Organizational Response: The Cost Performance Tradeoff

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Organizations constantly face a dynamic environment where they must respond both quickly and accurately in order to survive. In this paper, we examine the issue: do organizations need to employ costly designs in order to exhibit high performance in a dynamic situation. In the context of a computational framework we derive a set of logically consistent propositions about the interrelationship among task, opportunities for review, training, and cost and their relative impact on organizational performance. Our analyses indicate that complex organizational designs have drawbacks and design is often not the dominant factor affecting performance. The relationship between organizational complexity (hence cost) and performance is complex and depends on the level of time pressure, training, and the task environment. Within the context of the computational framework, we find that the benefits of re-thinking decisions and of matching the organizational design to the task environment are questionable. Further, these results suggest that applying scarce resources to mitigate the adverse impact of time pressure may have more impact on performance than using those resources to support a more complex organizational design.
(*Decision Making Accuracy; Cost; Opportunity for Review; Organizational Design; Simulation; Task Environment; Time Pressure; Training*)

1. Introduction

Organizational survival in a dynamic environment depends on the organization making both accurate and timely decisions (Aldrich 1979, Perrow 1984, Scott 1987). Organizational design (hence cost) is expected to affect both the accuracy (Rochlin 1991) and the timeliness (Pauchant et al. 1990) with which the organization makes a decision. It is clear that organizational performance is influenced by the flaws in individual memory and the way in which individuals make decisions and apply the information that they have (March and Simon 1958, Perrow 1984). Nevertheless, within organizational theory there is a vast body of research that suggests that organizational design, in and of itself, influences organizational performance (e.g., Galbraith 1977, Thompson 1967). Moreover, such design influences should be observable even when individuals are acting in an "error free" manner.

The organizational design (in terms of its cost), the match between the task environment and the organizational design, time pressure, opportunities for review, and the training personnel receive are expected to directly affect the organization's performance. Specifically, the following propositions follow from the literature:

PROPOSITION 1a. *Complex and thus more costly organizations tend to have a better performance than simple and thus less costly organizations (Krackhardt and Stern 1988; Roberts 1989, 1990; Rochlin 1989; Thompson 1967).*

PROPOSITION 1b. *Simple and thus less costly organizations tend to have a better performance than complex and thus more costly organizations (Carley 1992, Jablin et al. 1986).*

PROPOSITION 2. *The better the match between the organization's design and its environment the better its*

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performance (contingency theory Burton and Obel 1984, *Lawrence and Lorsch* 1967).

PROPOSITION 3. *As time pressure increases organizational performance decreases (studies of crises).*

PROPOSITION 4. *Organizations with more opportunities for review exhibit better performance than organizations with fewer opportunities for review (La Porte and Consolini* 1991, *Pauchant et al.* 1990).

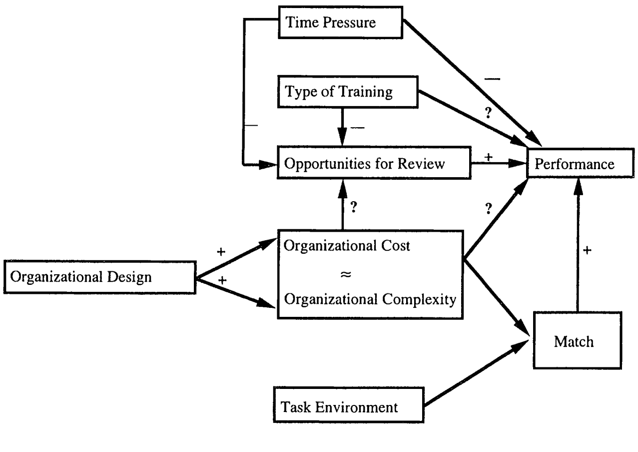
PROPOSITION 5a. *Training personnel to follow their experience improves performance over procedural training (Dunbar and Stumpf* 1989, *Green* 1989).

PROPOSITION 5b. *Procedural training improves performance over experiential training (Levitt and March* 1988).

The foregoing propositions speak to the direct impact of a series of factors on performance. There are additional arguments over the indirect effects of some of these factors. For example, lean and rigid organizational designs and standard operating procedures (SOPs) are expected to reduce the time required to process information and make decisions and so should create more opportunities for review (March and Simon 1958). Further, there are "definitions" in the literature relating some of these factors to underlying variables. For example, see Malone's (1987) definition of cost.

Figure 1 summarizes these relationships as they are described in the organizational literature. The variables time pressure, opportunities for review, training, cost, and match, are arguably, in and of themselves, important determinants of organizational performance in a dynamic environment. The question marks indicate that there is debate in the literature as to whether the relationship is positive or negative. There are several limitations to this "literature based" model. First, the proposed relationships are based on a series of case studies and empirical studies that typically look at different variables and that typically look at only one of the relevant variables. Because they rarely look at the same or comparable variables, it is often difficult to directly interrelate the results. Further, with few exceptions (Baligh et al. 1990), most of these studies have focused on only one or two of these variables. When multiple factors are considered, the analysis is often largely descriptive. At issue then, is what is the relative impact of design (hence cost), match, training, review opportunities, and time pressure on organizational performance sans human, data gathering, or communication errors. Second, most studies of organizational performance look at static tasks and so neglect the interplay between organizational design and decision review opportunities. Third, these studies rarely describe the process underlying the relationship among variables. These limitations underlie the aforementioned debates over the impact of different organizational designs. A comprehensive and systematic process-based analysis of these variables that leads to an understanding of their relative impact can be accomplished using computational techniques.

Figure 1 Expected Relationships among Variables



The difficulty in pulling these previous studies into a single coherent model can be illustrated by looking at the points where the propositions are in contradiction—1a and 1b, and 5a and 5b. For example, Carley (1992) and Jablin et al. (1996) are looking at experientially trained individuals, often working under conditions where information is missing or personnel are leaving, and where performance is measured in terms of accuracy or speed. In contrast, many of the individuals in the organizations looked at by Krackhardt and Stern's (1988), Roberts (1989, 1990), Rochlin (1989) and Thompson (1967) are following procedures. Although the issue of training is not explicit to these studies, it may be that the difference in their predictions for the impact of costly versus simple structures may be due to, at least in part, differences in the way in which the individuals in the organizations were trained.

Discussions of training have pointed both to the value of experiential (Dunbar and Stumpf 1989, Green 1989) and procedural (Levitt and March 1988) training. Dunbar and Stumpf (1989) and Green (1989) are primarily concerned with predominantly hierarchical organizations. In contrast, much of the work by March has dealt with alternative structural forms, including the organized anarchy (Cohen et al. 1972, March and Olsen 1976). Organizations that are under time pressure or facing relatively novel situations may find the value of individual experience particularly beneficial (Green 1989). Whereas, when organizations are facing substantial turnover, procedures can serve as the encapsulation of experience (Levitt and March 1988). In these studies, it may be that the differences in their predictions are due, at least in part, to looking at different organizational forms and under different environmental conditions.

With respect to both the structure or the cost of the organization and training, the results from the literature may be not so much contradictory as incomplete. That is, had these studies controlled for alternative structures or alternative training scenarios, the observed results might have emerged, but only as a special case. Had these studies all considered structure, training, time pressure, and environment at the same time, the results may not have appeared to be contradictory. However, a simultaneous coverage of these variables is generally not feasible in an experimental or case study condition.

In this study, we use a process model of organizational behavior that follows from work in information processing theory, open systems theory, and artificial intelligence. This process model is embodied in a simulation engine referred to as DYCORP[1] (DYnamic Computational ORganizational Performance) (Lin and Carley 1995). DYCORP generates performance for one or more organizations given basic information about the task environment, the organization's design, training/decision-making procedure, and time pressure. Moreover, within DYCORP, some of the variables shown in Figure 1, cost and opportunities for review, are also generated from this basic information.

Using DYCORP, we run a simulation experiment and systematically vary each of the basic independent variables (environment, design, training, and time pressure). The results allow us to evaluate the consistency of the propositions implied by the model in Figure 1. Process models by their very nature lead to a wide range of predictions (more than can be examined in a single paper). The results of this experiment will tell us which of the propositions are consistent with the theory (as embodied in DYCORP) and will provide information on the relative impact of these variables and the complex interactions among them.

Computational techniques have been used successfully by researchers in organizational studies (Cohen 1986, Cohen et al. 1972, Cyert and March 1963, Levitt et al. 1994, Carley 1992, Masuch and LaPotin 1989). Computer simulation is a powerful extension of human cognition. 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." Fararo (1989) also regards computational process as one of the three processes (the other two are theoretical and empirical processes) necessary to the development of any discipline. In this paper, we have used computer simulation to develop a theory of organizational performance that is process based and internally consistent.

Simulating organizational behaviors has several obvious and unique advantages. First, simulated organizations can emulate the behavior of specific organizations or resemble critical processes in the real world while not causing any disturbance to the operation of real world organizations. Second, in the real world there is little consensus on what constitutes good organizational performance while in the simulation, we can define performance directly in terms of indicators such as the accuracy of decisions. Decision accuracy is an important but difficult-to-measure component of performance. Third, it is virtually impossible to obtain sufficient data using case studies or surveys, except at a very macro level, for comparing organizations with a range of designs in various task environments. Fourth, using simulation, we can explore a wide range of organizational features and their impact on performance, thus providing a systematic basis for evaluation of

[1] DYCORP is written in C and has been run on HP workstations. Questions about DYCORP should be directed to the first author.

organizational measures and the inter-relationships among these features. Indeed, simulation is an accepted framework for examining and exploring the complex inter-relationships among scales and/or measures in most fields. Fifth, simulation can be used to determine the logical consistency of a set of propositions and the extent to which theoretical conclusions actually follow from theoretical assumptions. In some areas, formal logic plays this role. However, when there are multiple complex adaptive agents with interdependent actions, there is no sufficient multi-agent logic and computational models are currently the only choice. Finally, by using simulation, we can gain insight into important organizational factors and a wider range of factors with less cost than conducting human experiments or field studies. Human experiments or field studies can then be done to test the key theoretical results and provide important details.

First, we provide some background information; then we briefly describe the DYCORP framework for simulating stylized organizations and the virtual experiments. We then present our results indicating the impact of time pressure, opportunities for review, training, cost, and match on organizational performance and determine whether the set of propositions extant in the literature actually follow from the basic theory. Finally, we discuss the implication of the findings, limitations of the research, and future directions.

2. Background

Debates exist in the literature over the relative benefits of different organizational designs. Some theorists argue that more complex/redundant structures such as hierarchies may exhibit lower performance than simpler structures (Jablin et al. 1986, March and Simon 1958, Carley 1992), while others argue that they exhibit higher performance (Roberts 1989). Hierarchies may exhibit lower performance due to information loss through the process of information condensation (Jablin et al. 1986) or uncertainty absorption (March and Simon 1958, Simon 1962). However, whether complex designs (Krackhardt and Stern 1988) or loosely coupled designs (La Porte and Consolini 1991, Thompson 1967) or redundant designs (Roberts 1989, 1990; Rochlin 1989) will actually achieve better performance is unclear. Organizations, of course, must respond both in a timely and accurate fashion. Mackenzie (1978) suggests that hierarchies reduce redundancy and increase efficiency and therefore, presumably, can respond in a more timely fashion. By contrast, other researchers (Davis and Lawrence 1977, La Porte and Consolini 1988, Carley 1990, 1991) suggest that some less complex organizational designs can learn faster and respond more quickly than hierarchies under certain task environments. Further, issues of design are intimately tied to issues of cost (Malone 1987). There is general agreement that organizational operating costs increase as the level of complexity/redundancy increases. Thus the debate over the relative performance of different designs is also a debate over their relative cost effectiveness.

The debate over the best organizational design cannot be separated from the debate over the relative impact of design and environment. It is clear that both impact performance (March and Simon 1958, Scott 1987, Thompson 1967, Aldrich 1979). Further, contingency theorists (Baligh et al. 1990, Lawrence and Lorsch 1967, Lupton 1976) argue that the complexity of the organizational design must match the complexity of the task environment if the organization is to achieve high performance.

Further, within a dynamic environment, organizational performance can be severely affected by the degree of time pressure (Lin and Carley 1993, Means et al. 1992). Often, a late decision, whether or not it is correct, is a useless decision and may have severe consequences for the organization. This is particularly true in volatile and rapidly changing environments. For example, consider the Vincennes incident. The American warship, Vincennes, had to make a series of decisions within seven minutes about the hostility of an approaching aircraft in a very hostile and dynamic environment (Cooper 1988, Rochlin 1991). Failure to respond appropriately to a hostile aircraft could have resulted in the ship being attacked and possibly sunk. As another example, in the computer hardware industry failure to respond rapidly to changing client needs can result in loss of sales.

The more rapidly an organization can respond the more opportunities that organization should have to review its decision before making a final commitment. Such review opportunities can be vital to organizational performance. For example, investigation of the Vincennes incident suggests that the mistaken (in retrospect) decision to shoot down a nonhostile aircraft was due in part to the lack of opportunities for the organization to review its decision within the abbreviated decision period (Cohen 1988). Rapid response by software companies can result in the premature release of "buggy" products. Because both more reviews and rapid response have merit, many organizational researchers have advocated both (La Porte and Consolini 1991, Pauchant et al. 1990). The need for rapid response has caused some organizations to move to leaner and more rigid structures even though the ability of such structures to achieve high performance has not been adequately demonstrated (Hermann 1963, Staw et al. 1981).

Finally, organizational performance is affected by training. Providing personnel with experience and allowing them to act on the basis of this experience can improve organizational performance (Dunbar and Stumpf 1989, Green 1989, Carley 1992). Well-designed standard operating procedure or the use of a mechanical or electronic decision aid can also improve organizational performance (e.g., Levitt and March 1988). However, the value of training is indeterminate; i.e., organizational decision making can be flawed regardless of whether the personnel are following experiential or procedural rules. Indeed, Scott (1987) has argued that one of the major issues in organizational design is whether personnel should act based on experience or standard operating procedures.

3. Framework Description

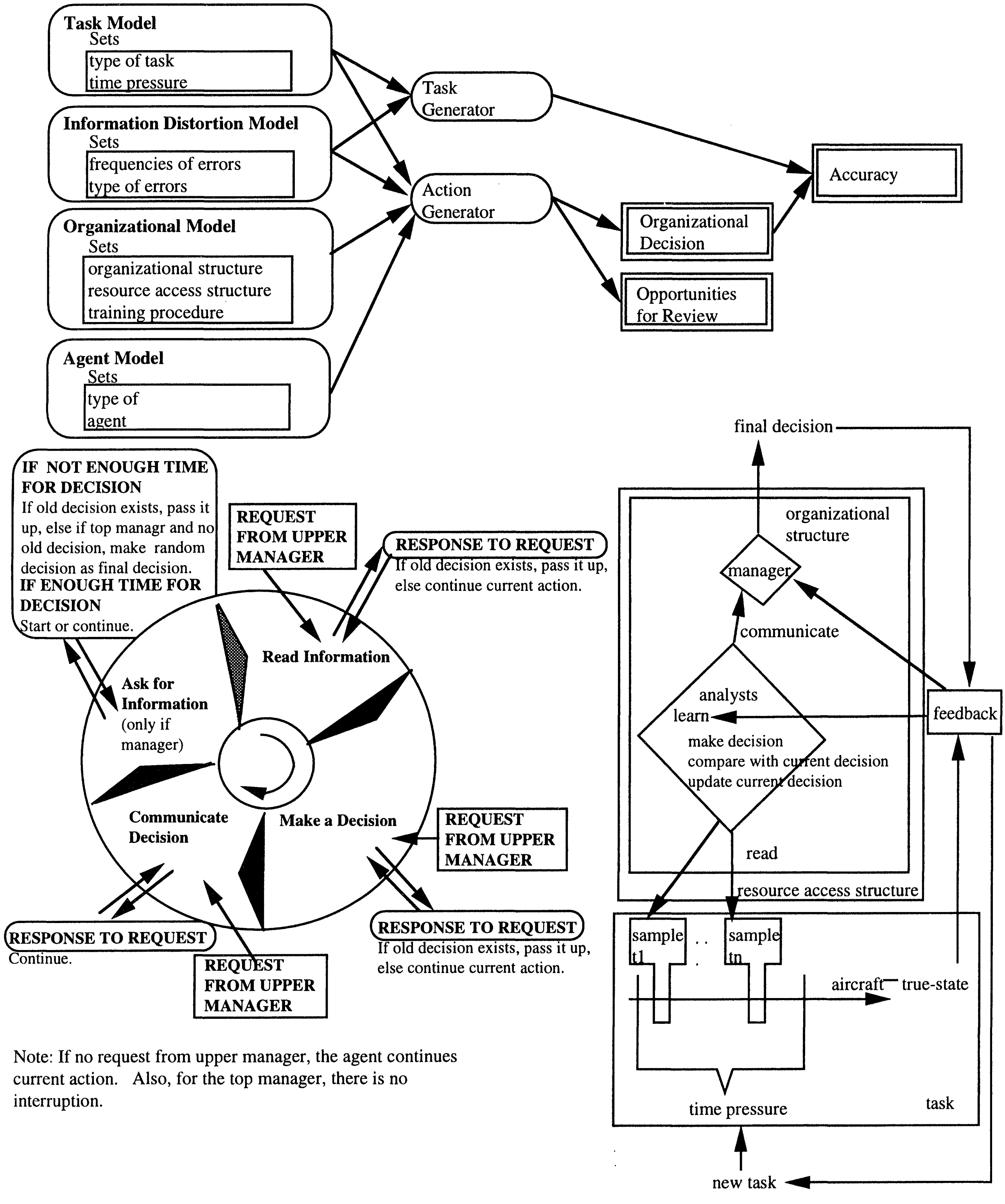
The DYCORP[2] framework is a computational testbed for examining the performance of simulated organizations faced with a dynamic classification-choice task. Classification-choice tasks, even those where the information evolves over time, are very common within organizations; e.g., budgeting and hiring decisions. In describing DYCORP, all variables used in the subsequent analyses will be placed in *Italic* type the first time they occur, and the values they can take on will be noted.

DYCORP is based on an information processing and open system view of organizations. The basic procedure by which information is processed and decisions are made is shown in Figure 2. At the top of Figure 2, input variables are shown in boxes and output variables are shown in double boxes. There are complex interactions among the various components of task, organizational design, agent, and information distortion in determining which actions each agent will take when, the number of opportunities for review, and what the organizational decision will be. By choosing options for each of the models the researcher defines the specific organization, its design, the type of agents, and the task environment to be modeled. These models determine the sequence of problems that the organization will face and which actions the agents can take when (including whether or not they learn from their mistakes, when and how they make their decisions, and whom they communicate to about what). Once an organization has been characterized, the decision-making and communication behavior of each organizational agents is simulated. Agents act, effectively, in parallel. This simulation involves processing a series of procedural rules and (sometimes) a series of equations. Because the application of some rules is stochastic, and because the task environment is also stochastic, Monte-Carlo techniques are used to estimate the average performance of each organization simulated. The exact series of rules and equations varies by organization, task, agent type, etc. being simulated (see Lin and Carley 1995, and Lin and Carley 1993 for additional details).

In DYCORP, the classification-choice task used is a highly stylized version of a radar detection task. We make no claims that we are simulating actual radar detection. The simulated organization, given information about the nature of an aircraft, must classify that aircraft as friendly, neutral, or hostile before the aircraft reaches the "red zone." The aircraft is moving, and so the information about it may change over time. However, the aircraft has a *true state* which is either friendly (=1), neutral (=2), or hostile (=3). The alternatives that the organization can choose between as the *organizational decision* are similarly limited (i.e., friendly (=1), neutral (=2), or hostile (=3)). The red zone is defined as the

[2] A detailed technical description of DYCORP appears in Lin and Carley (forthcoming).

Figure 2 An Overview of the DYCORP Framework



Note: If no request from upper manager, the agent continues current action. Also, for the top manager, there is no interruption.

point at which either the aircraft enters the danger zone[3] or the time limit is met,[4] which ever occurs first. The shorter the number of time units for making a decision (the shorter the period of time before the aircraft hits the red zone) the higher the *time pressure*. Time pressure is thus a continuous variable ranging from 1 to 60; however, for this study we have categorized it as low (41–60 time units = 1), medium (21–40 time units = 2), and high (1–20 time units = 3).[5] This categorization scheme divides the range into thirds. Further, when the time pressure is high, at most 25 percent of the organizations will have had the opportunity to complete a decision cycle. Whereas, when the time pressure is low, all organizations will have had the opportunity to complete two or more decision cycles and so will have been able to review their decision at least once.

The organization faces a sequence of these radar-detection problems. Each problem is defined as a single aircraft moving through the airspace. Each aircraft is characterized by nine indicators or parameters. Each parameter provides some information about the state of the aircraft. Analysts within the organization can access information about one or more of those parameters. Information about a specific parameter is not sufficient to determine the true state of the entire aircraft. After the problem is "over" (i.e., the aircraft has hit the red zone) the organization's decision at that point is recorded as its final decision. Then a new problem (i.e., aircraft) occurs and the process repeats (see bottom right of Figure 2). When an aircraft appears in the airspace the organization can track the aircraft and can make a series of preliminary decisions about the state of the aircraft, which may be overturned prior to the final organizational decision. The number of decisions made by the organization for each problem is recorded by the framework. However, organizational performance is judged only on the basis of the final organizational decision.

As the aircraft moves the values for some parameters may change[6]; e.g., its speed may increase. The true state of the aircraft cannot change. If an aircraft takes N time units before it hits the red zone then that aircraft has moved through N different sets of parameters. We can think of each set of parameters as a state description. The space of state descriptions for each aircraft in this study is sufficiently small that each state description is associated with the same true state. Thus, regardless of when an analyst gathers information on an aircraft (e.g., $t1$ or tN on the bottom right in Figure 2), the information gathered is of equal value in predicting the true state of the aircraft.

This task is distributed; that is, no analyst has access to information on all nine parameters. Further, the task does not require consensus; rather, it is sufficient that the CEO (chief executive officer) or a majority of the agents at the top level in the organization choose that alternative. The final organizational decision can only be reached through communication and coordination, and the organizational design structures these processes. The three components of design are the *organizational structure*, the *resource access structure*, and *training*. In DYCORP the organizations have procedures for providing feedback to agents, 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 the correct organizational decision.[7] In all organizations, agents communicate their decisions only to their immediate supervisor(s). Exactly how these various procedures are instantiated depends on the organizational design.

Which organizational members communicate what to whom depends on the organizational structure (a matrix linking organizational members to each other in terms of the flow of recommendations). All

[3] In DYCORP the danger zone occurs at a one-mile range or a 5000-foot altitude. The number of time units until an aircraft enters the danger zone depends on its speed, direction, angle, and altitude.

[4] The time limit is the maximum number of time units that the organization is allowed to spend on that problem. This number is between 1 and 60 and is randomly assigned to each problem. A time limit is needed as not all aircraft enter the danger zone.

[5] Storage constraints prevented saving the exact time pressure for each organization.

[6] The exact formula for change is given in Lin and Carley (forthcoming).

[7] During training, there was no time pressure. Each agent's memory includes information only on task categorization experience, not time pressure.

organizational structures have between one and three levels of personnel. The agents on the "bottom" level are referred to as analysts and are the only agents who can directly observe information about the nine parameters. All organizations in DYCORP have nine analysts, zero to three mid-level managers, and zero or one CEO. Exactly who makes the organization's decision depends on the organizational structure. When there is a CEO, the CEO makes the organizational decision. Otherwise, if there is a single mid-level manager, that agent makes the decision; otherwise the agents (all of whom are at the same level) vote, their votes receive equal weight, and a majority rule procedure is used to generate the organizational decision. In the voting case, if no alternative dominates then the organization randomly picks between the two or three alternatives with the same (and largest) number of votes. Among the structures in DYCORP are team with voting (=1), team with a manager (=2), hierarchy (=3), matrix_1 (=4), and matrix_2 (=5). In the team with voting there are only nine analysts, each of whom gets an equal vote toward the decision. In the team with a manager, the nine analysts report to a single manager who makes the organizational decision. In the hierarchy there is one CEO, three mid-level managers, and nine analysts. Three of the analysts report to each mid-level manager who in turn reports to the CEO. The CEO makes the organizational decision. Matrix_1 is a hierarchy where six of the nine analysts each reports to two mid-level managers.[8] Matrix_2 is a hierarchy where each of the nine analysts reports to two mid-level managers.

No one analyst sees information on all nine parameters. Which analyst has access to what information is defined by the resource access structure (a matrix linking analysts to task parameters). Managers (mid-level or CEO) only see the recommendations of their subordinates. The resource access structure[9] determines the distribution to the analysts of raw incoming information on the problem. We can think of the resource access structure as determining 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 set of characteristics (perhaps one). Among the resource access structures in DYCORP are the following: segregated_1 (=1), segregated_2 (=2), overlapped_1 (=3), blocked (=4), overlapped_2 (=5), and distributed (=6). In the two segregated structures, each analyst has access to one characteristic, although they differ in which analyst sees which characteristic. In the overlapped_1 structure each analyst has access to two characteristics and each characteristic is accessed by exactly two analysts. In the blocked structure each analyst has access to three characteristics. Further, three analysts see exactly the same three task components. 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). In the overlapped_2 structure each analyst has access to three characteristics. Further, each analyst shares one pair of characteristics with one other analyst, and another pair or characteristics with another analyst. In the distributed structure each analyst has access to three characteristics. Further, no two analysts see exactly the same information. If these analysts are in a hierarchy or a matrix then each middle-level manager has indirect access to all nine pieces of information.

There is an interaction between the organizational structure and the resources access structure as the impact of the resource access structure depends on who reports to whom. Teams do not have divisions[10]; thus, the effect of different resource access structures should be less pronounced in a team than in a hierarchy where the personnel divisions may or may not line up with the resource divisions.

[8] An important aspect of matrix organizations as defined by Davis and Lawrence (1977) is that individuals at one level will report to multiple individuals at another level, thus causing the same information to move between divisions. There are clearly other characteristics of matrix organizations. This is the only aspect that we consider.

[9] Resource access structure has also been referred to as the information access structure (Carley 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).

[10] 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-a-manager structures, the distinctions among divisions are not as apparent.

How an agent processes information depends on its type. Within DYCORP there are two types of agents—proactive and reactive. In Figure 2, (bottom left) the proactive agent used in this paper is illustrated.[11] A proactive agent engages in the organizational decision making process whenever possible. It orders its actions as follows: ask for information, read information, make a decision, pass decision (recommendation). The only other action an agent can take is to wait, which can occur at any time. Proactive agents do not wait to be told what to do but actively enter into this cyclic process and stay in it until the aircraft enters the red zone. At that point the organizational decision is made, the agent receives feedback and updates its memory (if it is experiential), and performance is calculated for the organization. Each action in this cycle takes a certain amount of time: ask (one time unit), read (number of pieces of information*one time unit), make a decision (if agent is untrained then one time unit, else if agent is procedurally trained then number of pieces of information*one time unit, else if agent is experientially trained number of pieces of information*two time units),[12] pass decision (one time unit), wait (one time unit). Each agent (except the CEO[13]) can be interrupted at any point in this cycle by a request from a supervisor for a decision. This is indicated by a box and arrow in the lower left of Figure 2. When the supervisor's request arrives the agent responds during the following time unit. If an agent has not previously made a decision it will make a guess and pass that guess on as its decision, otherwise it will pass on its current decision. Only actions that take more than one time unit (read information and make a decision) can be disrupted. After responding to the request, the agent returns to the action in which it was engaged when the supervisor's request arrived. The agent's organizational position (CEO, mid-level manager, or analyst) alters this process slightly. The mid-level manager can be interrupted as well as ask for information. Whereas, the CEO cannot be interrupted (because there is no superior), and an analyst cannot ask for information (because there is no subordinate). Further, when time runs out, the CEO's current decision is the final or organizational decision.

How agents update their current decision using new information depends on the type of training they have received. If agents are trained to follow SOPs then they use SOPs to make a new/current decision using only the new information. In contrast, experientially trained agents create a new decision by integrating new information with their old decision using a belief adjustment model. Specifically, each agent, regardless of position, changes its current decision from its old decision to its newly calculated decision for that problem if the new is different than the old and the agent's confidence in the new is 10 percent*(absolute difference between old and new decision) higher than its confidence in the old. If the new decision is the same as the old, the agent's current decision remains unchanged and the agent's confidence increases if the agent's confidence in its' new decision is higher than its' confidence in its' old decision. Otherwise, the agent's confidence remains unchanged.

Training determines how an agent adjusts its decision on a particular aircraft and how it learns from feedback. Among the types of training procedures in DYCORP are experiential training (=1), and procedural training (=0). The agents trained experientially are trained on a sequence of 19,683 problems (all possible problems in the task environment). During training there is no time pressure. 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 need to learn. For agents trained procedurally, training occurs "off line." The agents "memorize" standard operating procedures (SOPs). Within an organization all agents are either experientially trained or procedurally trained.

Experientially trained agents make new decision on the basis of current information and previous personal experience. First they classify the aircraft (e.g., the pattern is low high on three characteristics) and then they make the decision that has been most often correct in the past given that classification. Agents are fully trained in that they have previously encountered all possible aircraft and have received feedback as to the

[11] Within DYCORP there is also a reactive agent. The difference in the behavior of the two agents is discussed by Lin and Carley (1993).

[12] This reflects the idea that individuals making decisions using experience typically take longer to make decisions than individuals following standard operating procedures.

[13] Only supervisors can interrupt agents, and the top-level manager has no supervisor.

true state of each aircraft. Following standard learning theory procedures (Carley 1992), these agents build up memories based on their experience linking each possible incoming pattern of information to the frequency with which that pattern is associated with a particular outcome. These memories are treated as rules of the form "if the aircraft has pattern x then make as the decision the one that was most correct in the past." Experientially trained agents follow these rules without error and no longer alter their memory. Thus, their expectations remain fixed.

Procedurally trained agents make their new decision on the basis of current information and standard operating procedures (SOPs). This type of learning is often mentioned in organization theory, particularly in military settings. Procedurally trained agents sum the available information. Then they report that the aircraft is friendly if the sum is in the lowest third of the range; hostile if it is in the top third of the range; and neutral otherwise. The procedurally trained agents are effectively fully trained, follow these rules without error, and no longer alter their memory. Thus, their expectations remain fixed.

The distribution of possible problems constitutes the *task environment*. The task environment can vary. In each task environment there are 19,683 unique aircraft (this is based on the aircraft's initial values on the nine characteristics, each of which can take on three values). The nature of the task environment determines which of the possible states (friendly, neutral, or hostile) is the true state for each aircraft. Within DYCORP the task environments vary on two characteristics—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). The four resultant environments are (ordered from simple to complex): concentrated-decomposable (=1), dispersed decomposable (=2), concentrated nondecomposable (=3), and dispersed nondecomposable (=4).

A task environment is decomposable if there are no complex interactions among task characteristics that need to be processed in order to solve a particular problem. In contrast, when the task is nondecomposable the pieces of information do not contribute equally to the final decision, and task characteristics may interact to determine the aircraft's true state. A task environment is concentrated if the possible outcomes are not equally likely. The inequality of outcomes in the concentrated environments, or niches, biases perception. In contrast, in a dispersed environment approximately one third of the 19,683 aircraft (6,568) are hostile, one third are friendly, and the remaining third are neutral. This environment can be thought of as being uncertain because the chances of all three outcomes are identical.

Within DYCORP information distortions can cause analysts to access incorrect information, fail to access information, fail to report decisions, and so forth. In this paper, this feature is not used, and there are no information distortions other than those induced by the organizational design. Thus, the DYCORP results presented in this paper should be interpreted as showing organizational performance when all personnel are working at peak and error-free capacity or as employing decision aids that help them operate error free.

4. Simulation Experiment

The DYCORP framework, as is true for many of the modern computational frameworks, is sufficiently complex that not all aspects of the model can be simultaneously tested. Other models with this property include the Virtual Design Team (Levitt et al. 1994), the organizational consultant (Baligh et al. 1990), Hi-TOP (Gasser and Majchrzak 1992), and ACTION (Gasser and Majchrzak 1994). Thus, virtual experiments need to be run that control some factors and vary others. Within DYCORP the researcher can vary the organizational structure, the resource access structure, the training scenario, the agent style, the type and level of information distortions, and the task environment. By allowing these variables to be simultaneously considered, DYCORP effectively combines structural theory, resource dependency theory, institutional theory, and social theory in a single framework.[14]

Using DYCORP we run a virtual experiment by varying the organizational structure (five types), the resource access structure (six types), the training (two types), the task environment (four types), and the time pressure (three types). The variables identified result in

[14] For a discussion of the effect of agent style see Lin and Carley (1993).

Table 1 Measure of Organizational Cost

Resource Access Structure	Organizational Structure				
	Team with Voting	Team with Manager	Hierarchy	Matrix 1	Matrix 2
Segregated 1	18	37	46	64	73
Segregated 2	18	37	46	64	73
Overlapped 1	27	46	55	73	82
Blocked	36	55	64	82	91
Overlapped 2	36	55	64	82	91
Distributed	36	55	64	82	91

organizations with sixty different designs (5 × 6 × 2) operating in four different task environments, under three levels of time pressure, each faced with 19,683 problems/aircrafts. Each of these 720 scenarios are simulated twenty times. Within each scenario, the organization's opportunities for review, cost, match, and performance are calculated.

4.1. Opportunities for Review

In a dynamic task, the organization may have time to make more than one decision before the aircraft reaches the red zone. Thus, the organization has multiple opportunities to review its decision before coming to a final decision. The number of review opportunities is measured as the number of organizational decisions generated for a problem prior to and including the final organizational decision. The number of review opportunities is a function of the organizational structure, the resource access structure, the training procedure, and the level of time pressure.

4.2. Organizational Cost

The complexity of the organization can be thought of as organizational cost. Organizational cost can be measured as the summation of pieces of information being processed and reported and the communication linkages (Malone 1987). Malone (1987) defined organizational cost as the summation of production cost, coordination cost, and vulnerability cost. Production cost can be thought of as the information processing cost. Coordination cost can be thought of as the communication cost. Vulnerability cost is that cost due to failures at certain positions in the organization. As vulnerability cost is measured in terms of the expectation of such failure, it is not measurable in our model. Sans vulnerability, Malone's cost measure can be represented by the summation of the information processing cost and the communication cost. The information processing cost is the total number of pieces of information being processed and report by agent summed across the agents in the organization. The communication cost is the total number of communication links installed in the organization. We list the cost of each organizational form examined in Table 1. First, however, we illustrate how cost is measured in the following example:

EXAMPLE. For an organization with matrix_1 structure and distributed task decomposition scheme, there are thirteen agents in the organization, including nine analysts, six of which have two communication links with mid-level managers. Each analyst has access to three pieces of information and reports one decision, with six of them reporting to two mid-level managers. Each mid-level manager processes five pieces of information and reports one decision. The top-level manager processes three pieces of information and reports one decision. Thus, the total information processing cost is

$$P_c = 9*(3 + 1) + 6 + 3*(5 + 1) + 1*(3 + 1) = 64.$$

Because six analysts have two communication links with mid-level managers, the total communication cost is $C_c = 9 + 6 + 3 = 18$. Thus the organizational cost is $O_c = P_c + C_c = 64 + 18 = 82$.

4.3. Matching Task and Organizational Design

One of the basic ideas behind contingency theory (Proposition 2) is that the better the match between the

Table 2 Regression Analysis for Performance and Opportunities for Review Given Basic Model

	Opportunities for Review		Performance	
Variables	Coefficient (b)	Standardized Coefficient (β)	Coefficient (b)	Standardized Coefficient (β)
Constant	6.322***	0.000***	74.319***	0.000***
Time Pressure	−1.465***	−0.787***	−12.441***	−0.695***
Training	−1.016***	−0.334***	−2.349*	−0.080*
Cost	0.008***	0.114***	−0.049**	−0.071**
Review Opportunities			−0.124	−0.013
Match			0.914	0.059
R^2	0.743		0.483	
Adjusted R^2	0.742		0.478	

$n = 14{,}400$, significance of coefficients based on a t-test (2 tail) *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$.

organizational design and the task the better the organizational performance. Essentially, complex organizations should do well in complex environments, and simple organizations should do well in simple environments. Such a match was calculated as follows. First cost was recoded on a four point scale: more than one standard deviation below the mean (=1), at most one standard deviation below the mean (=2), at most one standard deviation above the mean (=3), and more than one standard deviation above the mean (=4). Because increasing cost corresponds to increasing the complexity of the organizational design and since the tasks were already ordered in increasing complexity, match is defined as 3 − abs(cost − task). The higher this value the better the match between task and organization in terms of their complexity.

4.4. Organizational Performance

Organizational performance is measured as accuracy; i.e., the percentage of correct decisions made by the organization given the set of 19,683 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 was friendly, neutral, or hostile matches the true state of that aircraft.

5. Results and Analysis

We begin by using the computational model to determine the extent to which the propositions about factors directly impacting performance as displayed in Figure 1 are consistent. The results of the multiple regressions for opportunities for review and performance as specified in Figure 1 are shown in Table 2. We find, that Propositions 1b, 3, and 5b hold on average. In other words, organizations with less costly/complex structures, procedural training, and under low time pressure exhibit higher performance. Further, for opportunities for review there is a negative relation between time pressure and training (procedural has more opportunities for review) and a positive relation with cost.

As previously noted, the literature is somewhat ambiguous on the impact of cost and training. The results in Table 2 speak to this issue. Our model suggests that the higher the organizational cost the lower the organizational performance. The reason has to do with the extent of communication. Essentially, more costly organizations have more communication. This increase in communication decreases the speed with which the organization can respond and increases the extent of information distortion, loss, and uncertainty absorption. These results are consistent with those forwarded by researchers in the information processing tradition. Our results move beyond this conventional wisdom by also demonstrating the impact of greater cost due to greater redundancy in access to information and resources. We find that there is a "cost" to this redundancy; i.e., it decreases the speed with which the organization can respond and it decreases the organization's performance. This result is consistent with basic information processing principles but flies in the face of the idea that redundancy decreases coupling and so provides safeguards that can improve performance (Perrow 1984). Additionally, these results suggest that an organization may be faced with at least two tradeoffs. Specifically, it can be either timely or accurate (although this is not significant), and it can have safety in redundancy or it can have high performance.

One might question why the R^2 for performance is so low. There are several reasons. Most importantly is the difference between a process model, Figure 2, and the model drawn from the organizational literature, Figure 1. The process model is not simply doing linear extrapolation or doing some type of numerical estimation. Rather, it is allowing a series of procedures and equations to dynamically interact and generate performance. The result depends on complex interactions among and across these variables. Second, within the process model time pressure severely constrains organizational performance. Third, within the process model, cost, match, and opportunities for review are not basic elements but products of other more fundamental processes. We now explore these issues.

Table 3 **Regression Analysis for Performance Given Basic Model and Interactions**

	Coefficient (b)	Standardized Coefficient (β)
Constant	116.916***	0.000
Time Pressure	−27.591***	−1.541***
Training	−14.470*	−0.495*
Cost	−0.630***	−0.910***
Review Opportunities	−13.208***	−1.374***
Match	−4.905	−0.316
Time Pressure * Training	1.758	0.139
Time Pressure * Cost	0.159***	0.716***
Time Pressure * Review Opportunities	5.363***	0.477***
Time Pressure * Match	0.880	0.150
Training * Cost	0.041	0.093
Training * Review Opportunities	3.722**	0.294**
Training * Match	0.954	0.073
Cost * Review Opportunities	0.096**	0.752**
Cost * Match	0.021	0.095
Review Opportunities * Match	0.995	0.260
R^2	0.552	
adjusted R^2	0.542	

n = 14,400, significance of coefficients based on a t-test (2 tail) *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$.

5.1. Interaction Effects

In Table 3 the results of the multiple regression for performance that considers both the direct effect of the base variables and interactions among them are shown. When these interactions are controlled for propositions 1b, 3, and 5b still hold and the fit of the model has increased. In contrast to the propositions we see that opportunities for review has a negative impact on performance. However, more review opportunities when combined with high time pressure, experiential training, or high cost results in higher performance. Further, the combination of high time pressure and high cost leads to higher performance.

Let us consider some of these interactions. First is the interaction among training and review opportunities. Procedurally trained agents do not benefit from review opportunities as they always take the most recent decision, with no consideration for previous experience. Thus, there is an increase in information loss over time which serves to decrease accuracy. Experientially trained agents can integrate (albeit slowly) their decisions over time and so do not suffer from this type of temporal information loss. Consequently, organizations with experientially trained agents and many review opportunities tend to exhibit higher performance. Second, we find a positive interaction effect for review opportunities and time pressure. When time pressure is high the more opportunities the organization has to review its decisions the higher the organization's performance; whereas, when time pressure is low fewer reviews are needed. For high time pressure it is not possible to have more than two opportunities for review. Any review improves performance as it moves the organization out of the realm of guessing. Whereas, under low time pressure multiple opportunities for review result ultimately in information distortion and so lower overall performance (especially for experiential organizations). For procedural agents, because they ignore the past, increased opportunities and low time pressure simply gives them more opportunities to make mistakes. For experiential agents, because they lock onto a decision and have difficulty changing it as new information is acquired, their chance of being inaccurate can increase over time. These results suggest the following irony: when organizations can least afford the time for additional review opportunities, such reviews are the most valuable.

We also find a positive interaction between cost and time pressure on organizational performance. At first glance, one might suppose this to be suggesting that under severe time pressure costly organizations exhibit higher performance. This would support Proposition 1a. However, if we examine the issue more closely (Figure 3) we see that what is really happening is that moderately costly organizations perform better under moderate time pressure. The mechanism underlying this finding is that more complex organizations generate more information during the decision-making process than do less complex organizations. This increase in information increases the chances of complex organization making accurate decisions. Under severe time pressure the communication and redundancy costs mitigate the value of increased information. Under low time pressure the problems with complexity (increased information distortion and ambiguity) come into play and mitigate the value of increased information. However, under moderate time pressure, moderate complexity works as there is no time for distortion and ambiguity to rear their ugly heads and there is enough time that some communication and redundancy delays can be tolerated.

5.2. The Impact of Time Pressure

As these analyses suggest, time pressure has an extremely strong impact on organizational performance. Indeed, time pressure accounts for more of the variance in performance than any other single variable: 47 percent. For most organizations, when time pressure is high there is little chance to make a decision. Examination reveals that under high time pressure performance is concentrated around 33 percent ($X = 33.412$, $\sigma = 0.931$). Most organizations are simply guessing. Whereas, when time pressure is low or medium performance is not only higher on average but is much more variable (low time pressure $X = 57.93$, $\sigma = 14.81$; medium time pressure $X = 48.93$, $\sigma = 10.71$).

A re-examination of the direct impact of training, cost, opportunities for review, and match on

Figure 3 Relationships among Time Pressure, Cost, and Organizational Performance

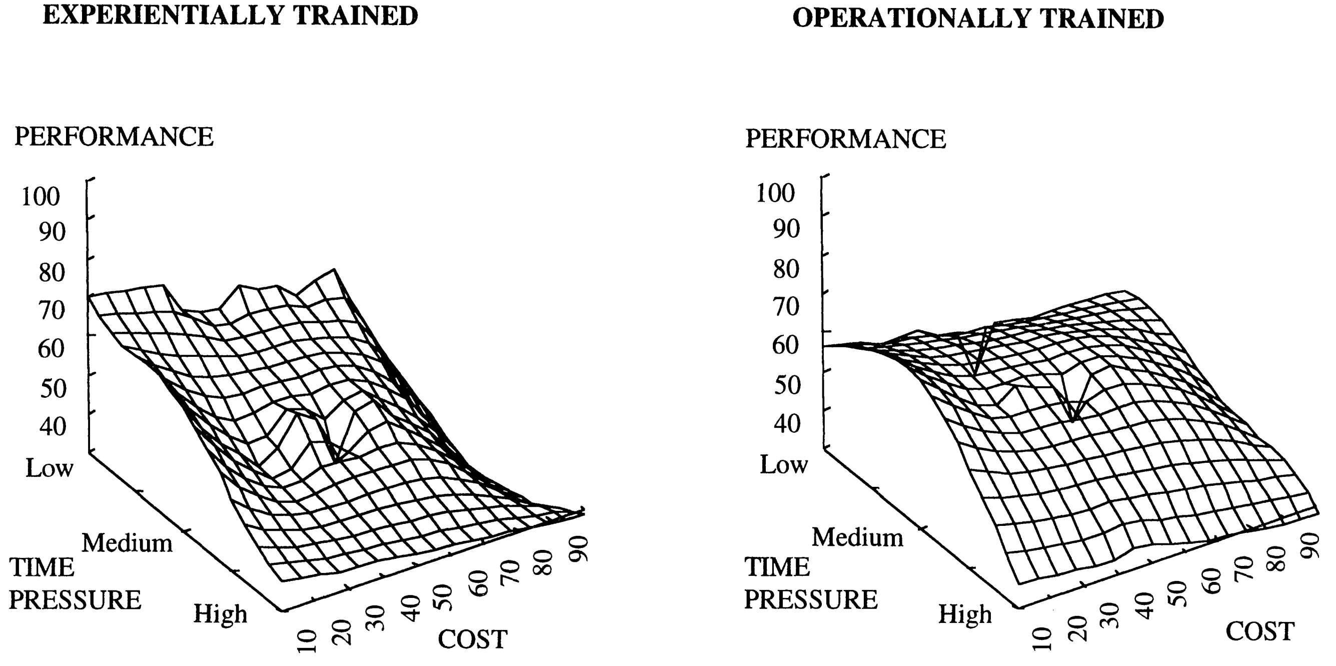


Table 4 Regression Analysis for Performance by Level of Time Pressure

	Performance		
Time Pressure Variables	Low Standardized Coefficient (β)	Moderate Standardized Coefficient (β)	High Standardized Coefficient (β)
Training	0.107	−0.136	0.002
Cost	−0.081	−0.159*	−0.070
Review Opportunities	−0.032	0.430***	0.727***
Match	0.066	0.044*	0.043
R^2	0.030	0.340	0.547
adjusted R^2	0.013	0.328	0.540

$n = 4{,}800$, significance of coefficients based on a t-test (2 tail) *** = $p < 0.001$, ** = $p = < 0.01$, * = $p < 0.05$.

performance for each of the three levels of time pressure is insightful. These results are shown in Table 4. Only standardized coefficient are presented. First, the lower the time pressure the less these traditional variables explain performance. Second, under both moderate and high time pressure, opportunities for review has both a significant effect and more of an impact on performance than does any other factor. Further, only under moderate time pressure do we see support for Proposition 1b, the lower the cost the higher the performance.[15] Also, only under moderate time pressure do we see support for Proposition 2, having a match increases performance. The fact that Propositions 1b, 2, and 4 are consistent with the model, but only under moderate time pressure, suggests that perhaps much of the prevailing wisdom in organizational science is drawn from studies of organizations under moderate, but not severe, time pressure.

In Tables 2 and 3 we saw that the impact of opportunities for review was not only not significant it was negative. By contrast, in Table 4 we see that under moderate and high time pressure opportunities for review have a strong and positive effect on performance. The basic reason for this difference is that the range of opportunities for review decreases dramatically with the level of time pressure. Thus, organizations with relatively many opportunities for review under both moderate and high time pressure still may have fewer absolute review opportunities than do organizations with low time pressure. Thus, the negative and insignificant overall effect seen in Tables 2 and 3.

Thus, let us consider the tradeoff between cost and the relative number of opportunities for review in effecting performance for each level of time pressure. In table 4, a low cost organization has a cost less than or equal to the mean cost; whereas, a high cost organization is greater than the mean. A low opportunities review organization has fewer than or equal to the mean number of opportunities for review for that level of time pressure; whereas, a high opportunities for review has more than the mean number of opportunities for review for that level of time pressure. As can be seen in Table 5 the impact of cost and opportunities for review changes as the time pressure changes. Low cost organizations with relatively fewer review opportunities do best when there is little, if any, time pressure. Whereas, under moderate and high time pressure, low cost organizations with relatively more review opportunities do best. These results suggest that time pressure and number of review opportunities are the two factors that most affect performance. Furthermore, only under moderate time pressure does the organization's design directly impact its performance.

Table 5 Relative Impact of Cost and Opportunities for Review on Performance

		Average Performance	
		Few Review Opportunities	Many Review Opportunities
Low Time Pressure	Low Cost	59.45	56.44
	High Cost	58.34	55.68
Moderate Time Pressure	Low Cost	45.10	55.92
	High Cost	43.35	53.51
High Time Pressure	Low Cost	33.27	36.33
	High Cost	33.23	33.44

[15] Previously, we saw that Proposition 1b held on average when controlling for time pressure. This effect held on average because there is always a trend that lower cost organizations exhibit higher performance, except under severe time pressure; but this trend is only significant when the time periods are separated for moderate time pressure.

6. Discussion and Conclusion

In this analysis we have employed computational techniques to derive a set of logically consistent propositions about the inter-relationship among time pressure, opportunities for review, training, cost, and the match between environment and design and their impact on organizational performance. Results from this process model demonstrate which of the propositions in the literature logically fit together. Specifically, we find that lower cost organizations (Proposition 1b), subject to low time pressure (Proposition 3), and employing procedurally trained agents (Proposition 5b) tend to exhibit the highest performance. Additional analyses show that these propositions are consistent with the process model only in general. When different levels of time pressure are considered, we see that not only does performance decrease as time pressure increases, but that under moderate time pressure lower cost organizations (Proposition 1b), match (Proposition 2), increased review opportunities (Proposition 4), and procedural training (Proposition 5b, although the effect is not significant) all are consistent with the process model. This result suggests that much organizational theory may really be a theory of performance under moderate time pressure. We find no support for Propositions 1a and 5a, which state that organizational complexity/cost and experiential training improve performance. Rather, we find that complexity and experiential training impact performance, but only through their interaction with other design components.

In a sense, we are following in the Weberian mold of analyzing ideal types and seeing what logically follows from these idealizations. Of course, these idealizations can be thought of as limits to the proposed model. Consider the following two idealizations. First, when we examine opportunities for review by organizations, we only look at the number of intermediate decisions made by the top-level manager. We do not count all the intermediate decisions made by other members of the organization. Future research might examine the impact of these intermediate decisions on the organizational performance. Second, we assumed that individuals were acting in an error-free and full information manner. As such, the results should not be interpreted as descriptive of actual organization behavior but as setting limits on the best that organizations can do without human or other information-processing error. In this vein, we have shown that organizational design, in and of itself, can influence organizational performance. Specifically, organizational design, because it influences the number of review opportunities, can have a major impact on organizational performance under both moderate and high time pressure. Under low time pressure, organizational design appears to be less important. Future research should look at the interaction between individuals' ability to process information and organizational design in influencing organizational performance under different levels of time pressure.

In this paper, we systematically examined the relationship among time pressure, training, opportunities for review, cost, the match between organizational design and task, and organizational performance. The results go beyond the traditional contingency theory argument, that the impact of design is relative, to a specified ranking of the variables based on their relative impact. We find that the major factor affecting performance is time pressure followed by the number of review opportunities. Further, these results suggest that organizations may be faced with at least two tradeoffs. Specifically, they can be either timely or accurate, and they can have safety in redundancy or high performance. There are, however, complex interactions among cost, review opportunities, and performance that change as the level of time pressure faced by the organization changes. Thus, organizations that can rapidly make decisions and so have many opportunities for review enjoy higher performance under moderate or high time pressure but not under low time pressure.

Finally, our results support the notion that more review opportunities and more information do not necessarily improve organizational decision-making performance, particularly when there is no time pressure. However, where Feldman and March (1981) argued that this was because much information served in a purely symbolic capacity, we argue that this result follows from structural constraints that the organizational design places on information flow.[16]

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