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ORGANIZATIONAL DECISION MAKING AND ERROR IN A DYNAMIC TASK ENVIRONMENT[☆]

ZHIANG LIN[a] and KATHLEEN M. CARLEY[b,*]

[a] *The Hong Kong University of Science and Technology;*
[b] *Department of Social and Decision Sciences, Carnegie Mellon University, Pittsburg, PA 15213, USA*

Organizational theorists have attributed organizational performance to a variety of factors including time pressure, training, organizational complexity, environment complexity, and the match between the organization and its environment. Using a computational model of organizational performance based on an information processing and resource dependency view of organizations the effects of these factors are simultaneously compared and their potential relative impact deduced. Following such an analysis we find that time pressure, training, organizational complexity, and organizational environment are stronger determinants of organizational performance than the match between the organization and its environment.

KEY WORDS: Contingent match, Organizational design, Organizational learning, Performance, Simulation, Task environment, Training

INTRODUCTION

One of the basic questions in organizational science is simply "What determines organizational performance?". A variety of factors have been forwarded as principal determinants. For example, institutionalists and open system theorists have argued that organizational performance is affected by the environment in which the organization operates (Powell and DiMaggio, 1991; Scott, 1987). Structural theorists argue that the form of the organization or its internal structure

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[*] Corresponding author: Tel.: 1-412-268-3225. Fax: 1-412-268-6938.
E-mail: kathleen.carley@cs.cmu.edu.

determines its performance (Mackenzie, 1978). Meanwhile, contingency theorists (Burton and Obel, 1984; Lawrence and Lorsch, 1967) argue that it is not the environment as such, but the match or fit between the organization and its environment that determines performance. A complimentary point of view is forwarded by population ecologists (Hannan and Freeman, 1977) who argue that the match between an organization and its environment is necessary for survival. In contrast, information processing theories take a more micro perspective and argue that organizational performance is a function of the behavior of the intelligent agents within the organization and their access to "enhancing technologies" such as information systems. These agents are complex adaptive, yet boundedly rational, agents capable of learning and making mistakes (Cyert and March, 1963; March and Simon, 1958). In this case, information processing and resource constraints at the organizational structural level or at the individual cognitive level are principal determinants of performance. It follows from this perspective that the training individuals receive and the information systems they have access to are critical to performance. Finally, as theorists of complexity and organizational response to crisis have pointed out, when the problem the organization is facing is dynamic and so the organization must respond both rapidly and accurately, time pressure also becomes a factor affecting performance (Perrow, 1984).

Clearly there are multiple factors that might affect organizational performance. Rarely have all of these perspectives been simultaneously contrasted. At issue is the relative dominance of these perspectives; whether, in fact, all of these factors are of equal importance in explaining performance. Such a study is difficult to carry out empirically as in most organizations these factors often co-occur in such a way that it is difficult to distinguish their effects, particularly with the limited data available. An alternate approach is to address the problem analytically using a formal model of organizational performance. Such a formal analysis has the advantage that the different factors can be isolated and controlled for. The resultant analysis provides theoretical guidance as to the relative impact of these various factors on performance. This is the approach taken in this paper. A formal model of organizational performance drawing from all of these perspective was developed. This model is a computational model referred to as DYCORP (Lin and Carley, 1995). Using DYCORP we conduct a virtual experiment in which the various factors that might affect

organizational performance are varied (time pressure, environment, training, organizational complexity, the match between the organization and its environment). In the following sections, we will first briefly describe the DYCORP framework and this virtual experiment. We then analyze the results and discuss the theoretical implications of these findings.

MODEL DESCRIPTION

DYCORP can be used to examine the behavior of organizations faced with dynamic problems. Within DYCORP the organization is modeled as a complex goal oriented system composed of complex adaptive agents of limited intelligence situated within a particular organizational structure and environment and faced with a dynamic task (Figure 1). The focus is on organizational performance. Organizational performance is a direct product of the organizational decisions. The organizational decision depends on the decisions and actions of the agents in the organization. These agents are boundedly rational complex adaptive agents whose information processing capabilities are determined by their particular information gathering styles (Lin and Carley, 1993; Carley and Lin, 1995) and decision making training. The behavior of the agents is a function of the information at their disposal and the way they process that information. What information they have is a function of the environment, time pressure, stress, and the form of the organization.[1] We note, at the outset, that DYCORP is a general purpose framework for studying organizational performance. It allows the researcher to carry forth many investigations other than that described herein.

Stylized Radar Task

In DYCORP, the tasks are limited choice tasks in which organizations make decision choices regarding the state of a moving aircraft given limited alternatives and subject to various types of information distortions. Choice tasks are quite common in organizations and include

[1] Stress appears in a lightened area in Figure 1 as stress is not manipulated in the experiments discussed in this paper.

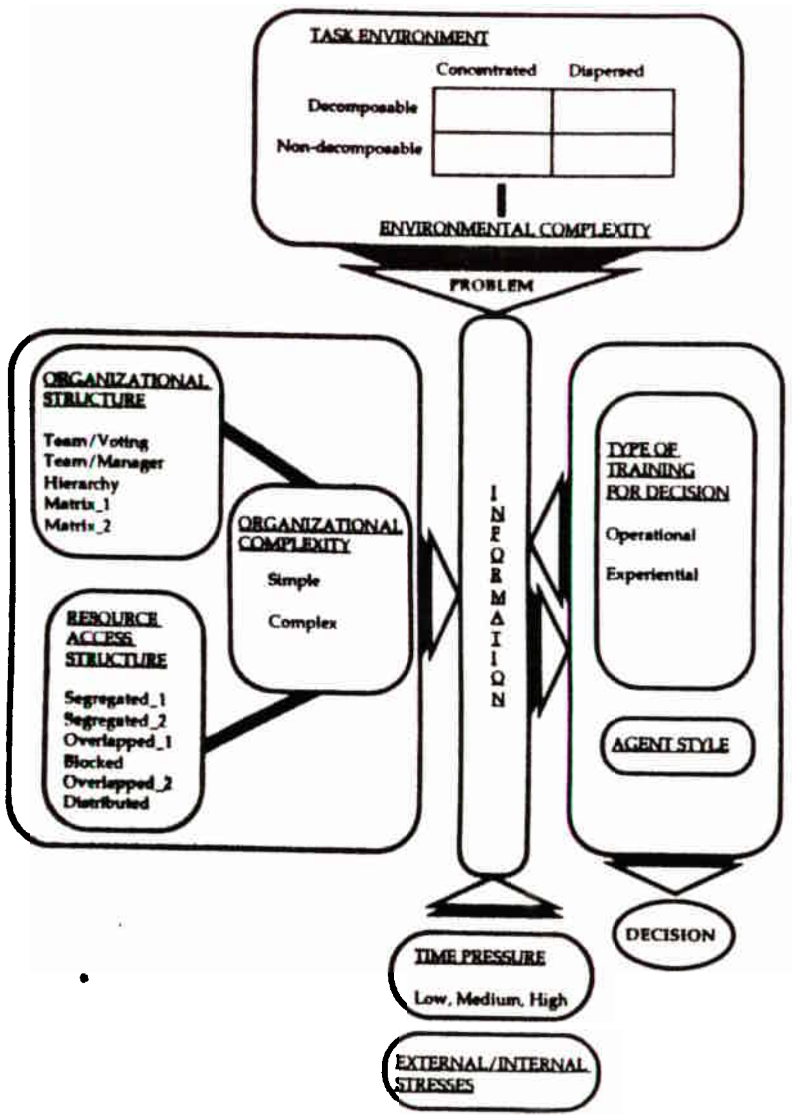

FIGURE 1 An Overview of the DYCORP Framework.

budgeting, production, and hiring decisions. Choice tasks are typically distributed; i.e., no individual has access to all the information or the capability to handle all the information necessary to make a decision. Here, for the sake of exposition, we describe the task as a sequence of stylized radar-detection problems. Each problem is defined as a single aircraft moving through the airspace. Each aircraft is characterized by 9 indicators or parameters. The organization gains information on those parameters through the resource access structures. The indication of a specific parameter may not reflect the true state of the whole aircraft. For example, just because the plane has emissions that indicate that it is carrying weapons does not necessarily mean it is hostile. For each problem the organization has three choices – decide whether the aircraft in the airspace is friendly, neutral, or hostile. This aircraft has a true state; i.e., it is actually either friendly (1), neutral (2), or hostile (3). The organization, to solve the problem, must make a decision before the aircraft reaches the "red zone" as to whether the organization "thinks" the observed aircraft is friendly, neutral, or hostile. The red zone is defined as being the point at which either the aircraft enters the danger zone (the range is less than 1 mile or the altitude is less than 5,000 ft) or the point at which the time limit on making a decision (set by the organization) has been met, which ever occurs first. After the problem is "over" (i.e., the aircraft has hit the red zone) the organization's final decision is recorded as its decision. A new problem (i.e., aircraft) occurs. Organizational performance is calculated by contrasting the true state of the aircraft and the organization's final decision about the state of that aircraft. The distribution of possible problems (aircraft) constitutes the task environment.

This is a dynamic task as some of the characteristics of the aircraft may change during the flight. The true state of the aircraft cannot change. Moreover, even though the aircraft's characteristics are changing they are changing in a bounded enough fashion that the true state of the aircraft does not shift during each problem. Since this is a dynamic task, the amount of time pressure faced by the organization will vary. Time pressure in DYCORP is represented by the number of time units the organization has to make the decision. The lower the number of time units the faster the organization must make its decision, the greater the time pressure. We define time pressure as one over the number of time units until the aircraft enters the red zone.

This number of time units is determined based on a combination of two factors – the number of time units assigned to this problem and the number of time units until the aircraft enters the danger zone. For each aircraft, the number of time units assigned can vary from 1 to 60, with the actual number being assigned randomly. For each aircraft, the number of time units until it enters the danger zone depends on its speed, direction, angle, and altitude.[2]

Modeling the Organization

In the organizational decision making process in DYCORP, no one agent has access to all information needed to make the decision. Further, the task does not require consensus, rather, for a particular alternative to be chosen, it is sufficient that the top-manager (CEO) or a majority of the people in the organization choose that alternative. Because each agent in the organization has access (directly or indirectly) to only some of the nine parameters, the final organizational decision requires communication and coordination among organizational members. Which agent receives what information depends on the resource access structure. How members of the organization communicate depends on the organizational structure. When agents acquire information depends on the agent style. How agents make decisions depends on the type of training. The organizational operation can be disrupted due to sub-optimal operating conditions.

The artificial organizations examined in DYCORP have procedures for feedback, communicating recommendations, combining recommendations to create an organizational decision, and training. In all organizations, agents during their training phase receive accurate and immediate feedback as to what is the correct organizational decision.[3] In all organizations agents communicate their decisions only to their immediate supervisor(s). In the team with voting, a majority rule combination procedure is used. In all other organizational structures the procedure for combining subordinates' recommendations is determined

[2] In DYCORP this danger zone is defined as occurring at a range ≤ 1 mile, or altitude $\leq 5{,}000$ ft.

[3] During training, there was no time constraint. Each agent's memory includes information only on task categorization experience, not time pressure, though they may be trained to be faster.

by the supervisor. In the DYCORP framework, the aircraft is moving. The organization can track the aircraft and can make a series of decisions about the state of the aircraft. The number of intermediate decisions made by the organization for each aircraft is recorded (in the simulation output), though the organization only reports one decision (its final decision) for each aircraft.

As previously mentioned, there are many options available to the researcher for characterizing the organization and its environment. In this paper, we use only a few of these. We assume only cases where the incoming information is correct and complete, all agents are always available, and all communication channels are always available. Similarly feedback is complete and timely. Further, each agent in the organization has a proactive style and thus they engage in the organizational decision making process whenever possible.[4] That is, each agent asks for information,[5] reads information if there is information available, makes a decision based on the information, then passes up its decision. This process repeats until time expires. Time expires when the aircraft enters the red zone. Each agent's process (except the top-level manager's[6]) can be interrupted when he or she receives a request from a superior for a decision. The agent will respond to the request by passing up a decision based on whether there is a previously made decision (when the agent has not previously made a decision the agent continues with the current action). There are minor differences among the top-level manager, middle-level managers, and analysts. The top-level manager cannot be interrupted (since there is no superior), and an analyst can not ask for information (since there is no subordinate), while a middle-level manager can be interrupted as well as ask for information. Further, the toplevel manager has the power to decide which decision will be used as the final organizational decision.

[4] In DYCORP, a reactive agent style is also built, in which agents tend not to make decisions unless being asked or absolutely necessary. By focusing on proactive agent style in this paper, we can better examine the impact of training that is less restricted by definitions.

[5] For an analyst, he or she does not have to ask for information as there is no subordinate.

[6] We assume that only supervisors can interrupt agents, and that the top-level manager has no supervisor.

VIRTUAL EXPERIMENT

Using DYCORP we constructed and ran a virtual experiment. In this experiment we examine the impact on organizational performance of time pressure, training, environmental complexity, organizational complexity, and the match between the environment's and the organization's complexity. Each organization simulated is faced with 19,683 problems. Given the task, regardless of the environment there are 19,683 unique[7] aircraft configurations. An aircraft is characterized as having a low, medium, or high value on each of nine characteristics. This generates 19,683 configurations. The underlying characteristic may be continuous, such as speed, or categorical, such as weapons type. These differences affect the way the aircraft changes its position in space. However, before this information gets to the individual decision makers it is always categorized into three variables – low, medium, and high. The cutoffs for each of these characteristics divide the range in thirds and so guarantee that one third of the aircraft take on each of the low, medium, and high values. The nature of the nine characteristics is not relevant to this simulation as herein, all are equally weighted and interchangeable. As in a human experiment, time and processing considerations limit the number of options that can be simultaneously considered.

Dependent Variables

We define organizational performance as accuracy – the percentage of problems for which the organization gives the correct final answer. A final answer is correct if the predicted state is the same as the true state of the aircraft. We examine three dependent variables: percentage of correct decisions, percentage of severe type-1 errors, and percentage of severe type-2 errors. Table 1 shows the general pattern of occurrence for type-1 and type-2 errors.

[7] Each aircraft is said to be unique if the characterization as of its nine characteristics are not repeated elsewhere. The value of two characteristics may be different when the characterization is the same. For example, Speed as 300 mile/h and 250 mile/h are both characterized as of low value or of friendly nature.

TABLE 1
Pattern of Errors and Performance

Decision	True state		
	Friendly	Neutral	Hostile
Friendly	Accurate	Type-1	Severe type-1
Neutral	Type-2	Accurate	Type-1
Hostile	Severe type-2	Type-2	Accurate

Percentage of Correct Decisions

In DYCORP, the Percentage of Correct Decision represents the accuracy of organizational response. It is measured as 100 * number of correct decisions made by the organization/number of problems presented to the organization.

Percentage of Severe Type-1 Errors

Percentage of Severe Type-1 Errors represents the extent to which the organization perceives aircraft as more friendly than they clearly are not. It is measured as 100 * number of times the organization made a friendly decision when the true state of the aircraft was hostile/number of problems where the true state was hostile.

Percentage of Severe Type-2 Errors

Percentage of Severe Type-2 Errors represents the extent to which the organization perceives aircraft as hostile when they clearly are not. It is measured as 100 * number of times the organization made a hostile decision when the true state of the aircraft was friendly/number of problems whose true state was friendly.

Independent Variables

Each of the perspectives on organizational performance, previously identified, are examined. This examination is carried out by varying, in a controlled fashion, the time pressure, training, organizational complexity, environmental complexity, and the match between organizational and environmental complexity.

Time Pressure

Recall that the organization must make a decision before the aircraft reaches the red zone. The longer it takes the aircraft to reach the red zone the less the time pressure. Three levels of time pressure are examined: low, medium, and high. A low time pressure (≥ 41 time units) puts little or no time constraint on the organizations. In this case, the organizational decision making process is least affected by time. A moderate time pressure (≥ 21 and ≤ 40) places some constraint on the decision process. A high time pressure (≤ 20) puts great pressure on an organization to quickly respond and so constrains the organization's decision making process. As DYCORP is a dynamic model, interactions among agents are affected by the time pressure. Time pressure can affect whether agents communicate, how they communicate, and which decision procedure they choose. These agent choices are dependent on the agent style (Lin and Carley, 1993).

Training

Two training procedures are contrasted – operational training (following SOPs) and experiential training. These training scenarios are stylized but they do reflect types of training conditions prevalent in real organizations and they help us illuminate the effect of training on organizational performance. Within an organization all agents are either operationally trained or experientially trained.

In the operational condition, the agents employ a standard operating procedure (SOPs) in making their recommendation. This type of training is often mentioned in organization theory, particularly in military settings. Agents are considered fully trained as they have perfect knowledge of the SOP and employ it without error.

In the experiential dominant condition, the agents make as their recommendation the decision that was most often correct in the past for this situation. For example, for a sub-task: "Speed = High", "Altitude = Medium", and "Size = Large", if the number of true decisions as "friendly", "neutral", and "hostile" are 300, 600, 900 respectively, then the experiential agent will always choose "hostile" as his or her decision. Agents have historical information on which they base their recommendation. The model is similar to a Bush and Mosteller (1955) stochastic learning model.

The agents trained experientially, are trained on a sequence of 19,683 problems. During training there is no time pressure involved. This reflects the fact that in the real world organizations can control

the training process, thus providing agents with the time to learn what they want to learn. For agents trained operationally, training occurs "off line." The agents can still see the 19,683 cases but they apply the standard operating procedures correctly the first time and every time.

DYCORP can record the organizational behavior during training or after training. We consider only the performance of organizations with fully trained agents. Thus, if the agents are trained experientially, we consider their performance on a second set of 19,683 cases which they see after they have been trained on a first set of 19,683 cases. The performance of all organizations, regardless of the type of training, are measured relative to this second set of 19,683 cases. Training does not continue while performance is being measured.

The two types of training that we examine vary in their degree of rigidity. Operational training, from the agents' perspective, is the most rigid as it allows no deviation in behavior from the SOPs. Experiential training is slightly less rigid. This is because agents with different backgrounds can make different decisions. We thus define a variable training to include operational training (0), and experiential training (1).

Organizational Form

Organizational theorists often speak of the complexity of the organization's design. This complexity is alternatively characterized in terms of general view of the organization, it's size, the way tasks are distributed, the types of processes (Burns and Stalker, 1961), the form of the organizational chart, the degree of centralization (Aldrich, 1979), and so on. Complexity, however, is really the byproduct of separable features of the underlying form of the organization. From an information processing perspective and resource dependency perspective differences in communication and coordination (Malone, 1987) and differences in access to information or resources (Pfeffer and Salancik, 1978) are important in characterizing the organization's form. Herein, the approach taken is to specify the organization's form from a joint information processing and resource dependency perspective and to derive complexity from the specific form. We operationalize differences in communication and coordination by specifying the organizational structure and differences in access to resource by specifying the resource access structure.

Organizational Structure

Five structures are examined: team with voting, team with manager, hierarchy, matrix_1, and matrix_2. Each structure consists of nine analysts (agents with direct access to information and resources). In addition, some structures employ middle and/or top-level managers. These structures are listed in terms of increasing complexity.

(1) Team with voting – This is a totally decentralized structure in which the organizational decision is the majority vote where each analyst in the organization gets an equal vote. Each analyst examines information and makes a recommendation. This recommendation is the analyst's vote.
(2) Team with manager – This is a flat hierarchy in which all analysts report to a single manager. Each analyst examines information and makes a recommendation. The manager examines these recommendations and makes the organizational decision.
(3) Hierarchy – This is a multi-leveled structure in which each analyst reports to his or her immediate middle-level manager, and the middle-level managers report to the top-level manager. Each analyst examines information and makes a recommendation. Each middle-level manager examines the recommendations from his or her subordinates and makes a recommendation. The top-level manager examines the middle-level managers' recommendations and makes the organizational decision.
(4) Matrix_1 – This is a multi-leveled structure in which six of the nine analysts each reports to two middle-level managers, and the middle-level managers report to the top-level manager. Each analyst examines information and makes a recommendation. Each middle-level manager examines the recommendations from his or her subordinates and other analysts' reports and makes a recommendation. The top-level manager examines the middle-level managers' recommendations and makes the organizational decision.
(5) Matrix_2 – This is a multi-leveled structure in which each analyst reports to two middle-level managers, and the middle-level managers report to the top-level manager. Each analyst examines information and makes a recommendation. Each middle-level manager examines the recommendations from his or her subordinates and other analysts' reports and makes a recommendation. The top-level manager examines the middle-level managers' recommendations and makes the organizational decision.

Resource Access Structure

The resource access structure[a] determines the distribution of raw (unfiltered) information to analysts in the organization. In DYCORP, what this means is that the resource access structure 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 six resource access structures. They are: segregated_1, segregated_2, overlapped_1, blocked, overlapped_2, and distributed. The resource access structures are listed in order of increasing complexity. Note, both segregated structures have the same level of complexity. Overlapped_2, blocked and distributed are equally complex in terms of direct links (each analyst sees 3 pieces of information) but they vary in terms of indirect links (i.e., which mid-level manager ultimately has access to how much information).

(1) Segregated_1 – In this structure each analyst has access to one task component.
(2) Segregated_2 – In this structure each analyst also has access to only one task component, but the task component each analyst has access to is now different from the one in segregated_1.
(3) Overlapped_1 – In this structure each analyst has access to two task components. Each task component is accessed by two analysts.
(4) Blocked – Each analyst has access to three task components. Three analysts see exactly the same three task components, i.e., they have the same mental model. If these analysts are in a hierarchy or a matrix then they all report to the same middle-level manager (i.e., they are in the same division).

[a] The resource access structure has also been referred to as the information access structure (Carley, 1991; 1992), or task decomposition scheme (Carley, 1990) or task process structure (Mackenzie, 1978). We use the term resource access structure to (1) emphasize the role of task environment 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).

(5) Overlapped_2 – In this structure each analyst has access to three task components. Each two task component is accessed by two analysts.
(6) Distributed – Each analyst has access to three task components. No two analysts see exactly the same information. Thus each analyst has a slightly different mental model. If these analysts are in a hierarchy or a matrix then each middle-level manager has indirect access to all nine pieces of information.

Complexity of Organizational Form

The organizational structures and the resource access structures were chosen as they represent unique, albeit stylized, patterns of distributing control and access to task information within the organization. These schemes represent a range of ways in which task based information can be differentially accessed by the agents in the organization. These structures vary on two dimensions – how much information overlap exists and where the overlap occurs. There should be an interaction between the organizational structure and the resource access structure as the impact of where the overlap in access to raw information occurs depends on who reports to whom. The teams do not have divisions[9] and so the impact of the different resource access structures should be different than in a hierarchy where the personnel divisions may or may not line up with the resource divisions.

In discussing the impact of organizational form, many empirical studies do not directly capture the organizational structure and resources access structure as such. Often, general indicators of the complexity of the organizational form or the level of bureaucratization are used instead. The complexity of the organization can be thought of as the organizational cost; that is, the summation of pieces of information being processed and reported and communication linkages (Malone, 1987; Mihavics and Ouksel, 1995; Lin and Carley, 1997). We define a measure of organizational complexity in terms of the number of direct and implied links. We define the organizations examined as being either simple or complex according to the number of links. The more links the more complex. We define four levels of complexity from low (1) to high (4). See Table 2.

[9] In this paper, each division consists of three analysts with a manager. This is true for hierarchy and matrix structures. But in team with voting and team with manager structures, the distinctions among divisions are not as apparent.

TABLE 2
Definition of the Organizational Complexity

Organizational structure	Resource access structure				
	Team/Vote	Team/Mgt	Hierarchy	Matrix_1	Matrix_2
Segregate_1	1	1	2	2	2
Segregate_2	1	1	2	2	2
Overlap_1	1	1	2	2	2
Blocked	3	3	4	4	4
Overlap_2	3	3	4	4	4
Distributed	3	3	4	4	4

In the ensuing analysis we examine the complexity of the organizational form, rather than the specific organizational structures or resource access structures as the structural theories rarely specify the exact form, but do specify the impact of complexity.

Environment

The aircraft has a true state which can be thought of as friendly (1), neutral (2), or hostile (3). The organization is not omniscient and the true state of the world is not known a priori. Rather it must be determined by the organization by examining the radar characteristics of the aircraft.

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. The nature of the task environment determines which of the possible states (friendly, neutral, or hostile) is the true state for each aircraft. Based on the literature, two types of manipulations of the task environment are considered. These are: the extent to which the task is decomposable (Roberts, 1990; Simon, 1962) and the extent to which it is concentrated (Aldrich, 1979; Hannan and Freeman, 1977).

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 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.

A task environment is concentrated if the possible outcomes are not equally likely. In a concentrated environment this inequality of outcome biases perception. Concentrated environments, or niches, are quite common. In a dispersed environment approximately one third of the 19,683 possible aircraft (6568) are hostile and one third of the aircraft are friendly. This environment can be thought of as an uncertain environment because the chances of all three outcomes are almost identical.

The true state of an aircraft is classified as friendly, neutral, or hostile by combining the values of all nine characteristics and then categorizing the aircraft (based on the combined value) relative to a set of cutoffs. By varying the combining rule and/or the cutoffs different organizational environments can be examined. We use two different combining rules and two different bias levels. This generates four different environments: concentrated-decomposable, dispersed decomposable, concentrated non-decomposable, and dispersed non-decomposable. In a decomposable environment the value of the characteristics are simply added (additive combining rule); whereas, in a non-decomposable environment some of the characteristics are multiplied together (multiplicative combining rule). In concentrated environments the cutoffs are set so that a high fraction of the possible 19,683 aircraft are hostile; whereas, in dispersed environments all three outcomes are equally likely. The combining rules and the cutoffs are given in Table 3.

The environmental complexity is jointly determined by concentration and decomposability. An environment can be thought of as more complex if similar inputs lead to different outputs and the higher the likelihood that there will be exceptions to rules or procedures. Concentration and decomposability work together such that environments that are high or low on both are simpler than mixed environments. Moreover, environments that are both concentrated and decomposable are the most simple by these standards (environmental complexity = 1). Dispersed and non-decomposable environments are the next simplest. Finally concentrated and nondecomposable are the most complex (environmental complexity = 4).

TABLE 3
Task Definitions

Environment	Rule
Decomposable	Sum = f1 + f2 + f3 + f4 + f5 + f6 + f7 + f8 + f9
Concentrated	low < 14, high > 17, else medium
Dispersed	low < 17, high > 19, else medium
Non-Decomposable	Sum = 2•f1•f2•f3 + 2•f4•f5 + f6 + f7 + 2•f7•f8•f9
Concentrated	low < 21, high > 23, else medium
Dispersed	low < 34, high > 49, else medium

Match

We examine how the match between the organization's form and its environment affects organizational decision making. Contingency theorists and population ecologists often argue that if there is a match between the organization's design and the environment then the organization's performance should be higher. The bases for such matching often has to do with the complexity of the organization relative to the complexity of the environment. From a niche-width theory perspective (Freeman and Hannan, 1983) the issue of match is in terms of the complexity or specialization of the organization and the concentration of the environment. Arguments are often forwarded that complex organizations are more capable of handling a broader range of tasks, whereas simpler organizations are seen as being inherently specialized. Here this match is operationalized as

$$\text{match} = 4 - |\text{environmental complexity} - \text{organizational complexity}|.$$

If this theory is right then the higher the match the higher the performance. Match takes on the values low (1) to high (4).

Experimental Design

Using DYCORP, we systematically vary each of the following: level of time pressure (3 levels), type of training (2 types), type of organizational structures (5 types), and types of resource access structures (6 types), environmental decomposability (2 types), and environmental concentration (2 types).[10] We record each of the three dependent variables. Notice that the computational organization is defined in terms of these independent variables so as to increase the veridicality of the model in terms of process. However, much empirical research does not directly measure factors such as organizational structure and resource access structure but instead focuses on theoretical constructs such as complexity and match. As discussed previously, complexity and match are composite variables built out of these, perhaps less theoretically interesting, structural variables. The organizational complexity, environmental complexity, and the match are three such composite variables

[10] We only look at optimal internal operating conditions, and proactive agents.

calculated from the independent variables. In the analysis, we focus on the impact of time pressure, training, organizational complexity, environmental complexity, and match.

RESULTS

We begin by examining the direct impact of time pressure, training, environmental complexity, organizational complexity, and match using regression analyses. The results are listed in Table 4. We see that all variables except the match in organizational and environmental complexity has a significant effect on performance. As expected, the higher the time pressure the lower the organization's accuracy and the higher the number of severe errors made by the organization. Organizations with operational training, facing more complex environments, and with less complex organizations exhibit higher performance. Importantly, the causes of the two types of errors are different; that is, while experiential organization make more type-2 errors, organizations with more complex structures make more type-1 errors. For this tasks, the artificial agents who can learn and act on the basis of their experiments come to see the environment as predominantly hostile and so respond more conservatively. Interestingly, humans faced with this same task also have this tendency to select the hostile or conservative outcome (Carley, 1996). In other words, individuals may act more conservatively than do the organizations they inhabit.

When interaction effects for time pressure and training are included, the situation changes somewhat (see Table 5). Time pressure interacts

TABLE 4
Regression Analyses of Performance, Main Effects

Independent variable	Dependent variable		
	Performance	Severe type-2 errors	Severe type-1 errors
Constant	76.415***	−1.382	12.612***
Time pressure	−13.702***	4.330***	12.534***
Training	−3.269***	29.066***	−0.504
Environment Complexity	2.393***	3.374***	2.372***
Organization Complexity	−1.251**	−0.897	−1.106***
Match	−0.571	−0.251	0.446
R2	0.477	0.380	0.570

Note. $N = 720$ for each dependent variable. $^{**}p < 0.01$, $^{***}p < 0.001$.

TABLE 5
Regression Analyses of Performance, Interactions

Independent variables	Dependent variables		
	Performance	Severe type-2 errors	Severe type-1 errors
Constant	65.471***	−28.690***	−20.730***
Time pressure	−9.236***	18.911***	13.950***
Training	4.338	71.976***	0.322
Environment Complexity	4.957***	7.466***	8.851***
Organization Complexity	−1.948	−2.433	2.148**
Match	1.085	−1.064	−2.598***
Time pressure × training	−1.793	−23.308***	4.872***
Time pressure × environment complexity	−2.141***	−3.727***	−1.883***
Time pressure × organization complexity	0.337	1.671*	−0.344
Time pressure × match	0.329	0.744	0.636
Training × environment complexity	3.435***	6.723***	−5.426***
Training × organization complexity	0.049	−3.612**	−0.708
Training × match	−4.631***	−1.349	1.759**
R2	0.521	0.574	0.661

Note. $N = 720$ for each dependent variable. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

with environmental complexity to decrease both accuracy and errors. Once interactions are controlled for we see that training no longer has a direct effect on performance, however it does affect severe type-2 errors. Again, this is due to experiential training leading to a conservative bias. Importantly, organizations with a complex structure are less likely to make severe type-2 errors when the agents are trained experientially. Organizational complexity can counteract the conservative bias of the individuals within the organization. Interestingly time pressure and training interact to affect the type of errors the organization makes such that as time pressure increases experiential organizations make more severe type-2 errors and operational organizations make fewer and the opposite is the case for type-1 errors. In other words, for experiential organizations the tendency toward conservatism increases under time pressure. This effect occurs without resorting to an emotional explanation for behavior under time pressure. A similar effect, but in the opposite direction, occurs with the interactions between training and environmental complexity follows the same pattern. For the simulated organizations, the conservative bias is the result of calculating the true state in a numeric fashion rather than a symbolic fashion; i.e., the calculations are in terms of the sum of 9 attributes each ranging from 1 to 3 rather than in terms of the frequency of low versus medium versus high attributes.

The relative impact of the different training scenarios is shown in Figure 2. Organizations with different training regimens respond differently as the complexity of the organization and its environment shift. What these results suggest is that the value of a match between the organizations and its environment is not a purely structural factor, as is often suggested in the literature. Rather, the match should take training into account. First, operationally trained agents can respond

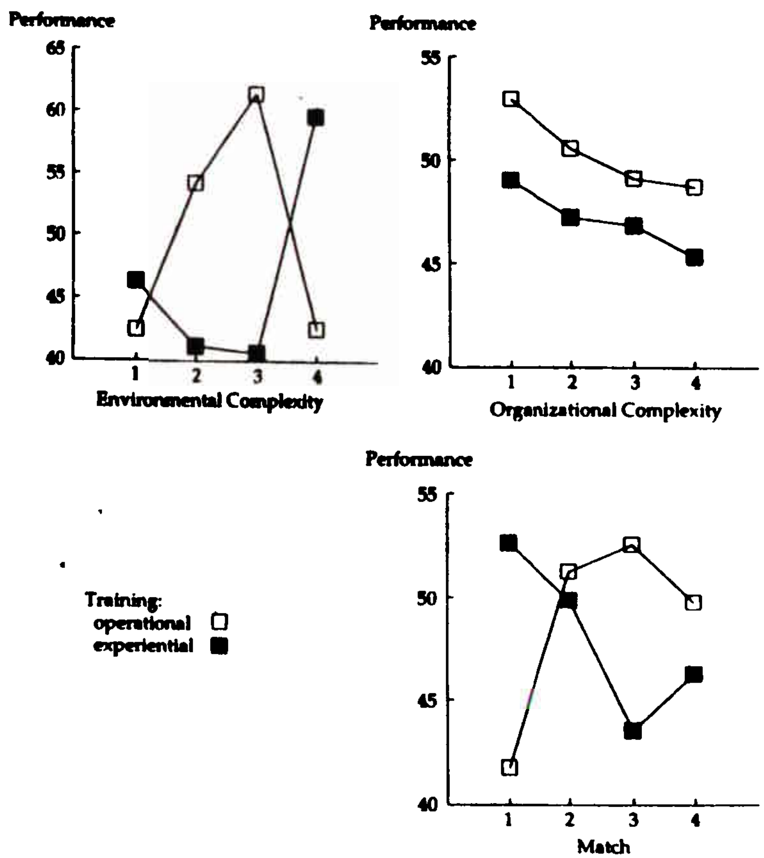

FIGURE 2 The Impact of Training.

slightly faster in a dynamic environment. Thus, as time pressure increases, these organizations get effectively more rounds to make their decision. Second, and more importantly, in experiential organizations middle level managers tend to become rigid in their response thus increasing the chance of errors in the more hierarchical experientially trained organizations. This rigidity of middle level management is especially pronounced in the experientially trained organization where the agents follow a dominance rule. Recall that operational training is the most rigid, and that experiential training with probabilistic rule is the least rigid. This suggests that training personnel to follow standard operating procedure can provide the highest overall benefit to the organization, although it may be at the cost of certain types of errors. These results, are based on averaging across all task environments and all levels of time pressure. Thus, they suggest that if the environment is unstable, and you don't know what environment you face or what kind of time pressure you face, having a rigid decision making procedure is beneficial.

Notice that there is an interaction between environmental complexity and training. In terms of the percentage of correct decisions, the highest performer is the operational trained organization in the dispersed decomposable task environments. Indeed, in any dispersed environment operational training is best. Finally, training agents to follow the experiential dominance rule has a distinct advantage for the organization. In terms of the percentage of type-1 errors, organizations with operational training exhibit the least errors when facing dispersed task environments, and organizations with experiential training with dominance rule exhibit the most errors when facing dispersed task environments. In terms of the percentage of type-2 errors, the pattern is almost the opposite. Organizations with operational training exhibit the most errors facing dispersed task environments, and organizations with experiential training with dominance rule exhibit the least errors facing dispersed task environments.

An aside on performance. On average, organizational performance looks fairly low in these figures. This is due to the fact that performance across levels of time pressure are averaged, and as Figure 3 indicates, performance drops almost to chance (33.3%) under severe time pressure. However, even when there is little or no time pressure performance is still on average between 60% and 70%.

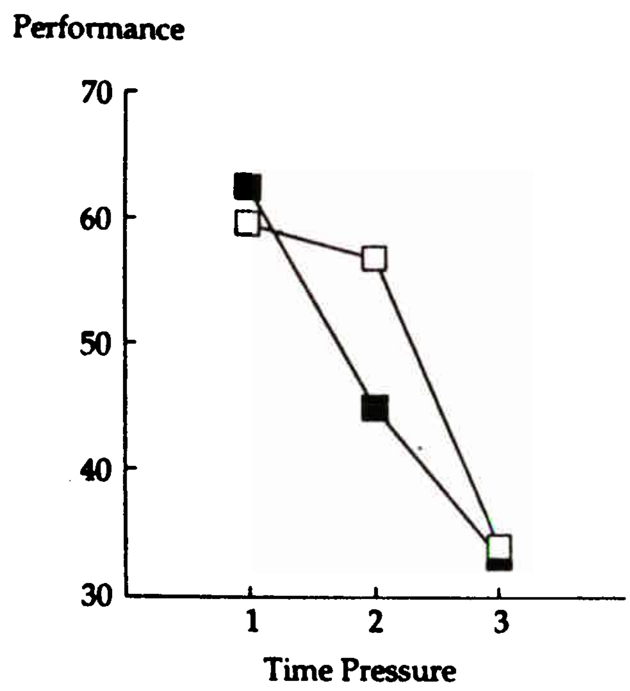

FIGURE 3 The Impact of Time Pressure.

Experiments with humans suggest that under no time pressure, human performance is comparable or a little worse (Carley, 1996).

DISCUSSION AND CONCLUSION

Our results suggest that for dynamic choice tasks, time pressure is the number one determinant of organizational performance. This suggests that organizations should employ procedures that facilitate rapid decision making and that curtail the existence of problems with drastically shortened temporal horizons. Importantly, re-engineering the organization to make it less complex (such as by reducing the number of organizational levels or moving to more segregated resource structures) thus reducing the amount of time it takes the organization to make a decision is not advantageous even when the organization is under high time pressure. Although less complex structures admit more rapid decisions they also admit more errors and so under high

time pressure are not necessarily advantageous. Rather the advantage of simplicity depends on both the time pressure and the environment being faced. Future work could build on these results by examining non-choice tasks and different types of matches between organizational complexity and the environment.

Our results suggest that for dynamic choice tasks, organizational complexity and the match between complexity and environment may not be the critical determinants of organizational performance; particularly, when match is defined from a predominantly structural perspective. Further, these results suggest that training and the environment are more powerful determinants of organizational performance than organizational design (at least as captured by complexity). Such impact is even greater than the fit between organizational complexity and task environment. Training has an impact because it affects both what the members of the organization learn and how they use or interpret that information. Organizational learning, to the extent it is encapsulated in personnel, becomes a major determinant of performance. Additionally, these results suggest that in thinking about the match between organizational and environmental complexity the researcher should take training into account.

This research suggests that training is a dominant factor, over which the organization has some control, that influences performance. Future work on organizational performance should consider how factors that affect training and so individual's ability to learn also affect organizational performance. Examples of such factors are the accuracy and rapidity with which feedback is provided. The impact of vague feedback and incorrect feedback may lead to different results than those portrayed here. These results are important however as many tasks within organizations are such that there is no possibility of getting accurate and rapid feedback. Future work should also examine the effect of insufficient learning and over learning on decision making. Another factor to consider is dramatic change in the environment. Herein, although the tasks were dynamic the set of tasks was not. The distribution of types of problems remained constant over time. At issue is whether the training will be as valuable when this distribution changes. Additionally, our results show that following standard operating procedures can help organizations under a dispersed task environment but not a more concentrated "niche-type" environment; whereas, experiential training is beneficial in such "niche-type" environments, but not more dispersed task environments. This suggests organizations should try to understand the technology and task they face before spending resources on training personnel.

We have demonstrated the use of a computational model to explore how the various factors influence organizational performance. One of the strengths of this approach is that it makes it possible for the researcher to simultaneously explore the relative impact of many different factors. This type of examination can lay bare the relations between various empirical constructs and can illuminate heretofor overlooked factors. Using such models it is possible to develop a theory of organizational design, and to clarify how design is related to performance.

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