DOCUMENT RESUME

ED 352 398 TM 019 312

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TITLE	Maydays and Murphies: A Study of the Effect of Organizational Design, Task, and Stress on Organizational Performance.
INSTITUTION	Pittsburgh Univ., Pa. Learning Research and Development Center.
SPONS AGENCY	Office of Naval Research, Arlington, Va.
REPORT NO	UPITT/LRDC/ONR-URI-HGD-2
PUB DATE	31 Jul 92
CONTRACT	N0001 -90-J-1664
NOTE	76p.
PUB TYPE	Reports - Evaluative/Feasibility (142)
EDRS PRICE	MF01/PC04 Plus Postage.
DESCRIPTORS	Air Traffic Control; Communications; Comparative Analysis; Computer Simulation; Decision Making; Models; *Organizational Effectiveness; Organizations (Groups); *Performance; *Problem Solving; Stress Management; *Stress Variables; Task Analysis; Training
IDENTIFIERS	*Crisis Management; *Radar Intercept Observers

ABSTRACT

How should organizations of intelligent agents be designed so that they exhibit high performance even during periods of stress? A formal model of organizational performance given a distributed decision-making environment in which agents encounter a radar detection task is presented. Using this model the performance of organizations with various organizational designs and task characteristics subject to various stresses is examined. The following two types of stress are distinguished: (1) external stress, such as hostile events or "maydays"; and (2) internal stress, such as communication channel breakdowns or "murphies". Simulations were run considering 192 organizational types under 20 operating conditions (5 optimal and 15 suboptimal) for a total of 3,840 cases. This formal analysis suggests that: (1) regardless of stress, performance is enhanced if there is a match between the complexity of organizational design and task; (2) task characteristics and maydays have more effect on performance than do murphies and organizational design; (3) the effects of murphies can be combated by training, but only to a limited extent; and (4) technology-induced stress typically is more debilitating than personnel-induced stress. Ten tables and 10 figures present simulation results. (Author/SLD)

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Technical Report No. UPITT/LRDC/ONR-URI-HGD-2

This work was supported in part by Grant No. N00014-90-J-1664 from the Office of Naval Research (ONR), United States Navy. The views stated or implied by this report are not necessarily those of the United States Government or the United States Navy, which has neither reviewed nor endorsed the reported findings.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	31 July 1992	Technical 1 May '91 - 29 July '92

4. TITLE AND SUBTITLE
Maydays and Murphies: A Study of the Effect of Organizational Design, Task, and Stress on Organizational Performance

5. FUNDING NUMBERS
G-N00014-90-J-1664
PE-61153N
PR-RR04206
TA-RR04206-01
R&T PR: URI 5205-9001

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8. PERFORMING ORGANIZATION REPORT NUMBER
UPitt/LRDC/ONR-URI-HGD-2

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Cognitive Science Program
Office of Naval Research
800 North Quincy Street
Code 1142 CS
Arlington, VA 22217-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Prepared for the working paper series.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
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14. SUBJECT TERMS
Stress, Organizational Design, Organizational Task, Stylized Radar Task, Task Characteristics, Procedures, Inter-relationship

15. NUMBER OF PAGES
167

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

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ABSTRACT

How should organizations of intelligent agents be designed so that they exhibit high performance even during periods of stress? We present a formal 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 organizational designs and task characteristics subject to various stresses. We distinguish two types of stress — external stress (such as hostile events that we call maydays) and internal stress (such as communication channel breakdown that we call murphies). This formal analysis suggests that: (1) regardless of stress, performance is enhanced if there is a match between the complexity of organizational design and task; (2) task characteristics and maydays (external stress) have more effect on performance than murphies (internal stress) and organizational design; (3) the effects of murphies (internal stress) can be combated by training, but only to a limited extent; (4) technology induced stress typically is more debilitating than personnel induced stress.

INTRODUCTION

It was July 3, 1988, the Persian Gulf. On board the most advanced Aegis warship, U.S.S. Vincennes, a group of operators was working intensively in front of the radar defense system. Suddenly, they detected a signal of attack by an "enemy F-14 fighter". The warning signal 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].

Investigations following the incident suggested many possible causes for the tragic mistake. One criticism was that 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 data from the radar system when facing a real and highly stressful situation such as the Persian Gulf (Cohen, 1988). Another criticism was that the Navy was not properly trained for low intensity conflict, but only for superpower confrontation, and their personnel as well as war machines were not suitable for the Persian Gulf situation (Duffy et al., 1988). Others forwarded the criticism that the Navy used biased judgments in dealing with the Gulf situation (Watson et al., 1988). 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". Others pointed out that incorrect information received by the radar system regarding whether the aircraft was civilian or military caused the tragedy (U.S. Congress, 1988). Still others challenged the commanding hierarchical structure of the Navy warship and argued that the mistake was caused because the error was passed to the captain without sufficient cross-checking (Watson et al., 1988).

The above incident demonstrates that a variety of factors may contribute to organizational performance. These factors include organizational design, task, and stress. Despite the often tacit acknowledgment that these factors 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 interactions between these factors. We examine the decision making performance of organizations with different designs and tasks, under conditions where there are either or both external and internal stress. The organizations we examine are engaged in a radar detection task, which though stylized, resembles that faced by the Vincennes.

The model used in this paper extends the work by Carley (1990,1991a, 1991b,1992) on organizational design. Carley examined organizational performance for organizations of intelligent agents with different organizational designs when the organization was faced with a binary choice task. Carley's agents learn from experience and make decisions on the basis of new information and their experience. The agent model is referred to as ELM, the experiential learning model. In this paper, we examine organizations of ELM agents faced with a trinary choice task (radar detection). This analysis enables us to determine the extent to which earlier results were a product of the specific task characteristics. In addition, using this framework we examine organizational designs, task characteristics, and stresses not heretofore considered. In doing this analysis we have found it necessary to generalize the nature of crisis by treating it as two types of stress (internal or murphies and external or maydays). The result of these extensions is a more comprehensive study of design. To preview our conclusions, we find that many of our results are consistent with those found by Carley. The consistency of results, despite moving from a binary to a trinary task, suggests that the results are a function of organizational design and stress rather than the number of choices available to the decision makers. The greater comprehensiveness of this study demonstrates that Carley's results are a special case because of the task environment examined, not because of the number of choices available to the agents. We demonstrate that the relationship between organizational design, task, and stress may be so strong that different designs are most cost effective for different task-stress combinations.

BACKGROUND

Stress

Organizations often face stress. Such stress often is characterized in terms of crises. For example, Perrow (1984) sees organizations as being stressed when they face "a crisis" — a critical, novel scenario which essentially is inevitable. As another example, March and Simon (1958) see organizations as being routinely stressed as they face suboptimal operating conditions. Other stresses discussed include turnover (Tushman et al., 1989; Carley, 1992), communication breakdown (Carley, 1991a), and environmental disasters, such as Bhopal (Shrivastava, 1987). Clearly a variety of types of stress or crises exist. They can, however, be characterized as to whether they are predominantly external to the organization or internal. We refer to predominantly external stresses or crises as maydays. They are characterized by a critical untypical event external to the organization that may have severe consequences (such as threat to life or the environment). Maydays stress the organization because they force individuals in the organization to face a situation for which they may not have been trained and for which the incorrect decision may have tragic consequences. We refer to predominantly internal stresses or crises as murphies.

They are characterized by the somewhat more common disruptions to the ideal decision making environment, such as missing information, incorrect information, communication breakdown, agent unavailability, and agent turnover. Murphies stress the organization because they force individuals in the organization to make decisions under suboptimal conditions.

In examining organizational performance it is important to consider both sources of stress. Maydays are important to consider because they may be inevitable (Perrow, 1984) and the consequences of the organization's decision so universally important. Murphies are important to consider because they are so pervasive (Cohen and Mach, 1974) and yet potentially capable of being reduced, if not prevented. The question remains, how can organizations cope with stress. Two strategies that have dominated the literature are "better technology" and "better trained". The better technology strategy (Neuhauser, 1971) is an engineering approach, and centers on the idea *if we can just design the procedure (and/or the associated equipment) right, then crises can be avoided.* But if Perrow (1984) is right, better technology may reduce stress but it will not completely eliminate it. The better trained strategy (Dunbar and Stumpf, 1989; Green, 1989) is a personnel approach and centers on the idea *if we can just train people then they will respond more quickly and accurately during crises thus minimizing the impact of crises.* But the value of training is indeterminate (Hammond, 1973; Ganster et al., 1991). A third strategy, which has received less attention is "better design". The better design approach (Malone, 1978; Burton and Obel, 1984; Carley, 1990,1991a,1991b,1992) is a structural approach, and centers on the idea *if we can just design the organization right, the impact of crises can be mitigated.* Contingency theorists have suggested that the right design is highly situationally specific and so little general guidance or simple theory of design can exist (Lawrence and Lorsch, 1967; Galbraith, 1973, 1977). Efforts at forging contingency theory into a theory of design have gone the route of creating expert systems replying on highly situation specific knowledge (Baligh et al., 1990; Baligh et al., 1992). 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".

We suggest that there is a systematicity to when what design is most effective, that there are underlying principles that guide design. By broadening the concept of organizational design to include aspects of task, and training, in addition to structure, and by examining performance from a combined design, task, and stress perspective, it is possible to develop a theory of design that suggests strategies for mitigating stress consistent with the organizational goals. Or as Carley (1990) suggests although the right design may be to an extent situationally specific, there is an underlying systematicity to what works when. Thus, although organizations with different designs perform differently given different tasks and subject to different stresses, there are systematic shifts in performance as these factors change. Consequently, organizations can choose that design which admits the highest performance given the type of stress and task they expect to encounter most frequently or for which, when encountered, has the most costly consequences.

Organizational Design

Organizational design has been viewed from a variety of perspectives. To some, organizational design is defined by the formal structure and the task decomposition structure (Mintzburgh, 1983; Burton and Obel, 1984). To others, factors such as the degree of hierarchy (Mackenzie, 1978), or the structure of the informal network (Krackhardt, 1989) characterize the organization's design. Others focus on procedures for combining information or making decisions (Panning, 1986; Radner, 1987). Still others focus on the information processing characteristics or cost of the organization (March and Simon, 1958; Galbraith, 1973, 1977; Malone, 1986; Carley, 1990, 1991b). Despite the numerous approaches there are still aspects of design that are neglected. An often neglected aspect of organizational design is the skill level of the employees, i.e., do you hire trained or untrained personnel.

The interest in design largely is due to the fact that organizations can alter their design. Hence, to the extent to which performance is related to design organizations can improve their performance by altering their design. In general there is the assumption, albeit often implicit, that organizational performance, or at least the organization's efficiency, is tied intimately to the organizational design. For example, Mackenzie (1978) argues that the degree of hierarchy is linked directly to the organization's efficiency. Alternatively, Malone (1986) and Carley (1990, 1991b) have suggested that the organizational design is related to its cost and consequent performance[2]. In large part, the relation between organizational design and performance is expected to hold because organizations are composed of intelligent agents who can, and do, learn from experience (March and Simon, 1958; Carley, 1991,1992; Carley et al, forthcoming). Thus the organization's performance depends on the performance of its members (Hastie, 1986). However, the agents' performance is affected by the organization's design which places constraints on the agents.

In this paper, organizational design is viewed as a combination of organizational structure, task decomposition scheme, and procedures. Through an examination of multiple designs, the expected relations between design and performance will be deduced. Thus, the focus of our analysis is on the relative performance of various designs. This is in contrast to that work on organizational design that given a set of constraints tries to locate the optimal design.

Organizational Task

The argument can be made that organizational theory began with the systematic study of tasks (Taylor,1916; Fayol, 1949). This tradition is followed today in the areas of job design and scheduling. Nevertheless, in much of current organizational theory, task is overlooked or treated exogenously as the problem to be solved (Perrow, 1967; Mackenzie, 1978). In part, task is overlooked as it viewed, as it is in this paper, as a feature or the environment. The task can be thought of as a set of problems external to the organization. And in some cases, the task is defined by the given technology (Scott, 1987). Within organization theory open system theory (Scott, 1987) and population ecology (Hannan and Freeman, 1977) have refocused attention on the environment, though not directly on the features of the task. Research in artificial intelligence, and of particular interest to organizational theorists, research in distributed artificial intelligence (Dreznick, 1986; Bond and Gasser, 1988; Carley et al., forthcoming), have clearly demonstrated the importance of the task. Such research demonstrates that features of the task serve as constraints on what organizations are most effective, and even possible (Levis, 1988; Demael and Levis, 1991). Despite the agreement that task constrains organizational action there is little agreement as to what are the salient features or dimensions of tasks.

Tasks vary on a large number of dimensions, not the least of which is complexity. There have been numerous studies of the effect of task complexity on organizational performance (Wood et al., 1990). These studies demonstrate that increases in task complexity correspond to decreases in performance. In addition, using a model similar to that used in this paper, Carley (1990) found that organizational performance tended to degrade with task complexity. One aspect of task that has received some attention is its decomposability. The common wisdom is "divide and conquer" (Babbage, 1832; Massie, 1965; Tausky, 1970). Decomposability is related highly to interdependence of task components (Roberts, 1989, 1990). Problems of coordination can occur if organizational design does not take the task decomposability into consideration. Another aspect of task is bias. Or to describe this another way, organizations can operate within niches. The niche defines what types of problems the organization sees. Some organizations operate within a highly specialized niche (Hannan and Freeman, 1977) and are therefore expected to perform well in a specialized environment. Other organizations operate within a more generalized niche and are therefore expected to perform well in a coarse-grained environment. From the perspective taken in this paper, organizations within a specialized niche are coping with a biased task, i.e., they have a tendency to see only one aspect of a more general problem. Organizations facing unbiased tasks see all aspects of the general problem and therefore are in a more generalized niche.

MODEL

Stylized Radar Task

The task is a stylized radar detection task. There is a physical 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 (1), neutral (2), or hostile (3). 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. For example, while the aircraft may have weapons, and so on the characteristic Radar Emission Type may appear hostile, the aircraft when all characteristics are considered may actually be friendly. The number of possible unique aircraft or problems is 19683 (3^9).

Place Figure 1 about here

We choose this stylized task for the following reasons: First, it is a real world problem. The task 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 think of this task as radar control, in reality it is a trinary choice task, and any task where the agents can choose between three options has features in common with this task. Third, because the true decision can be known, feedback can be provided and so issues of training can be addressed. Fourth, it is ideal for a distributed environment as the task is sufficiently complex that multiple agents can be used to work on different aspects of the task. Fifth, the task itself has a limited number of cases ($19683=3^9$) and so numerical enumeration techniques can be used to evaluate performance. Sixth, this task can also be thought as a trinary version of the binary choice task used by Carley (1990,1991a,1991b,1992), so admits replication and extension of this earlier work. And finally, this task is sufficiently interesting that it can be expanded later with relative ease to include many other factors, such as communication of different types of information or 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 in this area.

Task Characteristics

The true state of the world is a feature of the task that is external to the organization, and that is not manipulatable by the organization, at least in the short run. Such true states are often a product of the technology. For example, within the radar environment aircraft that are moving very fast, are within the corridor, are carrying weapons, and have an unknown identification typically are hostile. We can manipulate the "true state of the world" in order to examine different types of tasks, all within the radar scenario. By altering the "reality" faced by our organizations we are altering the definition of what constitutes a truly friendly, neutral, or hostile aircraft. Two such manipulations are particularly interesting, given the previous review of the literature, decomposability and bias.

A task environment is decomposable if there are no complex interactions among components that need to be understood in order to solve a problem. In a decomposable task 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 a more powerful or more important piece of information. In contrast, when the task is non-decomposable then the pieces of information do not contribute equally to the final decision, and portions of the information interact to determine the true nature of the aircraft. In this case, some agents may have greater "power" simply by virtue of having access to more powerful or more important information. Decomposable tasks are less complex than non-decomposable tasks due to the absence of complex interactions.

A task environment is biased if the possible outcomes are not equally likely. Biased environments are quite common. For example, during war time one might see many more hostile than friendly aircraft. In an unbiased environment approximately one third of the 19683 aircraft (6568) are hostile and one third of the aircraft are friendly. This environment can be thought of as an uncertain environment because the chance of all three outcomes are almost identical. In contrast, biased environments are more certain simply because the most common aircraft is hostile. Biased tasks thus are less complex than unbiased tasks due to the preponderance of a particular solution.

Based on these two manipulations, we examine four different "realities" or environmental situations.[3] These four environments are described in Figure 2. Given a particular reality, the 19683 problems can be classified as being "truly" friendly, neutral, or hostile. This classification involves first calculating a sum of the values of all nine characteristics and then categorizing the aircraft as either friendly, neutral, or hostile depending on the value of the sum. As can be seen in Figure 2 when the task is decomposable the sum is based on an unweighted linear combination of the characteristics; whereas, the non-decomposable task uses a weighted sum. Further, when the task is unbiased the three possible outcomes are equally likely; whereas, when the task is biased one outcome (hostility) is more likely. Thus, as shown in Figure 2, the number of aircraft that are "truly" friendly, neutral, or hostile depends on the environmental situation.

Place Figure 2[4] about here

Organization and Task

Each time period, the organization must scan the air space and make a decision as to the nature of the aircraft in that airspace. The organization goes through this process 19683 times, once for each unique aircraft.[5]

Each time period, some of the organizational agents (the analysts) access information on the aircraft, develop a recommendation (their opinion as to whether they think the aircraft is friendly (=1), neutral (=2), or hostile (=3)), and communicate this recommendation. How these recommendations are processed or combined by the organization depends on the organizational structure. This will be discussed in the next section. Regardless of the organizational structure, the processed (or combined) recommendations form the organization's final decision on that aircraft (the organization's decision that the aircraft is friendly (=1), neutral (=2), or hostile (=3).

The aircraft really exists, and is therefore "truly" friendly (=1), neutral (=2), or hostile (=3). The organization is not omniscient and the true state of the world is not known apriori. Rather, it must be determined by the organization by examining the radar characteristics of the aircraft. Given that organizations have only history and their understanding of their current technology to guide them the organization as a whole has only a vague understanding of the true state of the world. The organization's understanding resides both in the agents and in the pattern of relationships among the agents (Carley, 1992). The agents' understanding of the true state of the world depends on how they were trained. Each agent is assumed to be intelligent; i.e., each agent makes a recommendation or decision on the basis of all the task-based information available to the agent. What information is available to the agent depends both on what the current problem is and on how the agent was trained.

Organizational Design

In this paper, organizational design is characterized by three factors — the organizational structure, the task decomposition scheme, and the organizational procedures (herein limited to procedures for providing training, feedback, communicating recommendations, and combining these to create an organizational decision). By considering all three factors, design elements of structural theory, resource dependency theory, and institutional theory are combined in a single formal framework.

Organizational Structure

We examine four structures: team with a manager, team with voting, hierarchy, and matrix[6] (see Figure 3). Each structure consists of nine baseline analysts. In addition, some structures also employ middle and/or top-level managers.

Place Figure 3 about here

These structures are examined because they represent stylized version of real organizations. Each type of structure has been analyzed by various research traditions, but rarely has their performance been contrasted[7]. Each structure has features which have been touted as enabling it to perform well under some circumstance. The team with a manager, for example, is virtually a flat hierarchy such that while each analyst examines information and makes a recommendation, the ultimate 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 at simpler tasks. The team with voting is a collection of equals, not subject to any supervisor, who together make the final 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 arguably are quick to learn new information but are rarely resilient in the face of various forms of stress such as turnover (Carley, 1991a, 1992). The hierarchy is multi-leveled and designed such that each analyst examines information and makes a recommendation to his or her immediate supervisor who in turn makes a recommendation to the top-level manager who makes the ultimate organizational decision. Hierarchies have been extensively studied (Simon, 1973; Malone, 1987), and are expected to absorb uncertainty (Simon, 1973). 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 such that analysts report to multiple managers. Matrix organizations are supposed to be good at complex tasks and to sustain more uncertainty.

In the foregoing discussion, we tried to illustrate that these are unique organizational structures with different properties. Moreover, even the most cursory examination of the literature demonstrates that each of these structures is expected to have very different performance profiles. By examining these typical, albeit stylized, organizational structures we will gain insight into the impact of organizational structures on organizational performance.

Task Decomposition Scheme(Access)

The task decomposition scheme[9] determines the distribution of raw (unfiltered) information to members of the organization. In our model, what this means is that the task decomposition scheme determines which analyst has access to which type of radar or surveillance equipment. Each type of equipment allows that analyst to garner information on a particular (or a particular set of) characteristics. We examine four task decomposition schemes (see Figure 4). They are: segregated, overlapped, blocked, and distributed[10].

Place Figure 4 about here

As with the organizational structures, these schemes were chosen as they represent unique, albeit stylized, patterns of distributing the task information across analysts. These schemes represent a range of ways in which task based information can be differently accessed by members of the organizational structures. In choosing these schemes we varied two features — how much information overlap exists and where the overlap occurs. The segregated scheme essentially is employing the divide and conquer scheme. It has been studied by Cohen et al. (1972) who found that the segregated scheme is fragile under stress. Cohen et al. (1972) suggested that information overlap makes the organization less reliant on the whims of a particular employee and enables the organization to better deal with stresses such as communication breakdowns. While the overlapped, blocked, and distributed all have information overlap they differ in how that overlap affects the overall distribution of information across the organization. The blocked scheme provides complete redundancy within a division and none across divisions. Whereas, the overlapped scheme provides for some information being shared between divisions, and the distributed scheme guarantees that all information is available to all divisions. The teams of course, do not have divisions, so the impact of these different schemes may be less. By considering these variations we are able to see how different task decomposition schemes impact organizational performance.

Organizational Procedures

The artificial organizations we examine have procedures for feedback, communicating recommendations, combining recommendations to create an organizational decision, and training. In all organizations agents during their training phase received accurate and immediate feedback as to what was the correct organizational decision. In all organizations agents could communicate their decision only to their immediate supervisor(s). In the team with voting, a majority rule combination procedures was used. In all other organizational structures the procedure for combining subordinates' recommendations was determined by the supervisor. Training procedures were systematically varied across all organizations. We consider the effect of 3 training procedures — no training, experiential training, and training in standard operating procedures (SOPs). As with the organizational structures and the task decomposition schemes these training scenarios are stylized but they do reflect types of training prevalent in real organizations. These training conditions help us illuminate the effect of training on organizational performance.

At this point it is important to re-iterate that when we measure organizational performance we are dealing with organizations composed of fully-trained agents (other than under certain types of stressed conditions). In all cases we will be examining the performance of organizations after the training process has been completed. The agents are not going through a training process. Rather, the agents, already have as much training as they are going to get. Nevertheless, in order to fully appreciate why the organizations behave as they do it is necessary to understand the type of training the agents received, as well as the exact decision procedure followed by the agents. It is also important to point out that within an organization all agents are either untrained, experientially-trained, or operationally-trained (other than under certain types of stressed conditions where untrained agents become mixed with either experiential training or operational training).

No Training Procedure

In the untrained condition, the agents have no historical information or standard operating procedure on which to base their recommendation so they simply guess. This condition is interesting as it represents a baseline against which to compare all other organizational behavior. That is, given this baseline we can address the question *to what extent does training improve performance over and above guessing*.

Agent's Knowledge

The agent's knowledge consists only of current information For example, only the speed, direction, and altitude of the aircraft.

Training Procedure

There is no training procedure. The agent has never seen any of the problems before. The agent has been given no guidance on how to proceed.

Decision Procedure

Given a problem, the agent simply makes a random guess. This procedure is followed whether the agent has complete information 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 a series of surveillance systems, with no prior experience and told *OK tell me is that aircraft out there friendly, neutral or hostile*. The untrained agents in this situation will simply throw up their hands and guess or toss a three-sided coin.

Experientially-Trained Procedure

In the experiential condition, the agents have historical information on which they base their recommendation. The experientially trained agents are fully-trained agent in the sense that they have previously encountered all possible aircraft and have received feedback on each aircraft. The experientially trained agents follow the decision procedure identified below but they no longer alter their memory. Thus, their expectations remain fixed.

This condition is interesting as it represents agents who are empowered to act on the basis of their own assessment of the situation. Agents proceed as though they are following a historical dominance rule. That is, the agent after having classified an aircraft will make the decision that has been the historically dominant (most often correct in the past). This corresponds to a situation where all the agents placed in front of a series of surveillance systems have extensive prior experience and are told *OK tell me is that aircraft out there friendly, neutral or hostile.* Unlike the untrained agents, who in this situation will simply throw up their hands and guess, 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

In this scenario, 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 friendly, neutral, or hostile. 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 types of aircraft that an agent who can observe three pieces of information is 3^N, such that N is the number of pieces of information that the agent has access to when working on the sub-task.

Training Procedure

During training, each agent sees each of the 19683 possible aircraft, is asked to provide a recommendation, and is given feedback. The decision procedure followed during training is the same as that followed after training, what differs is the information that informs that procedure. 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.

Let us consider how the agent learns. The agent begins knowing nothing, and like the untrained agent previously described will start out by just guessing. As the agent sees each of the possible types of aircraft, his or her memory of the frequency with which that set of problem characteristics is associated with that true outcome is augmented. By the end of training each agent has seen all possible aircraft and has a memory of the frequency with which aircraft of a particular type are friendly, neutral, or hostile. 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, 1991a, 1992).

Decision Procedure

Each agent makes decisions only on the basis of his or her historical experience. The decision procedure varies slightly depending on whether the agent has complete or incomplete information.

Complete Information

When the agent has complete information, the agent first classifies the aircraft on the basis of the characteristics he or she observes. The agent looks up in his or her historical record, how often for that type the true decision was a friendly, neutral or hostile. Let us call, the number of times that, for a particular type, the true decision was "x", the expectation of "x". The decision procedure is described as follows:

If the expectation of a friendly aircraft is greater than the expectation of either a neutral or a hostile aircraft given that sub-task, the agent reports that the aircraft is friendly.

If the expectation of a neutral aircraft is greater than the expectation of either a friendly or a hostile aircraft given that sub-task, the agent reports that the aircraft is neutral.

If the expectation of a hostile aircraft is greater than the expectation of either a friendly or a neutral aircraft given that sub-task, the agent reports that the aircraft is hostile.

If neutral and hostile aircraft are equally likely and both greater than friendly aircraft, then the agent randomly chooses either neutral or hostile aircraft.

If friendly and hostile aircraft are equally likely and both greater than friendly aircraft, then the agent randomly chooses either friendly or hostile aircraft.

If neutral and hostile aircraft are equally likely and both greater than friendly aircraft, then the agent randomly chooses either neutral or hostile aircraft.

If friendly, neutral, and hostile aircraft are equally likely, then the agent randomly chooses either friendly, or neutral, or hostile.

By following this procedure the agent is acting as though it has perfect recall.[11] As the agent has no way to determine the "correctness" of the information, this procedure is followed whether or not the information acquired by the agent is correct. Since the agent can not discriminate between correct and incorrect information, if the information is incorrect then the agent will simply misclassify the aircraft. For example, the agent might think it is looking at an aircraft of type "a" when it in reality is looking at an aircraft of type "b". As a result, the agent recalls the expectations for aircraft of type "a" and not "b", and acts on these.

Incomplete Information

Incomplete information might occur because the radar detection system does not function well, or an analyst is off-line, or a communication channel is broken. When information is incomplete, the agent can not uniquely classify an aircraft. Instead, the agent matches only that information available (partial pattern matching). This may result in the selection of 3 or more types. Then, for each selected type, the agent sums up the expectations of friendly in all types, neutral in all types, and hostile in all types and acts on the basis of the combined expectations following the procedure previously dictated.

Operationally-Trained Scenario

In the operational condition, the agents have standard operating procedures (SOPs) on which they base their recommendation. Agents are considered fully-trained as they have perfect knowledge of the SOP and employ it without error.

This condition is interesting as it represents agents who are expected to mechanically follow accepted procedure. The SOP chosen is such that the agent acting purely on the basis of the criticality of his or her local current information. History, has no effect. The SOP decision procedure is such that agents proceed as though they were following a local dominance rule; i.e., they make the decision that appears most correct given just the agent's current knowledge. This corresponds to a situation where all of the agents are placed in front of a series of surveillance systems, and told *OK report whether that aircraft out there friendly, neutral or hostile.* Unlike either the untrained agent or the experientially-trained agent, the operationally trained agent will say *well, let's plug this data in to the SOP and the answer will pop out.* The agents in this case are following orders blindly, with no apparent concern for the consequences.

Agent's Knowledge

The agent's knowledge consists of current information and the standard operating procedure.

Training Procedure

All agents in the organization are told the standard operating procedure 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 followed is such that the total number of cases is equally divided into three parts. For example, for three pieces of information, the sum of information available to the agent ranges from 3 to 9. If the s 1 is between 3 and 5 the agent is to classify the airc aft as friendly, if 6 as neutral, and if between 7 and 9 it is to be classified as hostile.

3) Make as your recommendation/decision the category into which the sum falls.

In practice, this operating procedure appears slightly different if the agent has complete or incomplete information.

Complete Information

The agent, given information on an aircraft, simply adds the values of all the information, and reports the category into which the sum falls.

Incomplete Information

When information is not complete — due to either missing information, or other agent's unavailability, or communication channel break down — the agent adds the remaining known information and reports the modified category that the sum value falls in. 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 (in this case, the possible decisions 1, 2, and 3 are equally likely).

STRESS

We examine two types of stress — maydays and murphies.

Maydays

Maydays represent crises to the organization. As noted earlier they are stresses external to the organization (such as hostile events). This is similar to the definition of "stress" provided by Staw et al (1981). In this analysis, those aircraft that given a particular task definition are hostile are considered maydays.

Murphies

Murphies represent stresses or crises internal to the organization. As noted earlier they are internal stress (such as communication channel breakdown). Murphies are expected to create internal ambiguity within the organization (March and Simon, 1958). In this paper we examine 5 different types of murphies — missing information, incorrect information, agent unavailability, agent turnover, and communication channel breakdown. These types of murphies were chosen because they are prevalent in real organizations and the vary in terms of whether the represent technology based ambiguity (missing information and incorrect information) or agent based ambiguity (agent unavailability and agent turnover) or ambiguity due to some technology-agent interlink (communication channel breakdown).

In addition, we vary the degree of severity of such murphies. We examine three levels of severity — low (1 murphy occurs), medium (2 murphies occur), and high (3 murphies occur). In reality, during most crises multiple murphies of different types occur. In this paper, in order to examine the differential impact of different types of murphies, only a single type is examined at a time. Thus, even when there are multiple murphies they are all of the same type.

For each organization, the location of the one or more murphies is chosen randomly before each decision cycle. Thus, a technology based murphy is equally likely to occur for each of the 9 task characteristics. And an agent based murphy (or the communication breakdown) is equally likely to occur for each analyst.

Missing Information

Missing information is defined as occurring when one or more of pieces of the incoming information for a particular problem is not available. For example, the altitude of the aircraft may not be detected because certain surveillance equipment is broken.[12]

Incorrect Information

Incorrect information is defined as occurring when incoming information is erroneous, e.g. when the radar system reports an aircraft as being very fast when indeed it is moving slow. This can happen, for example, when some surveillance equipment does not work properly.[13]

Agent Unavailability

Agent unavailability is defined as occurring when one or more analysts is not available to help the organization solve the problem and so does not report his or her decision to his or her manager. Agent unavailability frequently results in erroneous organizational decisions. For example, this can happen when certain operators are sick and unable to be on duty.[14]

Communication Channel Breakdown

A communication channel breakdown is defined as occurring when one or more analysts are unable to report to a superior because the communication channel is unavailable. This can be thought of as a failure in the communication technology, or, as ignorance of the necessity of communication. For example, this can happen when some operators do not report their observations to their superiors.[15]

Agent Turnover

Agent turnover is defined as occurring when one or more analysts leave the organization and are replaced by a new analyst. In this study, new analysts in experientially-trained organization are untrained, and do not learn, and so proceed simply by guessing. Turnover, may be very debilitating. This can happen, for example, when some radar operators are transferred to other places or become a casualty of war, and new operators take over. [16]

PERFORMANCE MEASURES

Performance is defined as the percentage of correct decisions made by the organization given a set of problems presented to the organization. Recall that an organization's decision is considered correct if the final decision made by the organization as to whether the aircraft observed during that time period was friendly, neutral, and hostile matches the true nature of that aircraft given the objective definition. We examine performance relative to two sets of problems — all aircraft and maydays. All aircraft — performance is measured as the percentage of correct decisions made by the organization given all 19683 cases. This measure provides an indicator of the overall organizational performance. Maydays — performance is measured as the percentage of correct decisions made by the organization given all hostile aircraft (recall the number of hostile cases depends on the task). This measure provides an indicator of organizational performance under external stress. Mistakes under this condition have severe repercussions (e.g., the team might lose the war).

EXPERIMENTAL DESIGN

A series of simulations are run in which organizational structures (4), task decomposition schemes (4), training scenario (3), and type of task (4) are varied. Combining these parameters defines 192 unique organizational types. The performance of each organizational type was calculated under both optimal operating conditions (no murphies) and under each of the suboptimal internal stress conditions (one or more murphies). There are 20 such conditions (4 levels of severity, including "no" murphies, and 5 types of murphies). Thus, we examine 192 organizational types under 20 operating conditions (5 optimal and 15 suboptimal) for a total of 3840 cases.

This experiment is for the most part an exercise in numerical estimation. We consider all possible problem scenarios (all aircraft) in each case. The only Monte-Carlo aspect is when there are murphies, the location of each Murphy is randomly chosen each time period.

RESULTS

Baseline

We use as a baseline the case when all agents are untrained (and so act only on their hunches) and are faced with optimal operating conditions (no murphies). Under this circumstance, all organizations (regardless of task, structure, or task decomposition scheme) under all conditions (maydays or murphies) make the correct decision 33.33% of the time. When an agent guesses he or she is equally likely to decide that the aircraft is friendly, neutral or hostile. Thus, the chance of the agent making a correct decision is 1/3. In the team with voting, since majority rule is used, and since there are 9 analysts voting, since the probability of each one giving the correct answer is 1/3 and since all agents are independent, the probability that the overall vote will be correct is also simply 1/3. In all other organization's there is a CEO. For the CEO the input of subordinates to supervisors is irrelevant as the CEO no matter what he or she is told will simply guess. For the untrained organizations stress (either internal or external) does not affect performance.

Had there been only two choices, as in the experimental learning model examined by Carley (1990, 1991a, 1991b, 1992), the baseline performance would have been 50.00%. There are two points here. First, as a baseline, when the organization must choose between a set of options, the minimum acceptable performance is simply 1 over the number of options. Second, any performance, if less than this minimum, is unacceptable as organizational performance could be improved by simply guessing.

General Behavior

Generally, training improves performance (see Table 1).[17] Overall, organizations employing experientially trained agents tend to outperform those employing agents trained to follow SOPs and both outperform organizations where agents are simply guessing. This tends to be true whether the organization is operating under optimal or suboptimal conditions, and whether or not they are faced with maydays. The average performance of all organizations with experiential training (59.93), regardless of the operating conditions is significantly higher than the average performance of organizations with operational training (54.56) ($t=9.4$, $df = 1279$, $p < .001$). Both are significantly higher than the baseline.

Place Table 1 about here

When type of task is considered, experientially trained organizations outperform operationally trained organizations for biased tasks; whereas operationally trained organizations do better on unbiased tasks. Agent experience serves them best when the preponderance of their experience is in the same area (in this case hostile tasks).

Place Table 2 about here

Across all conditions, the top performing experientially trained organization is the team with voting, with a segregated scheme (mean=66.76, stderr=1.79, n=80), and the bottom performing organization is the team with manager with an overlapped scheme (mean=54.69, stderr=2.10, n=80). Across all conditions, the top performing operationally trained organization is the hierarchy with a distributed scheme (mean=56.28, stderr=1.05, n=80), and the bottom performing organization is the hierarchy with a segregated scheme (mean=52.16, stderr=1.20, n=80). Regardless of the type of training, which organizational types appear as the best and worse performers depends on the specific task environment. In fact, for the experiential organization the best performing organization becomes the matrix with a blocked scheme (mean=86.04, stderr=1.05, n=20) when facing biased non-decomposable task, and the worst performing organization becomes the team with manager with a segregated scheme when facing an unbiased non-decomposable task (mean=33.29, stderr=0.65, n=20). Whereas, in the operational organization, the best performing organization becomes the team with manager with a segregated scheme (mean=79.39, stderr=4.07, n=20) when facing an unbiased decomposable task, and the worst performing organization becomes the team with manager with a segregated scheme when facing a biased non-decomposable task (mean=43.01, stderr=0.67, n=20).

Generally, organizations perform better under maydays than they do across all external conditions regardless of the type of training (see Tables 1 and 2). This is good news for managers, as it suggests that when it really matters organizations will benefit from the effort they have expended on training. Organizations that employ experientially trained personnel, under optimal operating conditions, can exhibit perfect performance when faced with maydays. For example, in the most realistic environment (biased, non-decomposable) as long as the organization does not have a blocked task decomposition scheme the experientially trained organization makes the right decision every time (mean=100.00, stderr=0.00, n=20). However, if the organization employs operationally trained personnel, the same organizational structure (e.g., a team with a manager and a segregated task decomposition scheme) may exhibit much worse performance (mean=42.28, stderr=0.86, n=20) even given the same task environment.

Finally, on average, as the number of simultaneous murphies increases organizational performance degrades (see Figure 5[18]). This degradation is non-linear. Also, when the organization is operationally trained and the task is biased then the occurrence of a single murphy may actually improve performance. For experientially trained organizations, murphies on average degrade performance (optimal conditions mean = 62.18, stderr=0.96, n=320 and suboptimal conditions mean = 59.18, stderr=0.55, n=960). This difference is significant ($t = 2.71$, $df = 319$, $p < .005$). Similarly, for operationally trained organizations, murphies degrade performance (optimal conditions mean=57.29, stderr=0.75, n=320 and suboptimal conditions mean=53.66, stderr=0.33, n=960). This difference, too, is significant ($t = 4.43$, $df = 319$, $p < .0005$). When faced with maydays, murphies also degrade organizational performance (optimal conditions mean=96.63, stderr=0.43, n=320 and suboptimal conditions mean=91.30, stderr=0.43, n=960). This difference is significant ($t = 9.10$, $df = 319$, $p < .0005$). Similarly, for operationally trained organizations, murphies degrade performance (optimal conditions mean=72.92, stderr=0.98, n=320 and suboptimal conditions mean=68.98, stderr=0.51, n=960). This difference is significant ($t = 3.94$, $df = 319$, $p < .0005$). Experientially trained organizations under suboptimal conditions, across all external conditions and when faced with maydays, outperform operational organizations under optimal conditions. As a final point, particularly for the experiential organization, type of task environment has a stronger effect on performance than does the number or type of murphies, which is also shown in Table 2.

Place Figure 5 about here

In summary, we have observed four general patterns: training improves performance, empowering agents to follow their experience rather than SOPs leads to better performance, organizations faced with maydays exhibit better performance than they do across all external conditions, and as the number of murphies increases performance decreases. These particular patterns tend to be true regardless of the task environment. However, the specific level of performance and which organization performs best or worse when varies with the task environment.

Murphies

In general, technologically based murphies are more debilitating than are people based murphies (see Figure 6[19]). Mis-information is thus worse for the organization than communication breakdowns. However, if the organization is experientially trained then agent turnover, on average, degrades the performance most from performance under optimal conditions (mean=56.10, stderr=1.09, n=256). In operationally trained organizations turnover has less effect and incorrect information degrades the performance the most from performance under optimal conditions (mean=49.80, stderr=0.60, n=256).

A similar pattern emerges under maydays. Technologically based murphies are still generally more debilitating than are people based murphies (see Figure 6). Although, if the organization is experientially trained agent can be as bad or worse than technologically based murphies. Further, if the task is biased and decomposable, then turnover has the biggest effect on the experiential organization. When faced with maydays the organization may find murphies to have a greater affect than they do across all external conditions. Thus while task type is important generally in dictating performance level, under maydays murphies may appear more important.

Place Figure 6 about here

Design

General behavior

The following four figures show how organizations with different structures and task decomposition schemes perform under optimal operating conditions[20]. We first consider experientially trained organizations. On average (across all external conditions) the team with voting structure generally exhibits the highest level of performance, particularly when the task is unbiased (Figure 7). When the task is non-decomposable, organizations with blocked or distributed task decomposition schemes outperform organizations with less redundant schemes. This suggests that when the task requires integration of information redundancy in information access helps. In this sense, individuals are better than the organization at integrating information.

*** Place Figure 7 about here ***

Now consider the operationally trained organization under the same conditions (Figure 8). In this case the team with voting is still one of the better performing organizations. However, as can be seen by contrasting Figure 7 and 8, the performance in operationally trained organizations is lower. Operational training tends to decrease differences due to organizational structure and task decomposition scheme. This can be seen in the relative flatness of the drawings in Figure 8 as compared tot hose in Figure 7. Training personnel to follow SOPs thus reduces the reliance of the organization on its structure and scheme. This is particularly important for organizations that might expect to have rapidly changing designs such as might occur in response to rapid turnover. If such an organization follows SOPs then switching design may cause less damage in performance than if the organization allows the agents to follow their own historical information.

*** Place Figure 8 about here ***

So far we have been considering performance overall What happens if the organization is faced with maydays? In this case, in the experiential organization (Figure 9) organizational performance has improved to the point where the exact structure and task decomposition scheme chosen are less critical. In fact, in the simplest task, the biased decomposable task, all organizations do perfectly. Otherwise, organizational designs with more redundancy, either in structure or scheme, tend to be slightly better performers. Contrasting Figures 7 and 9 we see that while such redundancy may be a hindrance on average it helps in the critical cases. Such redundancy reduces performance on average due to the collapse in information in the more hierarchical structures and due to the potentially greater disagreement in opinions in the more redundant schemes. When faced with maydays, however, the incoming information is in a sense more consistent. Thus, there is less difference in information to get collapsed away by the structure and less possibility of disagreement in opinions particularly when the scheme is more redundant. Where redundancy works against the organization on average it works for it in the case of external crises.

*** Place Figure 9 about here ***

For the operational organization faced with maydays (Figure 10) redundancy is less important. As in the overall case (Figure 8) following SOPs reduce reliance on organizational design. However, following SOPs also reduce the benefits that the organization can derive from redundancy when the organization is faced with maydays. When SOPs must be followed, decreased differences in information are less important to the organization.

*** Place Figure 10 about here ***

In general, organizations perform better when facing maydays than they do on average. The organization with a team with voting structure and a segregated task decomposition scheme outperforms other organizational forms in general. But when faced with maydays or when operationally trained, organizations with matrix structure and distributed task decomposition scheme generally perform better. Under optimal operating conditions (no murphies) teams with voting outperform other structures as long as the task is unbiased and decomposable, which suggest such organizational structure may be better to balance all the factors and make less biased decisions. This confirms the result reported by Carley (1991a,1992). Further, this is true whether the organization is employing decision makers who make decisions following their own experience (Table 3) or SOPs (Table 4). However, as can be seen in Tables 3 and 4, teams with voting are not better in all circumstances. In fact, in what one might consider the most common real world situation, a biased non-decomposable task environment, teams with voting exhibit the worst performance. As a final point in examining Tables 3 and 4, it appears that under maydays organizations to exhibit high performance require slightly more management and a more complex task decomposition structures unless the task is one of the simpler tasks — the unbiased decomposable task. For this task the simplest organizational form teams with voting, with segregated scheme appear to be the best performer. These findings suggest that there may be a relationship between complexity and performance.

Place Tables 3 and 4 about here

Complexity

Given the organizational structure and the task decomposition scheme, 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 tasks. We define organizational complexity as: (a) simple organization — an organization with either a team with voting or a team with a manager structure and a segregated or an overlapped task decomposition scheme; (b) complex organization — an organization with either a hierarchical or a matrix structure and a blocked or a distributed task decomposition scheme; (c) moderate organization — all other organizations.

Task complexity is defined by its decomposability and biasness. A biased task is simpler than an unbiased one and a decomposable task is simpler than a non-decomposable one. Thus, we also have three levels of complexity for task: (a) simple task -- a biased decomposable task; (b) complex task -- an unbiased non-decomposable task; (c) moderate task -- all other tasks.

Using these measures, we can determine whether there is a match between the organizational complexity and task complexity. A poor match occurs if an organization is complex and a task is simple, or if an organization is simple and a task is complex; a perfect match occurs if an organization is simple and a task is simple, or if an organization is complex and a task is complex, or if an organization is moderate and a task is moderate; a moderate match occurs in all other cases.

The average performance at each level of match between organizational complexity and task complexity is shown in Table 5. The result indicates that overall, performance improves as the level of match increases. Complex organizations tend to help organizational performance when facing complex tasks and simple organizations tend to help organizational performance when facing simple tasks, regardless of training scenario. This confirms the observation by Staw et al. (1981). However, we find that the opposite is true in one case -- when the organization is operationally trained and facing maydays. This indicates that for operationally trained organizations, some redundancy in structure helps organizational decision making performance under hostile external conditions.

Place Table 5 about here

DISCUSSION

In this analysis we have focused on performance under friendly external conditions, as we treat type I and type II errors as being equally important. Under friendly external conditions (bias toward friendliness), organizational performance would tend to have a complementary pattern as hostile external conditions. In this sense, friendly and hostile conditions are mirror conditions in our model.

While we have begun to examine the effect of training we have limited ourselves to training that was largely "helpful". That is, agents were trained in the same type of organization for which their performance was measured and the SOPs were generally of the "right" type. Nevertheless, this model does indicate that organizations where agents received the wrong training may actually perform worse than totally untrained organizations. For example, organizations trained for a biased task when faced with friendly aircraft can do better by just guessing. This suggests, for example, that radar groups trained during peacetime, on predominantly civilian aircraft, when put in a combat situation may actually do worse than a group who never trained. This suggests that training does not 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 they were faced with a non-mayday. Our model would predict they are likely to make a mistake — which they apparently did. To investigate this issue of the extent to which training transfers between situations a more realistic model of human problem solving and memory may be needed.

A third caveat is that this study proceeded by using a stylized radar task, numerical enumeration, and computer simulation. Compared with experiments using human subjects, computer simulations are easier to control, more flexible, more objective, with less noise, and thus can examine more factors within less time. As pointed out by Ostrom (1988), computer simulation offers a third symbol system in studying social science, besides natural language and mathematics, because "computer simulation offers a substantial advantage to social psychologists attempting to develop formal theories of complex and interdependent social phenomena". Computer simulations are limited by the simplified assumptions, as well as the computer technologies. Such simulations do not always capture difference due to individual cognition. Thus, when facing a task requiring more subjective judgments, our model may need to be modified. Nevertheless, these simulation experiments provide a series of hypotheses which we can test both with human experiments and by using real organizational data. Since human experiments are costly to run, and it is often difficult to obtain large quantities of data on real organizations, these simulation experiments help us develop organizational theory and determine which parameters are most important to explore in other settings.

Finally, there are several interesting issues that are suggested by our analyses that are not addressed in this paper. First, different training orientations such as training for friendly environments may affect performance. Thus, it would be important to develop a better understanding of how training in situation "x" affects performance in situation "y". Second, it is often suggested that organizations when faced with external crises or maydays, should restructure themselves. This study does suggest that the structure that is best under maydays may not be the best in general; however, it does not provide insight into whether the process of shifting structures would degrade organizational performance. Further studies should examine whether this restructuring is beneficial given that personnel were trained on the old (non-mayday) structure. Third, it is often shown that under time pressure, performance degrades. In this study the aircraft examined were effectively holding still and so time pressure was not an issue. Further studies should examine how time pressure will affect the performance of organizations given the presence of murphies and maydays. Finally, many measures of organizational design have been proposed which are expected to be able to predict organizational performance (e.g., Mackenzie, 1978; Krackhardt, 1989). Rarely have they been tested and contrasted. The formal framework we used in this paper provides a testbed for doing this. We are engaged currently in a study using this framework to examine how well these measures are able to predict performance (Lin and Carley, 1991).

CONCLUSION

We have considered the inter-relationship between organizational design, task, and stress relative to organizational performance. These results confirm those found by Carley (1991a, 1992): training improves performance, the greater the severity of the internal crisis (more murphies) the lower the performance, turnover degrades performance, misinformation leads to lower performance than communication breakdowns, and teams outperform hierarchies. Such replication indicates that such results are a product of the organizational design and environment and not the number of choices available to the agents when making decisions. However, our results do more than just replicate these earlier studies. They also place these earlier results in a broader context and show limitations to these findings. Let us consider two of these — that turnover degrades performance and that teams outperform hierarchies.

Turnover degrades performance, but the effect may be minimal and even appear non-existent when agents are trained to follow SOPs. In experientially trained organizations, turnover can be even more debilitating than technological murphies. However, in an operationally trained organization turnover matters less. Thus, organizations which can not rely on SOPs should expand more effort to retain personnel, and to hire trained personnel. Organizations that employ SOPs need to worry less about personnel relations.

As to the second point, teams outperform hierarchies — but they do so predominantly when the task is unbiased decomposable. In a biased task, when one outcome is more likely than others, or a non-decomposable task, when the interrelationship between information is complex, more complex organizational structures outperform teams. We found that, in general, when facing complex tasks, complex organizations tend to help performance, but when facing simple tasks, simple organization tend to help performance instead, regardless of external stress and training scenarios. However, when the organizations face maydays the opposite seems to be the case. These results suggest that task complexity and external situation are stronger determinants of performance than either organizational design or murphies. Thus, the organization should first expend effort determining what tasks and external situations they are likely to face before settling on a particular organizational design or expending effort to minimize murphies.

A number of other policy implications can be drawn from these results. Let us consider a few of these. While turnover, and other murphies, can degrade organizational performance, the effect depends on the type of training received by organizational members. In general, technological murphies are more debilitating than agent based murphies, which means most organizations with limited budget should spend resources to get the information right in the first place. As the number of simultaneous murphies increases, organizational performance decreases, unless organizational members are trained to follow SOPs and are facing a biased task. This result suggests that more information does not necessarily help organizational performance, in fact, under certain conditions, organizations can benefit from less information. For biased tasks, experientially trained organization exhibit higher performance than operationally trained organizations overall, and the opposite for unbiased tasks overall. Thus, in general, organizations that are unsure of the environment (i.e., don't know if it is biased or unbiased) should not use SOPs, but should experientially train their employees as this admits maximum adaptation. If the organization knows the environment, then an appropriate SOP is generally better. But, if the organization expects and needs high reliability during maydays, then SOPs generally are less risky as an incorrect experiential training may severely hurt organizational performance.

This study addresses many important policy issues. First, this study shows that it is important to evaluate the procedure and purpose of training. Training may be a waste of time or even hurt organizational performance without being properly guided. Second, this study demonstrates that more information does not always result in better decisions. Rather, decision making performance depends on the training procedure, the location of communication links, and the task characteristics. Thus, organizations should be very careful expanding or altering their organizational or task decomposition structures during crisis situations. Third, this study suggests that there is a strong relationship between stress and organizational design. Organizations should determine what type of stress most affects their performance before spending money to alleviate stress, as many types of stress will have little impact. Fourth, this study indicates that task is extremely critical in the determinants of organizational decision making performance, and that for different tasks, organizations should be designed accordingly to be most effective.

Our results support the idea that the best design is contingent. However, we have also demonstrated that by using a framework containing elements of open system theory, structuralism, resource dependency, and institutionalism we can begin to place limits on when what type of design is most effective. We find that the environment places limits on performance that no design can overcome and that major performance improvements can often be achieved only by changing the nature of the environment in which the organization operates.

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[1]Though there has been other version of the incident recently, we still use this version to illustrate the point to be addressed in this paper.

[2]Lin and Carley (1991) also tested and contrasted the predictability of existing measures of organizational design. They found that no single measure predicted performance well under all conditions.

[3] 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 non-decomposable 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.

[4]For the unbiased decomposable task the categorization scheme shown in Figure 2 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 enabled the number of problems in each category to be more close to one third of the total problems.

[5] 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.

[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.

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

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

[11] 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 used perfect recall, and slightly lower than when they used SOPs. The particular performance of organizations with different structures and task decomposition schemes was essentially just scaled down.

[12] Missing information is a problem for many organizations. For example, in China, lack of information on the date and amount of rain in the 1991 season left the land unprepared. The countryside was devastated by the unexpected flood.

[13] Incorrect information frequently results in costly mistakes. For example, the failure of the Nazi Germans on D-day was due, at least in part, to their "information" that Caray was the place the Allies would invade instead of Normandy. Incorrect information detected by the allied troops is also, at least partially, why friendly fire resulted in the cause of the one in four casualties during the Gulf war.

[14] For example, the Americans were unprepared when the Japanese attacked Pearl Harbor, in part, because some officers were on leave.

[15]Prior to the Challenger accident (Rogers at al., 1989) there was communication breakdown between the contractor Thiokol and NASA management, resulting in information about the O_ring failing to be communicated. Communication breakdowns are also quite common in war-time when military units

must remain radio silent in order to preserve their secrecy.

[16] For example, in the chemical explosion disaster in Flixborough, Britain in 1974 (Lagadec, 1981) a new technician, who had little experience dealing with chemicals, was virtually unable to handle the situation and his lack of experience accelerated the disaster.

[17]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 maydays. The results demonstrated that training can degrade performance below guessing. An organizations whose members were trained in this way can perform even worse than an organization of untrained agents.

[18]For detailed data see the Appendix. Figure 5 is based on Table A1.

[19]For detailed data see Tables A2, A3, A4, and A5 in Appendix.

[20]We also have figures showing performance under murphies. The performance is flatter, which indicates that though murphies generally degrade organizational performance, under certain conditions murphies may also help organizational performance, such as in the case of missing information when an organization is operationally trained.

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APPENDIX

Table A1: Organizational Performance by Number of Murphies

Training Type	External Condition	Murphy Number=0	Murphy Number=1	Murphy Number=2	Murphy Number=3
Experientially Trained	Overall	62.18(0.96)	60.47(0.93)	59.27(0.94)	57.79(0.97)
	Maydays	74.91(2.18)	71.64(2.13)	69.53(2.12)	67.27(2.10)
Operationally Trained	Overall	57.29(0.75)	55.29(0.56)	53.79(0.55)	51.89(0.56)
	Maydays	85.67(0.67)	83.39(0.66)	80.83(0.70)	77.40(0.77)

Note: n=320 in each cell. Standard errors are in parentheses.

Table A2: Performance of Experientially Trained Organizations across all External Conditions by Task Environment and Murphy Type

Task Environment	Missing Information	Incorrect Information	Agent Unavailability	Communication Breakdown	Agent Turnover
Unbiased Decomposable	50.79 (1.47)	47.38 (1.36)	52.16 (1.53)	52.13 (1.54)	48.93 (1.64)
Unbiased Non-decomposable	45.74 (1.17)	44.31 (1.04)	47.97 (1.16)	47.86 (1.18)	41.90 (1.31)
Biased Decomposable	61.04 (0.38)	60.84 (0.33)	61.81 (0.50)	61.64 (0.50)	55.49 (1.04)
Biased Non-decomposable	85.04 (0.14)	84.67 (0.15)	85.39 (0.21)	85.39 (0.21)	78.06 (1.44)

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

Table A3: Performance of Operationally Trained Organizations across All External Conditions by Task Environment and Murphy Type

Task Environment	Missing Information	Incorrect Information	Agent Unavailability	Communication Breakdown	Agent Turnover
Unbiased Decomposable	68.15 (1.05)	60.49 (1.51)	71.34 (0.83)	71.93 (0.78)	77.81 (1.14)
Unbiased Non-decomposable	51.93 (0.57)	47.43 (0.85)	55.50 (0.34)	55.75 (0.35)	56.22 (0.31)
Biased Decomposable	47.45 (0.18)	45.03 (0.35)	48.33 (0.15)	48.52 (0.15)	47.80 (0.20)
Biased Non-decomposable	46.84 (0.47)	46.23 (0.47)	48.59 (0.37)	48.60 (0.37)	47.33 (0.49)

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

Table A4: Performance of Experientially Trained Organizations by Task Environment and Murphy Type When Faced with Maydays

Task Environment	Missing Information	Incorrect Information	Agent Unavailability	Communication Breakdown	Agent Turnover
Unbiased Decomposable	85.62 (1.50)	82.59 (1.77)	91.83 (1.06)	91.99 (1.07)	78.15 (2.31)
Unbiased Non-decomposable	95.19 (0.92)	90.25 (1.39)	94.52 (1.15)	94.47 (1.16)	79.58 (2.08)
Biased Decomposable	99.44 (0.12)	98.69 (0.26)	99.17 (0.32)	99.23 (0.33)	81.54 (2.47)
Biased Non-decomposable	99.99 (0.01)	99.48 (0.17)	99.98 (0.01)	99.98 (0.01)	90.86 (1.87)

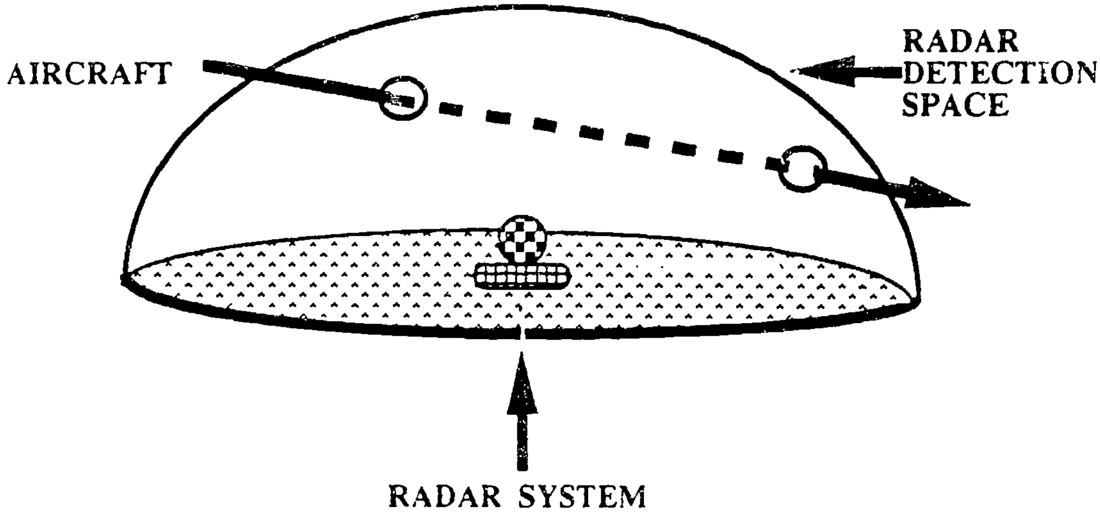
Note: There are 64 types of organizations in each cell. Standard errors are in parentheses.

Table A5: Performance of Operationally Trained Organizations by Task Environment and Murphy Type When Faced with Maydays

Task Environment	Missing Information	Incorrect Information	Agent Unavailability	Communication Breakdown	Agent Turnover
Unbiased Decomposable	83.61 (1.01)	75.20 (1.57)	89.67 (0.64)	90.25 (0.61)	92.97 (0.51)
Unbiased Non-decomposable	76.12 (0.82)	69.91 (1.17)	80.81 (0.56)	81.24 (0.58)	81.37 (0.56)
Biased Decomposable	65.80 (0.85)	61.17 (1.00)	70.49 (0.66)	70.91 (0.67)	69.62 (0.83)
Biased Non-decomposable	47.10 (0.61)	46.57 (0.61)	49.37 (0.48)	49.36 (0.48)	47.71 (0.62)

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

Figure 1. Stylized Radar Task


AIRCRAFT
RADAR DETECTION SPACE
RADAR SYSTEM

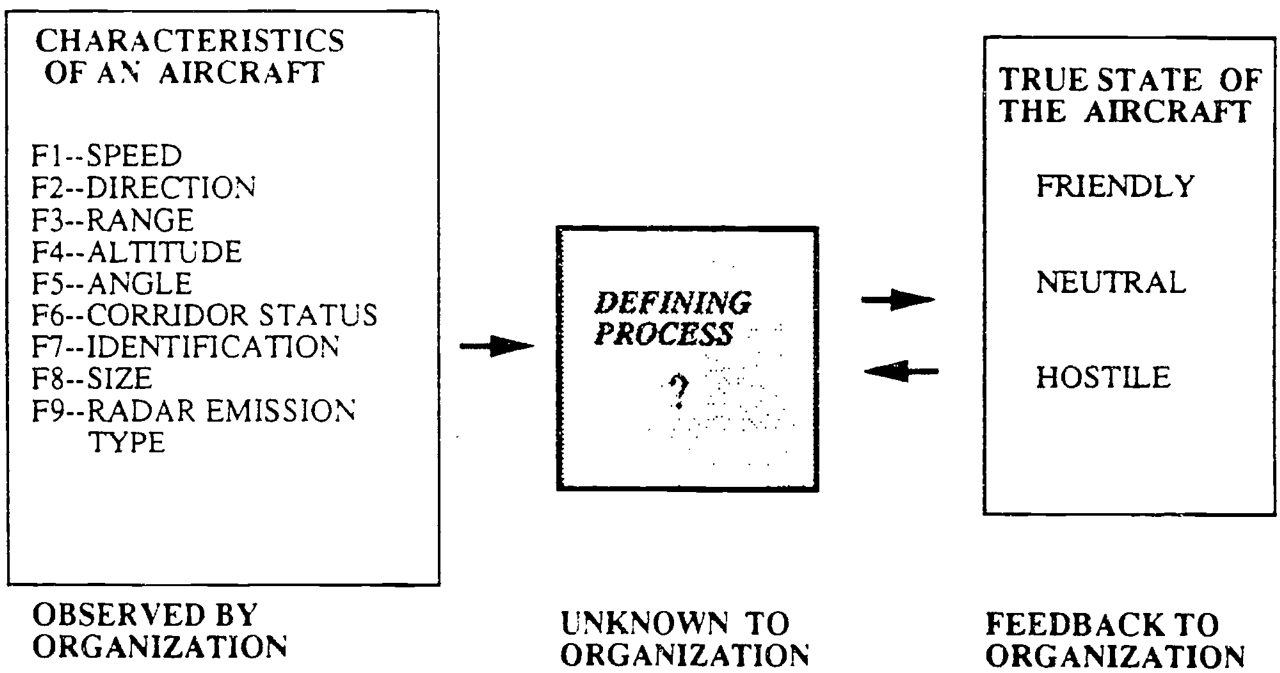

CHARACTERISTICS OF AN AIRCRAFT
F1--SPEED
F2--DIRECTION
F3--RANGE
F4--ALTITUDE
F5--ANGLE
F6--CORRIDOR STATUS
F7--IDENTIFICATION
F8--SIZE
F9--RADAR EMISSION TYPE
DEFINING PROCESS
?
TRUE STATE OF THE AIRCRAFT
FRIENDLY
NEUTRAL
HOSTILE
OBSERVED BY ORGANIZATION
UNKNOWN TO ORGANIZATION
FEEDBACK TO ORGANIZATION

Figure 2. Task Environments

TASK ENVIRONMENT

Unbiased Decomposable

$SUM = F1+F2+F3+F4+F5+F6+F7+F8+F9$

If $9 <= sum <= 16$ then aircraft is friendly
If $17 <= sum <= 19$ then aircraft is neutral
If $20 <= sum <= 27$ then aircraft is hostile

Unbiased Non-Decomposable

$SUM = 2*F1*F2*F3+2*F4*F5+F6+F7+2*F7*F8*F9$

If $8 <= sum <= 33$ then aircraft is friendly
If $34 <= sum <= 49$ then aircraft is neutral
If $50 <= sum <= 132$ then aircraft is hostile

Biased Decomposable

$SUM = F1+F2+F3+F4+F5+F6+F7+F8+F9$

If $9 <= sum <= 13$ then aircraft is friendly
If $14 <= sum <= 17$ then aircraft is neutral
If $18 <= sum <= 27$ then aircraft is hostile

Biased Non-decomposable

$SUM = 2*F1*F2*F3+2*F4*F5+F6+F7+2*F7*F8*F9$

If $8 <= sum <= 29$ then aircraft is friendly
If $21 <= sum <= 23$ then aircraft is neutral
If $24 <= sum <= 132$ then aircraft is hostile

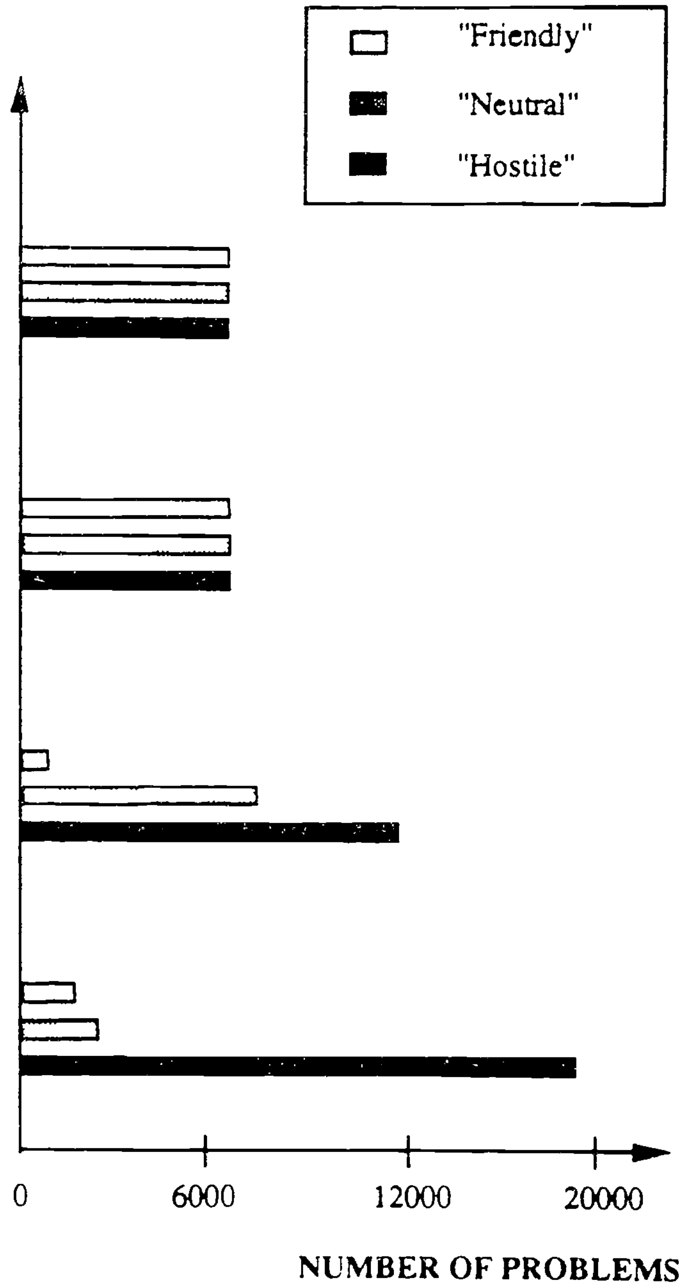
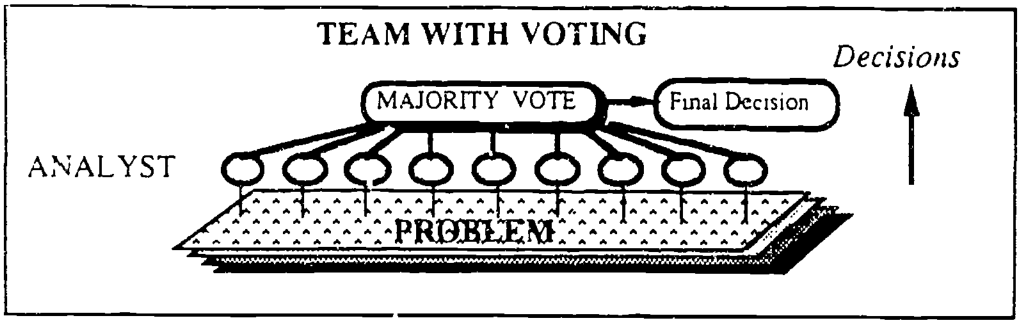
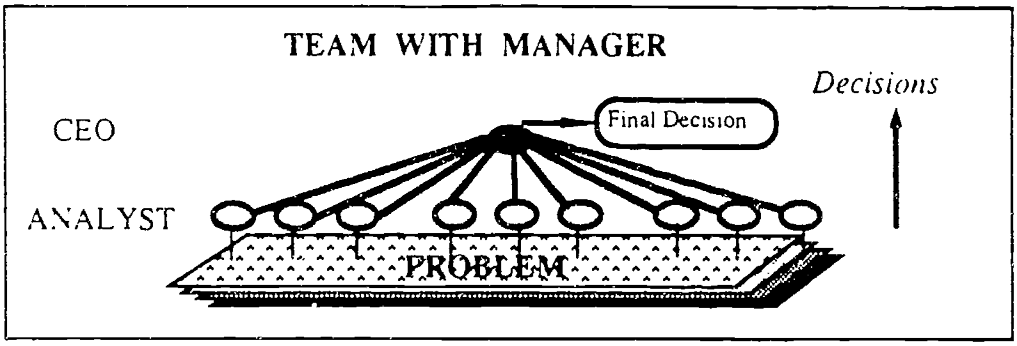
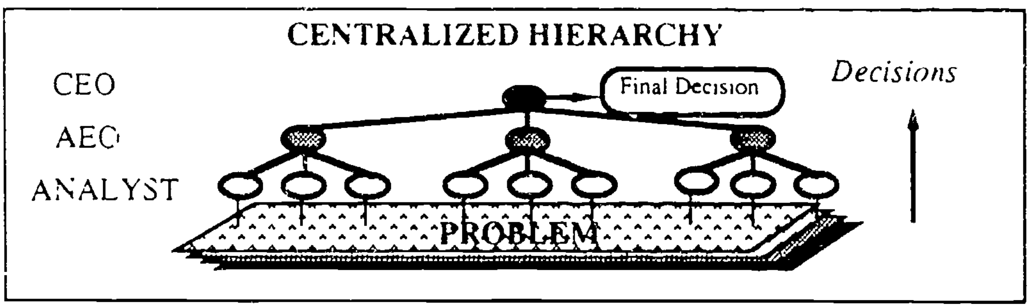


Figure 3. Organizational Structures


TEAM WITH VOTING
Decisions
MAJORITY VOTE
Final Decision
ANALYST
PROBLEM


TEAM WITH MANAGER
Decisions
CEO
Final Decision
ANALYST
PROBLEM


CENTRALIZED HIERARCHY
CEO
AEO
ANALYST
Final Decision
Decisions
PROBLEM

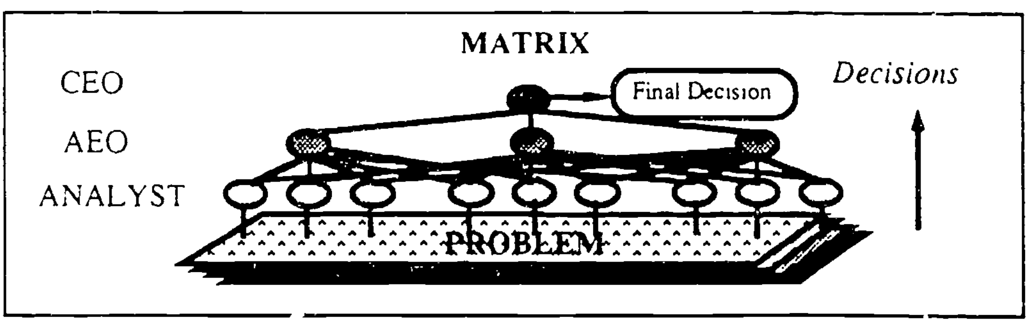

MATRIX
CEO
AEO
ANALYST
Final Decision
Decisions
PROBLEM

Figure 4. Task Decomposition Schemes

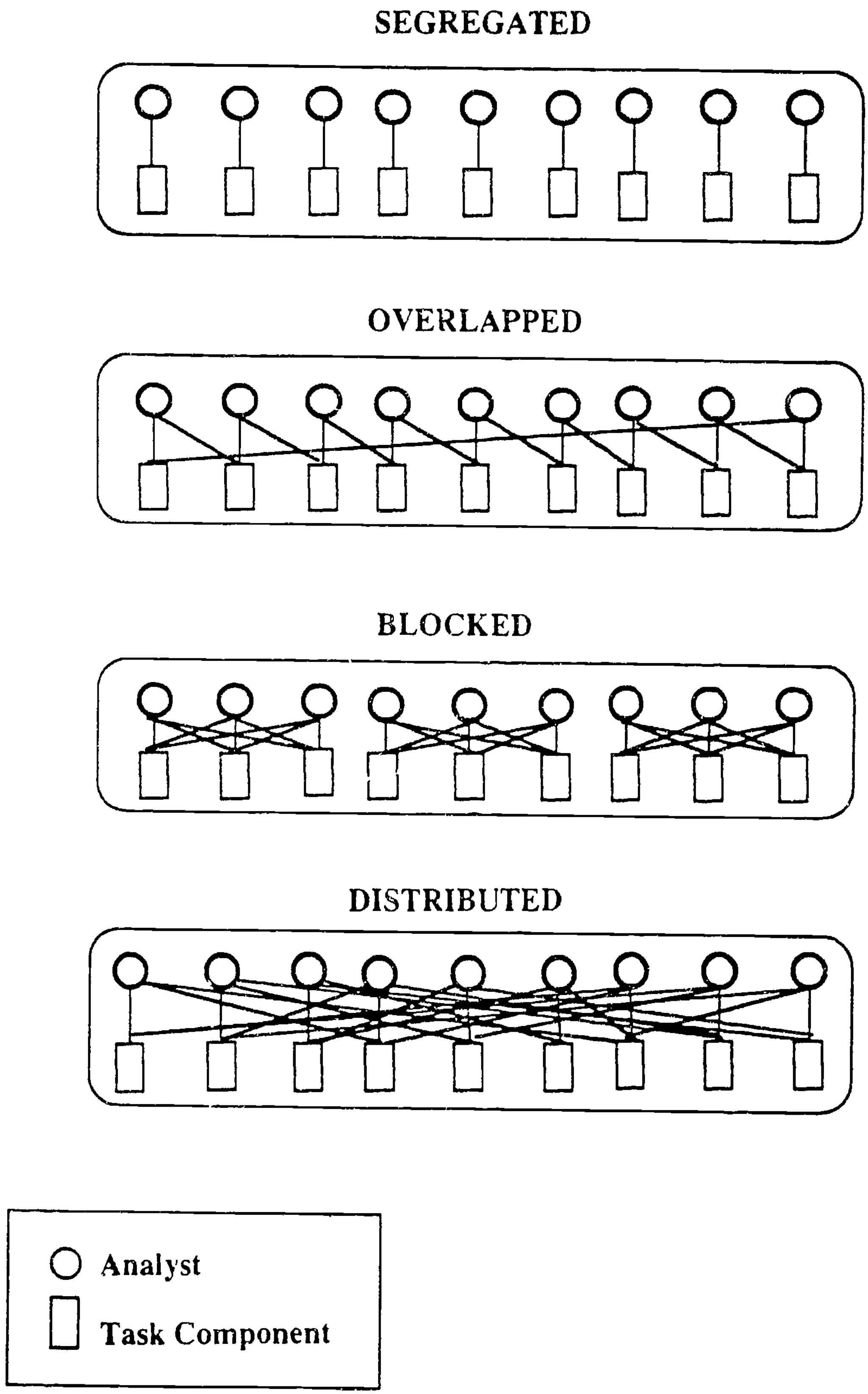

SEGREGATED
OVERLAPPED
BLOCKED
DISTRIBUTED
Analyst
Task Component

Figure 5. Organizational Performance by Number of Murphies

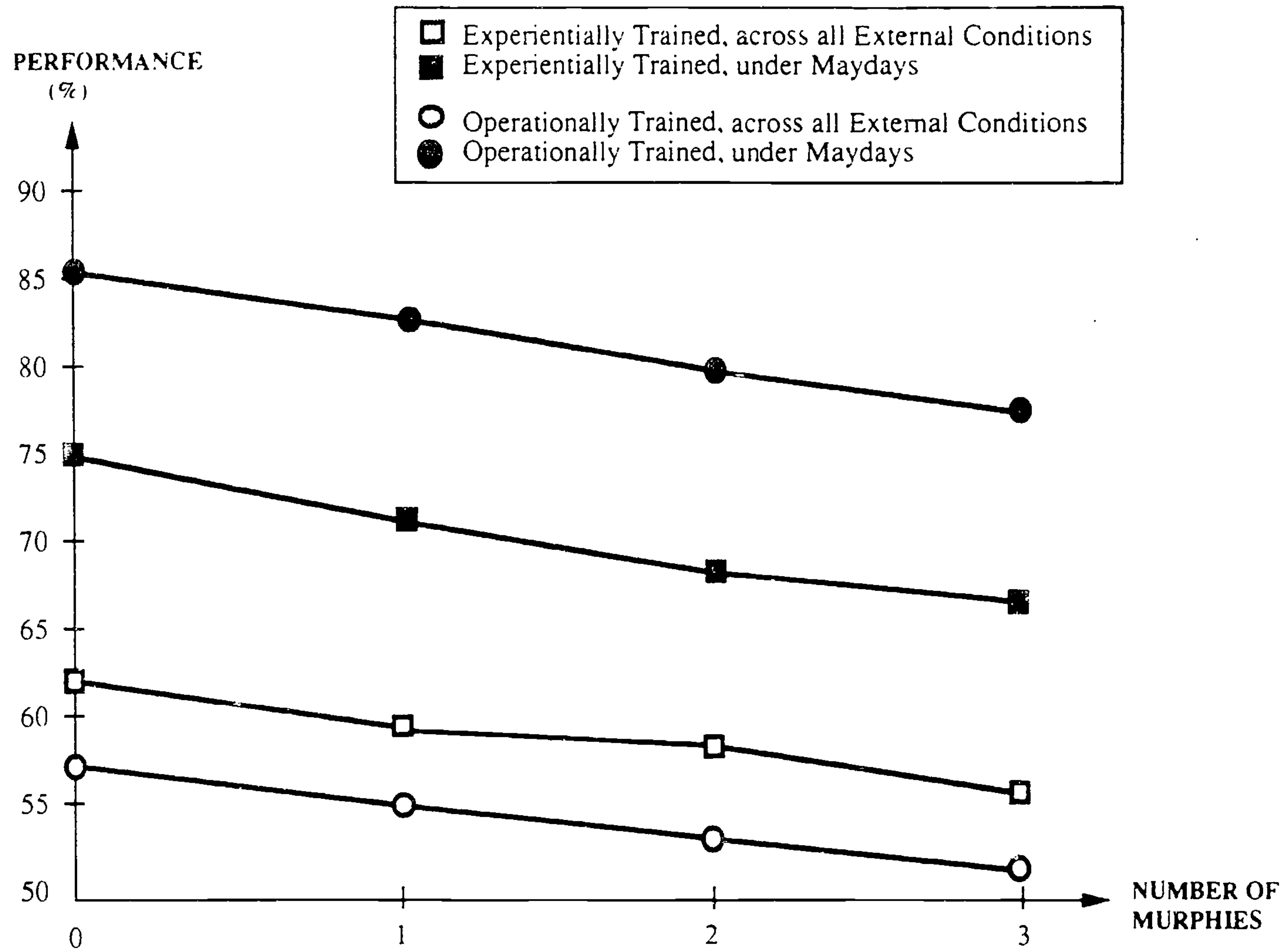
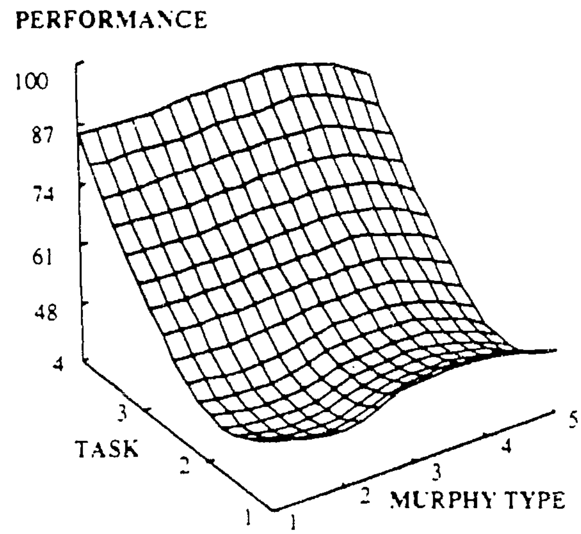
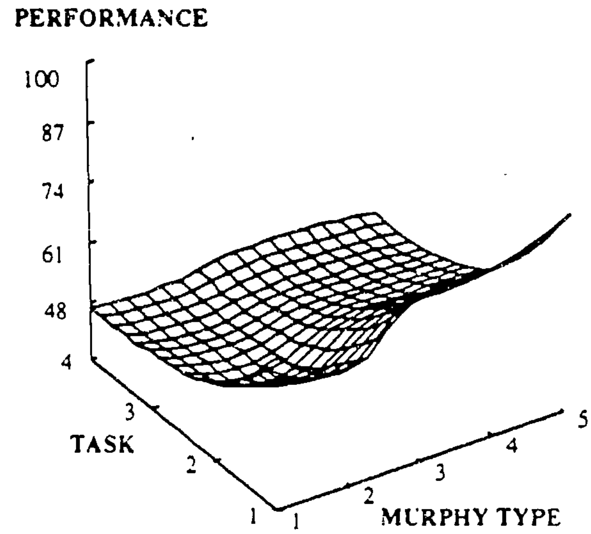

Experientially Trained, across all External Conditions
Experientially Trained, under Maydays
Operationally Trained, across all External Conditions
Operationally Trained, under Maydays
PERFORMANCE (%)
90
85
80
75
70
65
60
55
50
0
1
2
3
NUMBER OF MURPHIES

Figure 6. Organizational Performance by Task Environment and Murphy Type

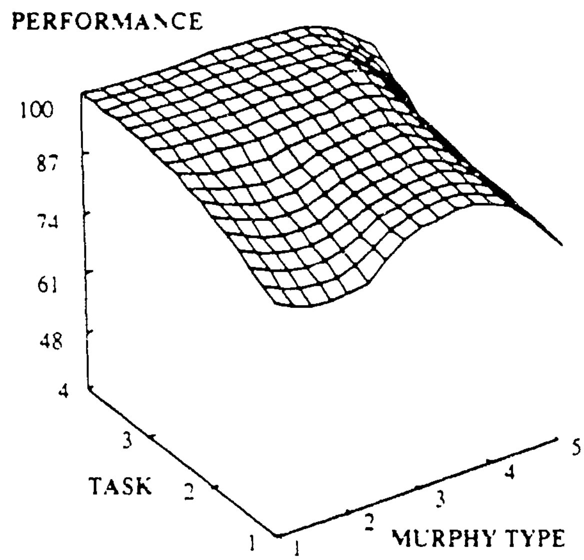
EXPERIENTIALLY TRAINED
ACROSS ALL EXTERNAL CONDITIONS



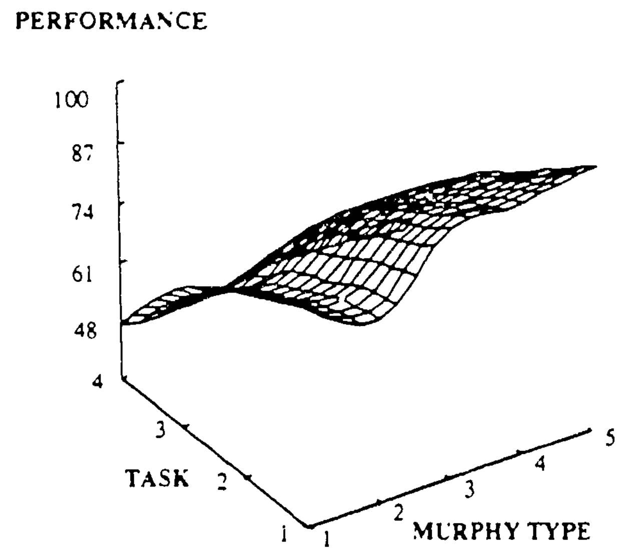
OPERATIONALLY TRAINED
ACROSS ALL EXTERNAL CONDITIONS



EXPERIENTIALLY TRAINED UNDER MAYDAYS

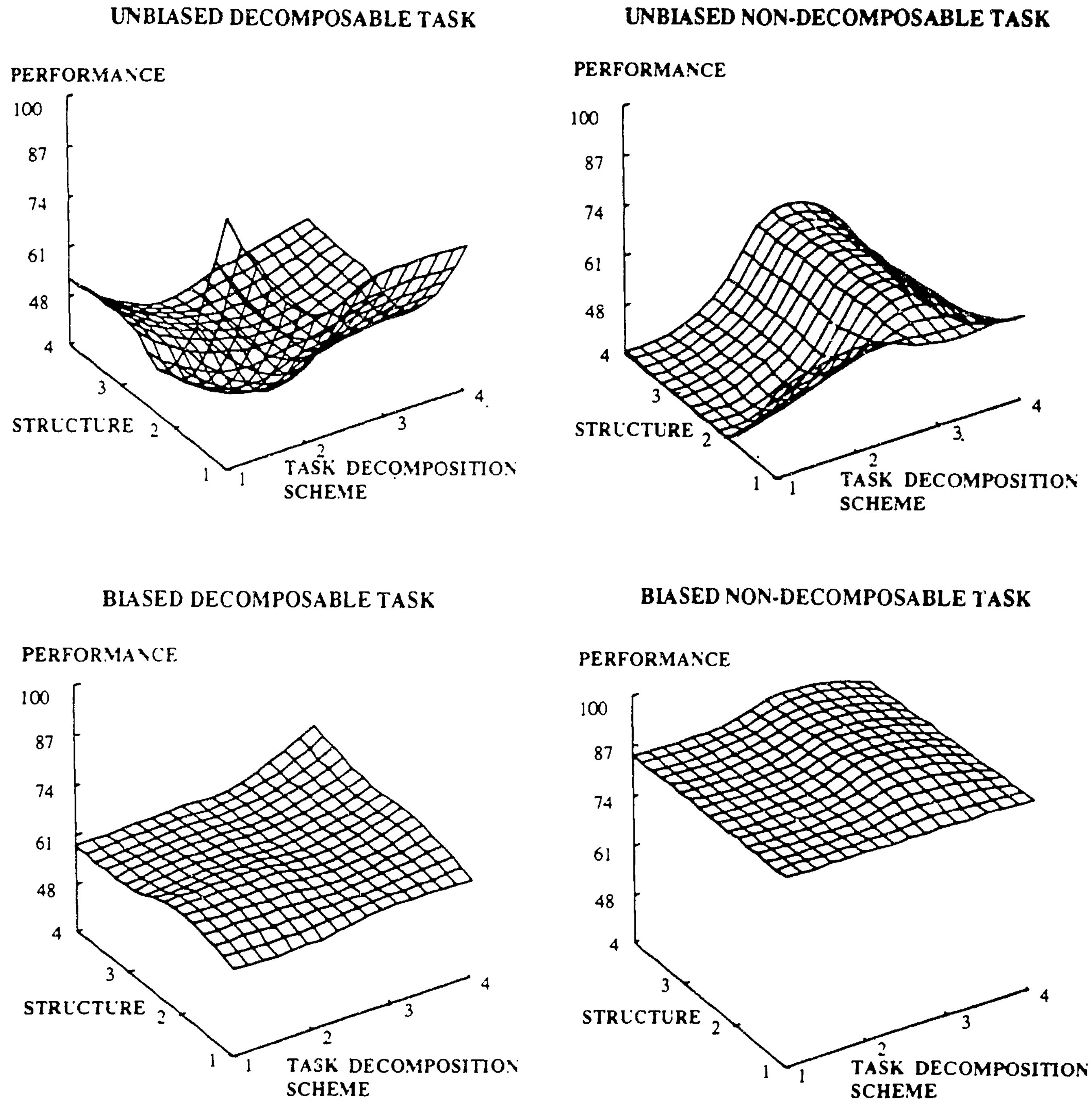


OPERATIONALLY TRAINED UNDER MAYDAYS



TASK	MURPHY TYPE
1--UNBIASED DECOMPOSABLE	1--MISSING INFORMATION
2--UNBIASED NON-DECOMPOSABLE	2--INCORRECT INFORMATION
3--BIASED DECOMPOSABLE	3--AGENT UNAVAILABLE
4--BIASED NON-DECOMPOSABLE	4--COMMUNICATION CHANNEL BREAKDOWN
	5--AGENT TURNOVER

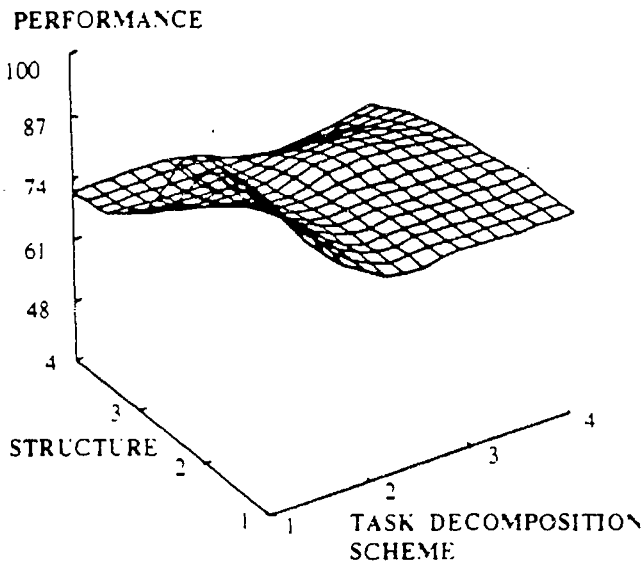
Figure 7. Average Performance of Experientially Trained Organizations under Optimal Operating Conditions



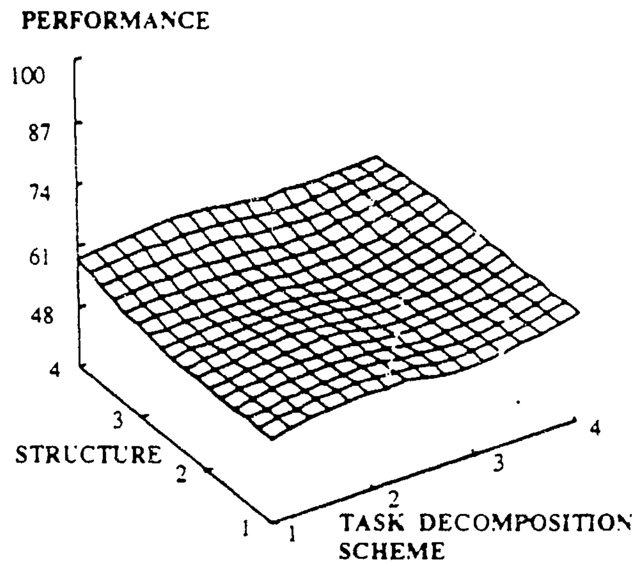
STRUCTURE	TASK DECOMPOSITION SCHEME
1--TEAM WITH VOTING	1--SEGREGATED
2--TEAM WITH A MANAGER	2--OVERLAPPED
3--HIERARCHY	3--BLOCKED
4--MATRIX	4--DISTRIBUTED

Figure 8. Average Performance of Operationally Trained Organizations under Optimal Operating Conditions

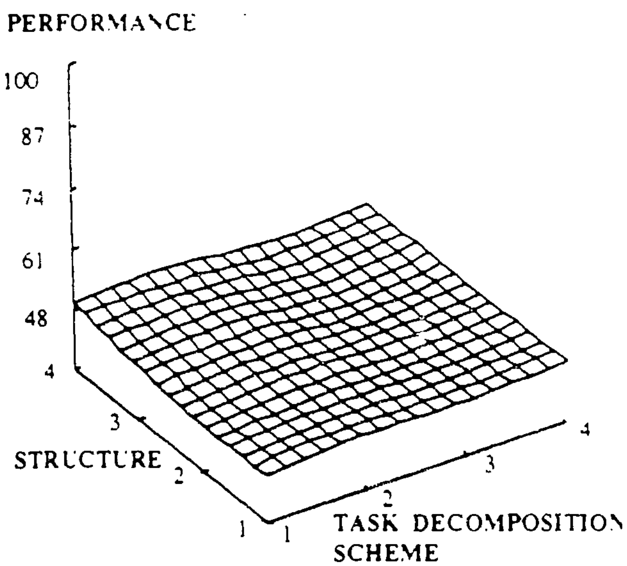
UNBIASED DECOMPOSABLE TASK



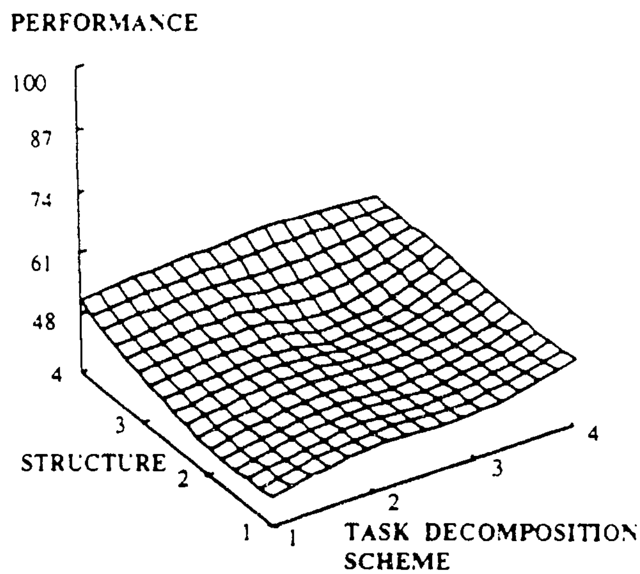
UNBIASED NON-DECOMPOSABLE TASK



BIASED DECOMPOSABLE TASK



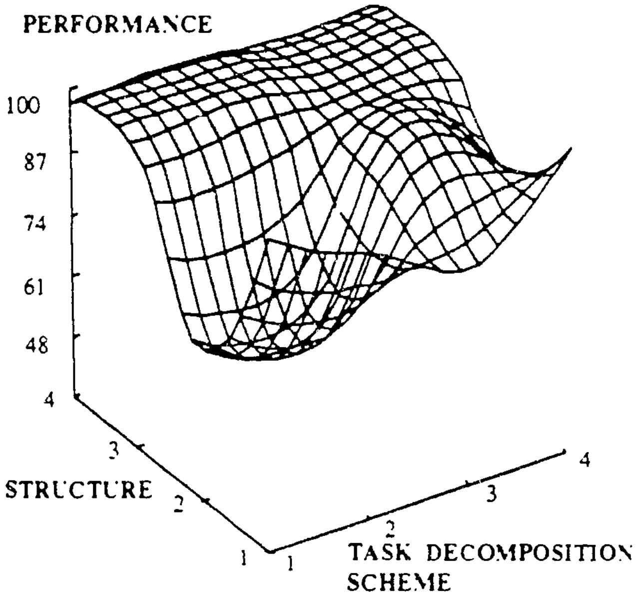
BIASED NON-DECOMPOSABLE TASK



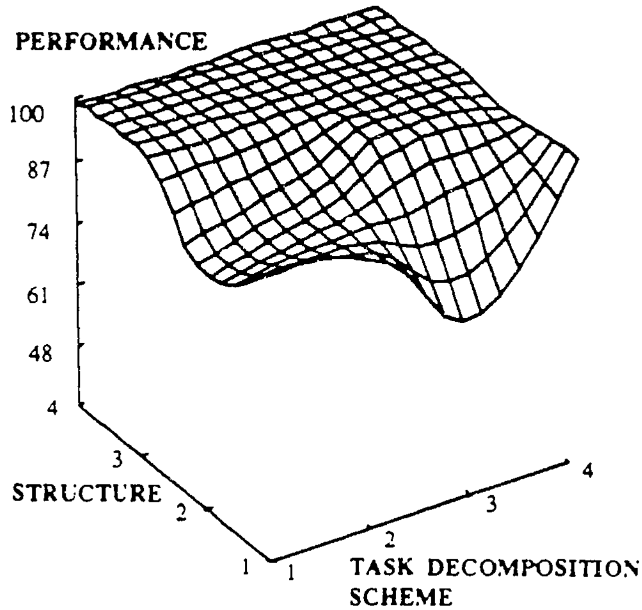
STRUCTURE	TASK DECOMPOSITION SCHEME
1--TEAM WITH VOTING	1--SEGREGATED
2--TEAM WITH A MANAGER	2--OVERLAPPED
3--HIERARCHY	3--BLOCKED
4--MATRIX	4--DISTRIBUTED

Figure 9. Performance of Experientially Trained Organizations under Optimal Operating Conditions when Faced with Maydays

UNBIASED DECOMPOSABLE TASK



UNBIASED NON-DECOMPOSABLE TASK



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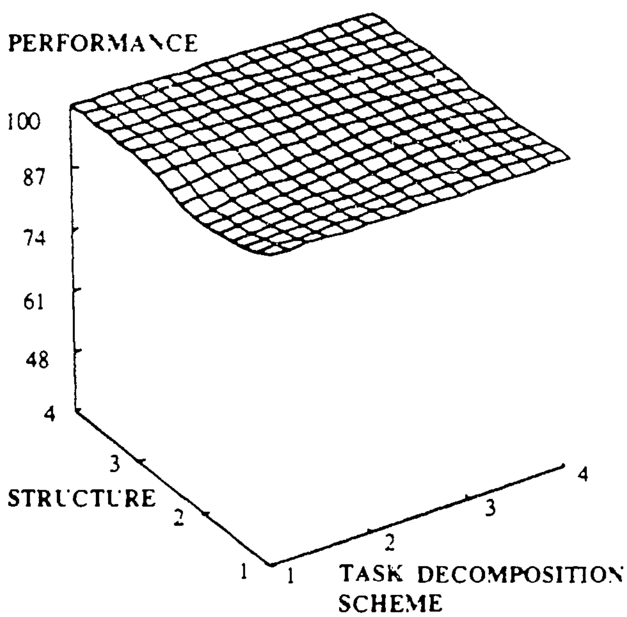

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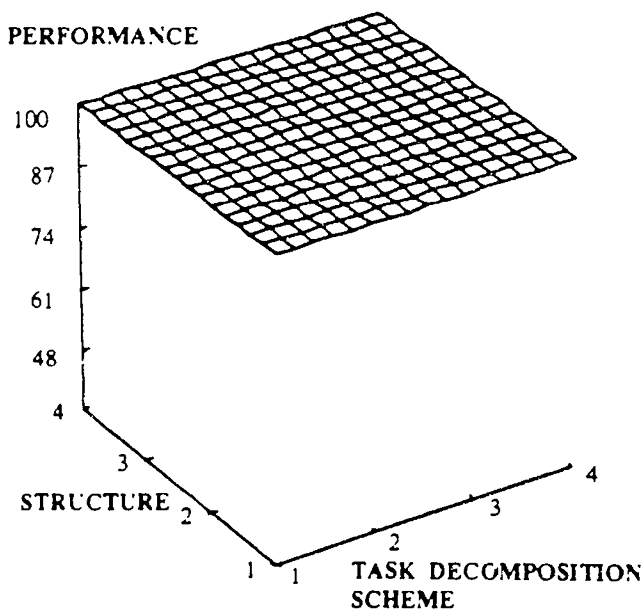
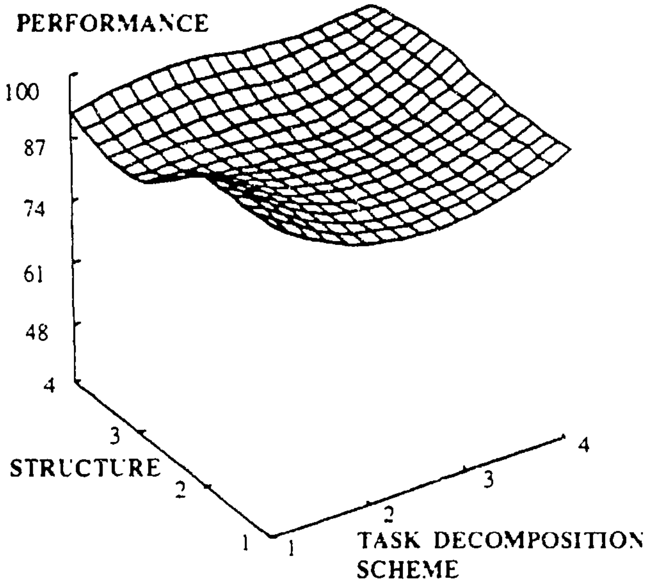


STRUCTURE	TASK DECOMPOSITION SCHEME
1--TEAM WITH VOTING	1--SEGREGATED
2--TEAM WITH A MANAGER	2--OVERLAPPED
3--HIERARCHY	3--BLOCKED
4--MATRIX	4--DISTRIBUTED

Figure 10. Performance of Operationally Trained Organizations under Optimal Operating Conditions when Faced with Maydays

UNBIASED DECOMPOSABLE TASK



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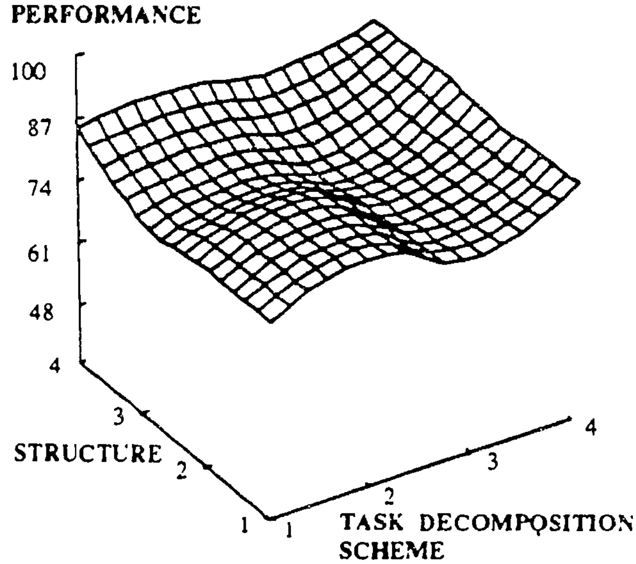

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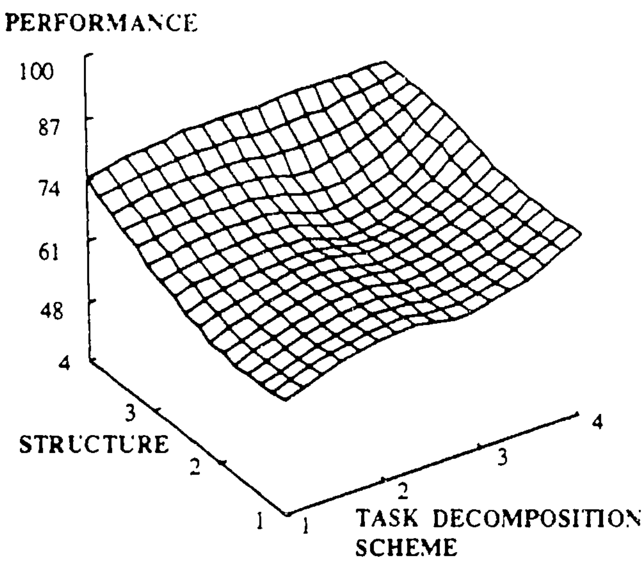

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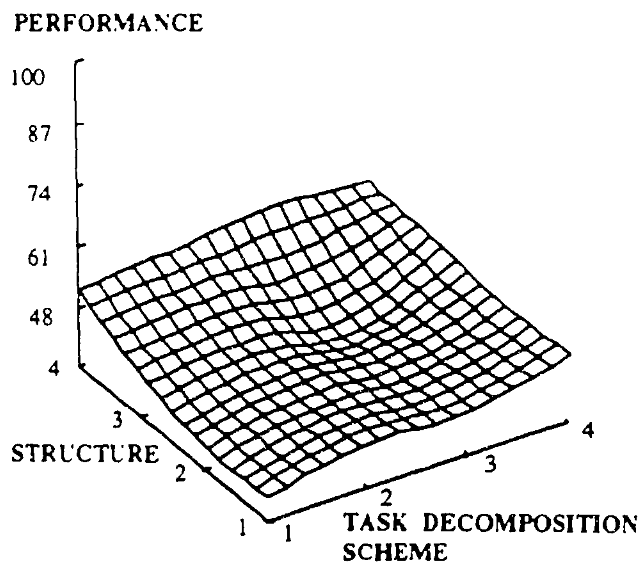

STRUCTURE	TASK DECOMPOSITION SCHEME
1--TEAM WITH VOTING	1--SEGREGATED
2--TEAM WITH A MANAGER	2--OVERLAPPED
3--HIERARCHY	3--BLOCKED
4--MATRIX	4--DISTRIBUTED

Table 1: Organizational Performance by Type of Training

Organizational Training Type	Internal Operating Condition	External Condition: Overall	External Condition: Maydays
Untrained	Overall	33.33(0.00)	33.33(0.00)
	Optimal	33.33(0.00)	33.33(0.00)
	Murphies	33.33(0.00)	33.33(0.00)
Experientially Trained	Overall	59.93(0.48)	92.63(0.35)
	Optimal	62.18(0.96)	96.63(0.43)
	Murphies	59.18(0.55)	91.30(0.43)
Operationally Trained	Overall	54.56(0.31)	69.96(0.45)
	Optimal	57.29(0.75)	72.92(0.98)
	Murphies	53.66(0.33)	68.98(0.51)

Note: In each training type consisting of three rows, for the first row n (types of organizations) =1280, for the second row n=320, and for the third row n=960. Standard errors are in parentheses.

Table 2: Organizational Performance by Task Environment

Task Environment	External Condition	Organizational Training Type	
		Experiential	Operational
Unbiased Decomposable	Overall	53.48(1.85)	77.81(1.02)
	Maydays	91.51(1.29)	92.97(0.46)
Unbiased Non-Decomposable	Overall	48.61(1.15)	56.22(0.28)
	Maydays	95.45(0.83)	81.37(0.50)
Biased Decomposable	Overall	61.23(0.36)	47.80(0.18)
	Maydays	99.56(0.12)	69.62(0.74)
Biased Non-Decomposable	Overall	85.39(0.19)	47.33(0.44)
	Maydays	99.98(0.01)	47.71(0.56)

Note: In each cell, n = 80 types of organizations. Standard errors are in parentheses.

Table 3: Performance of Experientially-Trained Organizations Under Optimal Operating Conditions

Task Environment	External Condition: Overall — Top	Overall — Bottom	Maydays — Top	Maydays — Bottom
Unbiased Decomposable	Team with voting Segregated (per=100.00)	Team with manager Overlapped (per=37.38)	Team with voting Segregated (per=100.00)	Team with manager Overlapped (per=62.79)
Unbiased Non-decomposable	Team with voting Overlapped (per=62.48)	Team with manager Segregated (per=34.50)	Hierarchy or matrix Blocked (per=100.00)	Team with voting Blocked (per=72.40)
Biased Decomposable	Matrix Distributed (per=70.06)	Team with voting Segregated (per=57.97)	Any structure Blocked (per=100.00)	Team with manager Segregated (per=96.02)
Biased Non-decomposable	Hierarchy or matrix Blocked (per=88.83)	Team with voting Except blocked (per=84.58)	Any Structure Except blocked (per=100.00)	Any structure Blocked (per=99.92)

Note: Performance is measured as percentage of correct decisions over presented problems.

Table 4: Performance of Operationally-Trained Organizations Under Optimal Operating Conditions

Task Environment	External Condition: Overall — Top	Overall — Bottom	Maydays — Top	Maydays — Bottom
	Top	Bottom	Top	Bottom
Unbiased Decomposable	Team with voting or team with manager Segregated (per=100.00)	Matrix Distributed (per=66.04)	Team with voting or team with manager Segregated (per=100.00)	Hierarchy Overlapped (per=88.62)
Unbiased Non-decomposable	Team with voting Segregated (per=59.99)	Matrix Blocked (per=52.80)	Matrix Distributed (per=88.13)	Team with manager Blocked (per=76.07)
Biased Decomposable	Team with voting or team with manager Segregated (per=50.58)	Hierarchy Overlapped (per=45.20)	Matrix Distributed (per=79.27)	Team with manager Segregated (per=59.16)
Biased Non-decomposable	Matrix Blocked (per=53.62)	Team with voting or team with manager Segregated (per=41.31)	Matrix Blocked (per=56.13)	Team with voting or team with manager Segregated (per=40.30)

Note: Performance is measured as percentage of correct decisions over presented problems.

Table 5: Organizational Performance by Match of Organizational Complexity and Task Complexity

External Condition	Training Type	Internal Condition	Match =1	Match =2	Match =3
Overall	Experientially Trained	Overall	54.05(0.99,160)	59.45(0.69,640)	62.52(0.79,480)
		Optimal	56.82(1.82,40)	61.74(1.45,160)	64.55(1.55,120)
		Murphies	53.13(1.17,120)	58.69(0.79,480)	61.85(0.91,360)
	Operationally Trained	Overall	49.61(0.37,160)	54.90(0.48,640)	55.77(0.49,480)
		Optimal	51.50(0.47,40)	57.98(1.19,160)	58.30(1.16,120)
		Murphies	48.98(0.46,120)	53.87(0.49,480)	54.92(0.52,360)
Maydays	Experientially Trained	Overall	88.98(1.07,160)	92.21(0.53,640)	94.40(0.48,480)
		Optimal	95.14(0.90,40)	96.15(0.76,160)	97.76(0.44,120)
		Murphies	86.93(1.34,120)	90.90(0.65,480)	93.28(0.61,360)
	Operationally Trained	Overall	73.81(0.62,160)	70.09(0.65,640)	68.51(0.81,480)
		Optimal	77.42(0.81,40)	73.25(1.42,160)	70.97(1.76,120)
		Murphies	72.61(0.76,120)	69.04(0.72,480)	67.69(0.90,360)

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;

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