS; (b) complex—an organization with either a hierarchical or a matrix OS and a blocked or a distributed RAS; (c) moderate—all other organizations.

Task environment complexity is defined in terms of decomposability and bias. A biased environment is simpler than an unbiased one and a decomposable environment is simpler than a nondecomposable one. This results in three levels of complexity for task environment: (a) simple—a biased decomposable task environment; (b) complex—an unbiased nondecomposable task environment; (c) moderate—all other task environments.

Using these measures, we can determine whether there is a match between organizational complexity and task environment complexity. A poor match occurs for a complex organization and a simple environment, or vise versa; a perfect match occurs if the level of complexity is the same in both organization and environment; a moderate match occurs in all other cases.

The average performance at each level of match is shown in Table 6. Overall, the better the match the better

Table 6 Organizational Performance by Match of Organizational Complexity and Task Complexity

Information Distortion Condition	Training Type	Match = 1	Match = 2	Match = 3
Information Distortion Free	Experiential	56.82 (1.82, 40)	61.74 (1.45, 160)	64.55 (1.55, 120)
	Procedural	51.50 (0.47, 40)	57.98 (1.19, 160)	58.30 (1.16, 120)
Distortions Only	Experiential	53.13 (1.17, 120)	58.69 (0.79, 480)	61.85 (0.91, 360)
	Procedural	48.98 (0.46, 120)	53.87 (0.49, 480)	54.92 (0.52, 360)
Overall	Experiential	54.05 (0.99, 160)	59.45 (0.69, 640)	62.52 (0.79, 480)
	Procedural	49.61 (0.37, 160)	54.90 (0.48, 640)	55.77 (0.49, 480)

Note: Standard errors and number of cases (n) are in parentheses. Match is defined as: 1—complex organization with simple task, or simple organization with complex task; 2—moderate organization with complex task, or moderate organization with simple task, or complex organization with moderate task, or simple organization with moderate task; 3—complex organization with complex task, or simple organization with simple task, or moderate organization with moderate task.

the performance. Regardless of training, complex organizations facing complex environments and simple organizations facing simple environments exhibit higher performance. These results support Proposition 11 but not Proposition 10.

In summary, we observe several general patterns: (1) Information distortions degrade performance (Proposition 1, supported). In addition, our results demonstrate that different types of distortions have different effects on performance, with misinformation being, on average, the most debilitating. Agent turnover has a bigger impact on performance in experiential organizations. (2) Hierarchical and matrix organizations perform better when organizations are procedurally trained (Proposition 4 and 7, partially supported). However, on average and for organizations faced with an unbiased environment, the team with voting performs best (Proposition 5, 6, and 9, conditional support). However, we also find that RAS has a major impact on performance, a factor not fully captured by any of the propositions. (3) Training improves performance (Proposition 2, supported; Proposition 3, not supported). Further, experiential organizations perform better than procedural organizations on average. (4) Experiential organizations, which are more discretionary, fit better in a biased task environment (or a narrow niche) than in an unbiased task environment (or a generalized setting). The opposite is the case for procedural organizations, which are more rigid. (5) Matching the complexity of the organizational form to the task environment generally improves performance for experiential organizations under information distortion, but not so for procedural organizations (Proposition 11, conditional support; Proposition 10, not supported).

7. Discussion

We used a computational framework with a ternary choice task to examine the basis of organizational performance. Using this framework we examined a wide range of propositions extant in the literature to determine whether they were internally consistent. We found a set of nine propositions that followed (sometimes with qualifications) from our model. Additionally, we found important qualifications and extensions to these propositions. We suggest that there is a systematicity to when each design is most effective; i.e., there are underlying principles that guide design. By broadening the concept of design to include training, in addition to structure, and by examining performance from an information perspective, it is possible to develop a theory of design that suggests strategies for mitigating information distortion consistent with organizational goals. The theory, as developed here, is based on a model of organizations comparable in some ways to neural networks. In this paper, the focus was on what was learned and not the learning process; i.e., the behavior of only full-trained networks were examined. Future research might consider the learning process itself. Further, this information-based network view of organizations leaves out many important elements such as the role of informal structure and culture. The advantage, however, is that this type of model lays bare the value of different types of structures.

We focused on two environmental dimensions: bias and decomposability, and fixed the number of components. This may limit the results. For example, we defined bias as differential frequency of the outcomes. However, bias can also be caused by different risk assessments of decision choices. Such a source of bias may have a completely different effect on performance. We can incorporate this type of bias into the model by altering the probabilities of potential risks and losses. Second, the number of components can contribute strongly to complexity and so affect performance. Future research might consider the impact of these adjustment.

While we have begun to examine the effect of training we have limited ourselves to training that was largely "helpful." Agents were trained in the type of organization for which their performance was measured and the SOPs were generally of the "right" type. Nevertheless, this model does indicate that when agents receive the wrong training, the organization may actually perform worse than if agents are untrained; e.g., organizations trained for a biased task when faced with friendly aircraft can do better by guessing. This suggests that radar groups trained during peacetime, on predominantly civilian aircraft, when put in a combat situation may actually do worse than untrained groups. Training may not satisfactorily transfer to novel situations. We can apply this result to the Iranian airline incident, where the group was trained in an environment where most events, albeit hypothetical, were hostile. They were trained for war; but were faced with a friendly situation (non-combat zone and peacetime). Our model would predict that they are likely to make a mistake—which they apparently did. To investigate the extent to which training transfers between situations a more realistic model of human problem solving and memory may be needed.

Another caveat is that this study proceeded by using a stylized radar task, computer-assisted enumeration, and computer simulation. Computational techniques have been used in many areas such as military training, business administration, and theory developing. Computational techniques can grasp the fundamental nature of human information processing behavior (Simon 1981). Compared with human experiments, formal models are easier to control, more flexible, more objective, with less noise, and can be used to examine more factors in less time. As Ostrom (1988) notes, computer simulation is a symbol system which "offers a substantial advantage" to researchers "attempting to develop formal theories of complex and interdependent social phenomena." Formal models are limited by simplifying assumptions and the computer technologies. Such models do not always capture difference due to individual cognition. Thus, when facing a task environment requiring more subjective judgments, our model may need to be modified. Nevertheless, analyses of such models can provide a series of hypotheses which can be tested with experimental and field data. Since human experiments are costly to run, and it is often impossible to obtain sufficient quantities of field data, these models help us develop organizational theory and determine which parameters are most important to explore in other settings.

Clearly there are many interesting issues related to this study but not addressed. One such issue is time pressure. In this study the aircraft examined were effectively holding still and so time pressure was not an issue. Future studies should examine how time pressure will affect performance given the presence of information distortion. While SOPs admit faster response than experience, they may not be as accurate; thus one expects a speed performance tradeoff.

8. Conclusion

We have considered the inter-relationship between information distortion, organizational design, and task environment relative to performance. These results confirm those found by Carley (1991, 1992) using a binary choice task: training improves performance, the greater the number of information distortions the lower the performance, turnover degrades performance, misinformation leads to lower performance than communication breakdowns, and teams outperform hierarchies. Such replication indicates that the results are a function of organizational design and information distortion rather than the number of choices available to the decision makers. The greater comprehensiveness of this study demonstrates that earlier results are a special case due to the task environment examined, not because of the number of choices available to the agents. We also demonstrated that the relationship between information distortion, organizational design, and task environment may be so strong that different designs are most cost effective for different combinations of environment and distortion. In addition, our results place these earlier studies in a broader context and show their limitations. Let us consider two findings—turnover degrades performance and teams outperform hierarchies.

Turnover degrades performance, but the effect may be minimal and even appear non-existent when agents follow SOPs. In experiential organizations, turnover can be more debilitating than technological distortions; however, in procedural organization turnover matters less. Organizations which cannot rely on SOPs should expend more effort to retain personnel and to hire trained personnel. Organizations that employ SOPs need to worry less about personnel relations.

Teams outperform hierarchies, but they do so predominantly when the task environment is unbiased decomposable. In a biased environment, when one outcome is more likely than others, or a non-decomposable environment, when the interrelationship between information is complex, more complex organizational structures outperform teams. Generally, complex organizations exhibit higher performance when facing complex environments and simple organizations exhibit higher performance when facing simple environments, regardless of the information distortion or the training scenario. These results suggest that environmental complexity is a stronger determinant of performance than either design or information distortion. Thus, the organization should first expend effort determining what task environment it is likely to face before settling on a particular organizational design or expending effort to minimize information distortions.

Consider some of the policy implications that can be drawn from these results. While turnover, and other information distortions, can degrade organizational performance, the effect depends on the type of training received by organizational members. Generally, technological distortions are more debilitating than agent based distortions, which means most organizations with a limited budget should spend resources to get the information right in the first place. Performance decreases as distortions increase, unless agents are trained to follow SOPs and are facing a biased task environment. More information does not necessarily improve performance, in fact, under certain conditions, organizations can benefit from less information. Experiential organizations exhibit the highest performance in biased environments; procedural organizations exhibit the highest performance in unbiased environments. Thus, in general, organizations unsure of their environment should not use SOPs, but should experientially train their employees as this admits maximum adaptation. If the environment is known an appropriate SOP is generally better.

We demonstrated the importance of evaluating the procedure and purpose of training. Improperly guided training may waste time or even hurt performance. Second, we demonstrated that more information does not guarantee better decisions. Rather, performance depends on the training procedure, the location of communication links, and the environment. Organizational redesign efforts that focus on only one aspect, rather than the connections among them, may not result in performance improvements. Third, we demonstrated a strong relationship between information distortion and organizational design. Depending on the organization's design alleviating distortions may have little impact on performance. Fourth, we demonstrated that task environment is a critical determinant of performance and that effective organizations are those tailored to their environment. Our results go beyond supporting the idea that the best design is contingent by demonstrating the use of a comprehensive computational framework to place limits on when what design is most effective. The environment places limits on performance that no design can overcome and major performance improvements can often be achieved only by changing the environment in which the organization operates.[19]

[19] An earlier version of this paper was presented at the 87th Annual Meeting of the American Sociological Association, Pittsburgh, Pennsylvania, August 24, 1992. This work was supported in part by Grant No. N00014-90-J-1664 from the Office of Naval Research (ONR), United States Navy.

References

Babbage, C., *On the Economy of Machinery and Manufactures*, Carey and Lea, Philadelphia, PA, 1832.

Baligh, H. H., R. M. Burton, and B. Obel, "Devising Expert Systems in Organization Theory: The Organizational Consultant," in Michael Masuch (Ed.), *Organization, Management, and Expert Systems*, Walter De Gruyter, Berlin, 1990, 35–57.

——, ——, and ——, "Validating the Organizational Consultant on the Fly," in K. M. Carley and M. J. Prietula (Eds.), *Computational Organization Theory*, Lawrence Erlbaum Associates, Hillsdale, NJ, 1994, 179–194.

Bond, A. and L. Gasser, *Readings in Distributed Artificial Intelligence*, Kaufmann, San Mateo, CA, 1988.

Burton, R. M. and B. Obel, *Designing Efficient Organizations: Modeling and Experimentation*, Elsevier Science, Amsterdam, 1984.

Carley, K. M., "Trading Information Redundancy for Task Simplicity," *Proc. 23rd Annual Hawaii International Conf. on System Sciences*, IEEE Computer Soc. Press, 1990.

——, "Designing Organizational Structures to Cope with Communication Breakdowns: A Simulation Model," *Industrial Crisis Quarterly*, 5 (1991), 19–57.

——, "Organizational Learning and Personnel Turnover," *Organization Sci.*, 3, 1 (1992), 2–46.

—— and J. Harrald, "Hurricane Andrew Response—Comparing Practice, Plan, and Theory," *Natural Hazards Observer*, 17, 2 (1992), 1–3.

——, J. Kjaer-Hansen, M. Prietula, and A. Newell, "Plural-Soar: A Prolegomenon to Artificial Agents and Organizational Behavior," in M. Masuch and M. Warglien (Eds.), *Artificial Intelligence in Organization and Management Theory*, North-Holland, Amsterdam, 1992, 87–118.

—— and Z. Lin, "Organizational Designs Suited to High Performance Under Stress," *IEEE Systems Man and Cybernetics*, 25, 1 (1995), 221–230.

Cohen, A. M., "Changing Small-Group Communication Networks," *Admin. Sci. Quarterly*, 6 (1962), 443–462.

Cohen, M. D. and J. G. March, *Leadership and Ambiguity*, McGraw Hill, New York, 1974.

——, J. G. March, and J. P. Olsen, "A Garbage Can Model of Organizational Choice," *Admin. Sci. Quarterly*, 17, 1 (1972), 1–25.

Cohen, R., "Blaming Men, Not Machines," *Time*, August 15, 1988, 19.

Cooper, N., "Seven Minutes to Death," *Newsweek*, July 18, 1988, 18–23.

Davis, S. M. and P. R. Lawrence, *Matrix*, Addison-Wesley, Reading, MA, 1977.

Demael, J. J. and A. H. Levis, "On Generating Variable Structure Architectures for Distributed Intelligence Systems," Technical Report C3I-WP-1, Center for Excellence in C3I, George Mason University, Fairfax, VA, 1991.

Dreznick, R. F., *A Mathematical Organization Theory*, North-Holland, Amsterdam, 1986.

Duffy, B., R. Kaylor, and P. Cary, "How Good Is This Navy, Anyway?" *U.S. News and World Report*, July 18, 1988, 18–19.

Dunbar, R. L. M. and S. A. Stumpf, "Trainings that Demystify Strategic Decision-Making Processes," *J. Management Development* (*UK*), 8, 1 (1989), 36–42.

Etzioni, A., *Complex Organizations: A Sociological Reader*, Holt, Rinehart and Winston, New York, 1961.

Galbraith, J. R., *Designing Complex Organizations*, Addison-Wesley, Reading, MA, 1973.

Ganster, D. C., P. Poppler, and S. Williams, "Does Training in Problem Solving Improve the Quality of Group Decisions?" *J. Applied Psychology*, 76, 3 (1991), 479–483.

Gasser, L., I. Hulthage, and A. Majchrzak, "Organizational Knowledge and Analysis/Design Decision Making in Action," paper presented at the Mathematical and Computational Organizational Theory Workshop, ORSA/TIMS, Boston, MA, April 1994.

Green, F. E., "When Just-in-Time Breaks Down on the Line," *Industrial Management*, 31, 1 (1989), 26–29.

Hammond, K. R., "Negative Effects of Outcome-Feedback in Multiple-Cue Probability Learning," *Organizational Behavior and Human Resources*, 9 (1973), 30–34.

Hannan, M. T. and J. Freeman, "The Population Ecology of Organizations," *American J. Sociology*, 82 (March 1977), 929–964.

Hastie, R., "Experimental Evidence on Group Accuracy," in F. M. Jablin, L. L. Putnam, K. H. Roberts, and L. W. Porter (Eds.), *Handbook of Organizational Communication: An Interdisciplinary Perspective*, Sage, Beverly Hills, CA, 1986.

Hollenbeck, J. R., D. R. Ilgen, D. Tuttle, and D. J. Sego, "Team Performance on Monitoring Tasks: An Examination of Decision Errors in Contexts Requiring Sustained Attention," *J. Applied Psychology*, 80 (1995), 685–696.

Houskisson, R. E. and C. S. Galbraith, "The Effect of Quantum Versus Incremental M-form Reorganization on Performance: A Time Series Exploration of Intervention Dynamics," *J. Management*, 11 (1985), 55–70.

Hummon, N. P. and T. J. Fararo, "Actors and Networks as Objects." *Social Networks*, 17 (1995), 1–26.

Ilgen, Daniel R., Debra A. Major, John R. Hollenbeck, and Douglas J. Sego, "Decision Making in Teams: Raising an Individual Decision Making Model to the Team Level," Tech. Rep. No. 91-2, Michigan State University, Department of Management and Psychology, East Lansing, MI, 1991.

Ilgen, D. R. and J. R. Hollenbeck, "Effective Team Performance Under Stress and Normal Conditions: An Experimental Paradigm, Theory and Data for Studying Team Decision Making in Hierarchical Teams with Distributed Expertise," Final Report, NR. 93-2. Michigan State University, Department of Management and Psychology, East Lansing, MI, 1993.

Jablin, F. M., L. L. Putnam, K. H. Roberts, and L. W. Porter (Eds.), *Handbook of Organizational Communication: An Interdisciplinary Perspective*, Sage, Beverly Hills, CA, 1986.

Janger, A. R., *Matrix Organization of Complex Businesses*, Conference Board, 1979.

Krackhardt, D., "Graph Theoretical Dimensions of Informal Organizations," in K. M. Carley and M. J. Prietula (Eds.), *Computational*

Organization Theory, 89–112, Lawrence Erlbaum Associates, Hillsdale, NJ, 1994.

—— and R. N. Stern, "Informal Networks and Organizational Crises: An Experimental Simulation," *Social Psychology Quarterly*, 51, 2 (1988), 123–140.

Lagadec, P., *Major Technological Risk: An Assessment of Industrial Disasters*, Pergamon Press, Translated from French by H. Ostwald, 1982, Anchor Press Ltd., 1981.

Lawrence, P. R. and J. W. Lorsch, *Organization and Environment: Managing Differentiation and Integration*, Graduate School of Business Administration, Harvard University, Boston, MA, 1967.

—— and ——, *Developing Organizations: Diagnosis and Action*, Addison-Wesley, Reading, MA, 1969.

Levis, A. H., "Human Organizations and Distributed Intelligence Systems," *Proc. IFAC Symposium on Distributed Intelligence Systems*, Pergamon Press, Oxford, England, 1988.

Levitt, B. and J. March, "Organizational Learning," *Ann. Rev. Sociology*, 14 (1988), 319–340.

Mackenzie, K. D., *Organizational Structures*, AHM Publishing Corporation, Arlington Heights, IL, 1978.

Malone, T. W., "Modeling Coordination in Organizations and Markets," *Management Sci.*, 33, 10 (1986), 1317–1332.

March, J. G. and H. A. Simon, *Organizations*, Wiley, New York, 1958.

—— and J. P. Olsen, *Ambiguity and Choice in Organizations*, Universitetsforlaget, Bergen, 1976.

Mintzberg, H., *Structures in Five: Designing Effective Organizations*, Prentice-Hall, Englewood Cliffs, NJ, 1983.

Neuhauser, D., "The Relationship Between Administrative Activities and Hospital Performance," *Research Series* 28, Center for Health Administration Studies, University of Chicago, Chicago, IL, 1971.

Ostrom, T. M., "Computer Simulation: The Third Symbol System," *J. Experimental Social Psychology*, 24 (1988), 381–392.

Panning, W. H., "Information Pooling and Group Decisions in Nonexperimental Settings," in F. M. Jablin, L. L. Putnam, K. H. Roberts, and L. W. Porter (Eds.), *Handbook of Organizational Communication: An Interdisciplinary Perspective*, Sage, Beverly Hills, CA, 1986.

Pete, R., K. R. Pattipati, and D. L. Kleinman, "Distributed Detection in Teams with Partial Information: A Normative Descriptive Model," *IEEE Trans. on Systems, Man, and Cybernetics*, 23, 6 (1993), 1626–1648.

Pfeffer, J., *Organizational Design*, AHM Publishing Corporation, Arlington Heights, IL, 1978.

Perrow, C., *Normal Accidents: Living with High Risk Technologies*, Basic Books, New York, 1984.

——, *Complex Organizations: A Critical Essay*, Scott Foresman, 1979.

Radner, R., *Decentralization and Incentives*, University of Minnesota Press, Minneapolis, MN, 1987.

Roberts, K., "New Challenges to Organizational Research: High Reliability Organizations," *Industrial Crisis Quarterly*, 3, 3 (1989), 111–125.

——, "Some Characteristics of One Type of High Reliability Organizations," *Organization Sci.*, 1, 2 (1990), 160–176.

Rogers, W. P., et al., *Report of the Presidential Commission on the Space Shuttle Challenger Accident*, Government Printing Office, Washington, DC, 1986.

Scott, W. R., *Organizations: Rational, Natural, and Open Systems*, Prentice Hall, Englewood Cliffs, NJ, 1987.

Shaw, M. E., *Group Dynamics: The Psychology of Small Group Behavior*, McGraw-Hill, New York, 1981.

Shrivastava, P., *Bhopal: Anatomy of a Crisis*, Ballinger, Cambridge, MA, 1987.

Simon, H. A., *Administrative Behavior*, Free Press, New York, 1947.

——, "Applying Information Technology to Organizational Design," *Public Admin. Rev.*, 33 (1973), 268–278.

——, "Studying Human Intelligence by Creating Artificial Intelligence," *American Scientist*, 69, 3 (1981), 300–309.

Staw, B. M., L. E. Sanderlands, and J. E. Dutton, "Threat-Rigidity Effects in Organizational Behavior: A Multilevel Analysis," *Admin. Sci. Quarterly*, 26 (1981), 501–524.

Tauski, C., *Work Organizations: Major Theoretical Perspectives*, F. E. Peacock, Itasca, IL, 1970.

U.S. Congress, *Iran Airflight* 655 *Compensation Hearings before the Defense Policy Panel of the Committee on Armed Services, House of Representatives, Second Session (Held on August* 3, *and* 4, *September* 9, *and October* 6, 1988), U.S. Government Printing Office, Washington, DC, 1989.

Watson, R., J. Barry, and R. Sandza, "A Case of Human Error," *Newsweek*, August 15, 1988, 18–21.

Wood, R. E., A. J. Mento, and E. A. Locke, "Task Complexity as a Moderator of Goal Effects: A Meta Analysis," *J. Applied Psychology*, 72, 3 (1987), 416–425.

Accepted by Richard M. Burton; received July 1993. This paper has been with the authors 10 months for 3 revisions.