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DYCORP: A COMPUTATIONAL FRAMEWORK FOR EXAMINING ORGANIZATIONAL PERFORMANCE UNDER DYNAMIC CONDITIONS*

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In an attempt to systematically address what factors affect organizational performance, we built a dynamic computational framework for examining organizational performance in which organizations are composed of intelligent adaptive agents. Using this framework the user can contrast organizations with different designs, existing in different task environments, and subject to different stresses. We demonstrate the value of this model by examining how training and stress affect organizational performance.

KEY WORDS: Computational organization theory, organizational design, organizational learning, organizational performance, simulation, stress.

INTRODUCTION

Why do some organizations perform better than other organizations? Why do some organizations sustain stress while others do not? How does training affect organizational performance? These questions have puzzled generations of researchers in organizations, who, from different perspectives, have provided numerous, yet often contradictory explanations to these phenomena.

A variety of factors contribute to organizational performance (Scott, 1987; Thompson, 1967). These factors include: (1) task environment, which can be characterized in terms of decomposability (Carley, 1992; Roberts, 1989, 1990), bias, niche-centeredness or concentration (Carley, 1990; Carley, 1991a; Aldrich, 1979; Hannan and Freeman, 1977), and timing (Lin and Carley, forthcoming; Peters et al., 1984); (2) organizational design which includes factors such as structure (Cohen,

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March and Olsen, 1972; Mackenzie, 1978), resource access structure[1] (Mintzberg, 1983; Thompson, 1967), training scenario (Hammand, 1973; Salas et al., 1992), and agent style (Blumberg, 1987; Lin and Carley, forthcoming; Pauchant et al., 1990); and (3) stress which includes external stressors such as crises (Perrow, 1984; Shrivastave, 1987), internal stressors such as murphies (March and Olsen, 1976; Perrow, 1984), and time pressure (Means et al., 1992; Rothstein, 1986). Each factor may have a unique impact on organizational performance, and no single factor is the sole determinant of organizational performance.

Despite the often tacit acknowledgment that these factors are intimately related (Scott, 1987; Zey-Ferrell, 1979), few studies have systematically and simultaneously explored, from both a theoretical and an empirical perspective, the impact of these factors on organizational performance. Contingency theory has demonstrated that there is no one best design and that what design works when is contingent on a large number of factors. However, as noted by critics of contingency theory (Schoonhoven, 1981; Scott, 1987) the contingency arguments do not provide a set of precise predictions regarding how the various elements of design affect performance. In addition, contradictions exist in the literature as to the impact of these factors on performance. For example, Mackenzie (1978) argues that the degree of hierarchy is linked directly to the organization's efficiency. Roberts (1989) suggests that "hierarchical structures should increase the reliability of performance." In contrast, other people claim that hierarchies may exhibit lower performance due to information loss through the process of condensation (Jablin et al., 1986) or inability to absorb uncertainty under internal stresses (March and Simon, 1958). Davis and Lawrence (1977) suggested that a matrix only exhibits high performance if the task environment is complex. However, Houskisson and Galbraith (1985) showed that matrix type organizations improved organizational performance even when the task environment is simple.

This paper presents a computational framework that can be used to systematically explore the contingencies underlying organizational performance. Using this framework the researcher can generate a series of precise, and therefore refutable, predictions about the relationships among design, task, stress and performance. The model allows for crucial factors that must be inter-related, non-linearity of the interrelations, and adaptiveness of the agents in the organization (and so the adaptiveness of the organization).

The use of a computational framework is complementary to the expert system's approach of Burton and Obel (1990). Burton and Obel (1990), based on multiple previous empirical studies, developed an expert system in which optimal organizational design can be suggested for organizations to obtain better performance under certain situations. Our approach is to develop a computational learning framework that the user can employ to compare and contrast the performance of organizations with various factors in which researchers of organizations are interested.

We will first describe the characteristics of the DYnamic Computational ORganizational Performance (DYCORP) framework, illustrating the framework by a description of one of the organizations that can be built and examined.

[1] Resource access structure has also been referred to as task decomposition scheme (e.g., Lin and Carley, 1993), or information access structure (e.g. Carley, 1991a, 1992).

TABLE 1
Possible Organizational Designs and Environments

Feature	Categories	Number
Organizational Structure	team with voting team with manager hierarchy matrix	4
Resource Access Structure	segregated overlapped blocked distributed	4
Training	experiential operational none	3
Agent Style	proactive reactive	2
Murphies	missing information incorrect information agent unavailability communication channel breakdown agent turnover	5
Murphy level	none low medium high	4
Time Units Assigned	low 1 to high 60	60
Task Environment	concentrated decomposable, dispersed decomposable, concentrated nondecomposable, dispersed nondecomposable	4

DESCRIPTION OF DYCORP

DYCORP is built in the C language, with modules for task environment, organizational design, and stress. Within DYCORP, there are four models written in UNIX C. We have run them on an HP workstation.

DYCORP can be used to examine the impact of one or many factors on organizational performance. Each of the organizations simulated in DYCORP is modeled as an open system with links to the task environment. Further, each organization can be subjected to various types of stress.

Organizational Design

DYCORP enables the researcher to contrast a total of 460,800 unique organization and environment combinations, as summarized in Table 1. Organizational design in DYCORP is characterized using four design elements—organizational structure, resource access structure, organizational procedures (herein limited to procedures for providing training, feedback, communicating recommendations, and combining these to create an organizational decision), and agent style.

Organizational Structure

Four structures can be examined in DYCORP: team with voting, team with manager, hierarchy, and matrix.[2] Each structure consists of nine analysts. In addition, some structures employ middle and/or top-level managers.

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 a 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 th eorganizational 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—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[3] determines the distribution of raw (unfiltered) information to analysts in the organization. Each analyst can garner information on a particular (or a particular set of) characteristics, and a researcher can examine four resource access structures: segregated, overlapped, blocked, and distributed.

1. Segregated—In this structure each analyst has access to one task component.
2. Overlapped—In this structure each analyst has access to two task components. Each task component is accessed by two analysts.
3. 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.

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

[3] The resource access structure has also been referred to as the information access structure (Carley, 1991a, 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).

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).

4. 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.

These structures vary on two dimensions—how much information overlap exists and where the overlap occurs. There should be be an interaction between the organizational structure and the resources access structure as the impact of where the overlap occurs depends on who reports to whom. The teams do not have divisions[4] 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.

Organizational Decision Making Procedures Due to Training

The artificial organizations examined in DYCORP have procedures for feedback, communicating recommendations, combining recommendations to create an organizational decision, and training. 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 by the supervisor. Agents during their training phase receive accurate and immediate feedback as to what is the correct organizational decision. Training procedures can be systematically varied across all organizations.[5] DYCORP can be used to examine the effects of 3 training procedures—no training, experiential training, and training in standard operating procedures (SOPs).

DYCORP can record organizational performance during training or after training. The untrained agent simply guesses and it is correct 33% of the time. The agents trained experientially, are trained without time pressure on a sequence of problems[6] representing all possible initial conditions. For agents trained operationally, training occurs "off line." The agents can still see the problem cases but they apply the standard operating procedures correctly the first time and every time. In the untrained condition, the agents have no historical information or standard operating procedure on which to base their recommendation so they simply guess.

Agent Styles

In DYCORP two types of agents are available to the user: proactive and reactive.

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[4]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.

[5]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.

[6]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 miles/hr and 250 mile/hr are both characterized as of low value or of friendly nature.

Within a proactive organization, each agent asks for information,[7] reads information if there is information, makes a decision based on the information, then passes up the decision. This process repeats until a time limit expires. Each agent's process (except the top-level manager's[8]) 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 cannot ask for information (since there is no subordinate), while a middle-level manager can be interrupted as well as ask for information. Further, the top-level manager has the power to decide which decision will be used as the final organizational decision.

Within a reactive organization, each agent continues reading information (if there is any) until a time limit expires or the agent is told by the top-level manager to stop.[9] All agents other than the top-level manager can be interrupted by a request for a decision from an upper manager. Upon receiving a request an agent will stop reading information (if not finished yet), make a decision, and pass up the decision. Unlike the proactive agent case, a reactive agent will not make a decision and pass on the decision unless requested to do so by his or her manager. Again, there are differences in styles among the top-level manager, middle-level managers, and analysts, as described in the last paragraph.

Stress

DYCORP can be used to examine three types of stress—external stress, internal stress, and time stress.

Crises to the organization are stresses that emerge external to the organization (such as hostile events). Crises typically have the potential to result in catastrophic consequences. This is similar to the definition of "stress" suggested by Staw et al. (1981).

Murphies represent internal, and to an extent, unsurprising internally based stress. Murphies are expected to create internal ambiguity within the organization (March and Olsen, 1976; March and Simon, 1958), thus impeding the organizational decision-making process. In DYCORP the researcher can examine 5 different types of murphies—missing information, incorrect information, agent unavailability, agent turnover, and communication channel breakdown.

Within DYCORP the user can vary the degree of severity for murphies. Three levels of severity can be examined—low (1 murphy occurs), medium (2 murphies occur), and high (3 murphies occur). In reality, multiple types of murphies typically co-occur, but within DYCORP, only a single type of murphy can be examined at a time, even when there are co-occurring murphies.

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[7]For an analyst, he or she does not have to ask for information as there is no subordinate.
[8]We assume that only supervisors can interrupt agents, and that the top-level manager has no supervisor.
[9]The top-level manager asks for information first, then tries to read decisions from subordinates.

For each organization, the location of the one or more murphies is chosen randomly before each decision cycle. For example, a technology based murphy such as missing information is equally likely to occur for each of the 9 task characteristics. An agent related murphy is equally likely to occur for each analyst.

1. Missing Information—This occurs when one or more of pieces of the incoming information for a particular problem is not available.
2. Incorrect Information—This occurs when incoming information is erroneous.
3. Agent Unavailability—This occurs when one or more analysts is not available to help the organization solve the problem and so does not report his or her decision to his or her manager.
4. Communication Channel Breakdown—This occurs when one or more analysts are unable to report to a superior because the communication channel is unavailable. This can be thought of as a failure in the communication technology, or, as ignorance of the necessity of communication.
5. Agent Turnover—This occurs when one or more analysts leave the organization and are replaced by a new analyst.

Time Stress (Time Pressure)

Within DYCORP the researcher can examine three levels of time pressure: low, medium, and high. A low time pressure puts little or no time constraint on the organizations. In this case, the organizational decision making process is least affected by time. A high time pressure puts great pressure on an organization to quickly respond and so constrains the organization's decision making process. A moderate time pressure places some constraint on the decision process. As DYCORP is a dynamic model, interactions among agents is 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).

MEASURES OF ORGANIZATIONAL PERFORMANCE

Organizational performance is defined as the percentage of correct decisions made by the organization given a set of problems presented to the organization. DYCORP examines performance relative to overall organizational performance, and with respect to organizational performance under external stress. Mistakes under this condition have severe repercussions (e.g., the organization might lose the war). DYCORP can also measure performance relative to the number of time units allowed.

INPUT AND OUTPUT

The DYCORP framework is composed of four models: one focusing on organizations that are experientially trained and composed of proactive agents; another focusing on organizations that are experientially trained and composed of reactive agents; another focusing on organizations that are operationally trained and composed of proactive agents; and the last focusing on organizations that are opera-

TABLE 2
Output from DYCORP

Column ID	Header	Possible Values
1	type of task environment	1—concentrated decomposable 2—dispersed decomposable 3—concentrated non-decomposable 4—dispersed non-decomposable
2	type of organizational structure	1—team with voting 2—team with manager 3—hierarchy 4—matrix
3	type of resource access structure	1—segregated 2—overlapped 3—blocked 4—distributed
4	type of murphies	1—missing information 2—incorrect information 3—agent unavailability 4—communication channel breakdown
5	level of murphies	0—no murphies 1—one murphy 2—two murphies 3—three murphies
6	level of time pressure	1—high level of time pressure 2—medium level of time pressure 3—low level of time pressure
7	percentage of correct answers over all 1000 problems	
8	percentage of one-away answers over all 1000 problems	
9	percentage of two-away answers over all 1000 problems	
10	percentage of answers as friendly over friendly	
11	percentage of answers as neutral over friendly	
12	percentage of answers as hostile over friendly	
13	percentage of answers as friendly over neutral	
14	percentage of answers as neutral over neutral	
15	percentage of answers as hostile over neutral	
16	percentage of answers as friendly over hostile	
17	percentage of answers as neutral over hostile	
18	percentage of answers as hostile over hostile	

tionally trained and composed of proactive agents; and the last focusing on organizations that are operationally trained and composed of reactive agents.

The performances generated by the four models are stored in four corresponding output files, formatted as matrices. They can be read in and analyzed by standard statistical packages. Each row in these matrices corresponds to a different organizational design and environment combination. Each of the 18 columns corresponds to a different design or environment characteristic or a performance measure, as defined in Table 2.

AN ILLUSTRATION OF THE DYNAMICS OF DYCORP FOR A SPECIFIC CASE

We illustrate the process by which DYCORP organizations make decisions through a detailed example, in which the organization has a hierarchical structure and a segregated resource access structure. The organizational hierarchy is 3-tiers, and is composed of a top-level manager, 3 middle-level managers, and 9 analysts. Each analyst reads one piece of information. The agents are experientially trained and proactive, and all are fully trained. The organization faces a dispersed decomposable task environment and is subject to moderate time pressure (30 time units per problem) and missing information.

The organization faces a sequence of 1000 problems. For each problem, the organization must arrive at a decision (see Figure 1 for a top level description of the decision process). Since this is a distributed decision making process, each agent in the organization works according to his or her role. Agents coordinate through communication links.

Constrained by time and resource, each agent has a set of possible actions: (1) ask for information, (2) read information or get a recommended decision from lower personnel, (3) make a decision, (4) pass up (or stores, as for top-level manager) the decision, and (5) wait. Each action takes a certain number of time units[10] depending on number of pieces of information and the decision procedure involved. For example, an analyst who reads information from one source takes one third of the time needed by another analyst who reads information from three sources. Experiential decisions take twice the time of operational decisions. This is because experiential decisions involve analyzing current information and correlating experience with current information; whereas, operational decisions only involve analyzing current information.

During the organizational decision making process, each agent in the organization reads information and generates an opinion based on plausible actions. Clearly there are 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 cannot ask for information (since there is no subordinate), while a middle-level manager can be interrupted as well as ask for information. Further, the top-level manager has the power to decide, if more than one decision is made within the time period, which decision will be used as the final organizational decision.[11] How agents communicate depends on their position in the organization and their style.

As time permits, the top-level manager continues to search for plausible actions, chooses action based on his or her preference, then takes a possible action such as

[10]In this paper, we set two seconds as one time unit. This is according to initial lab experiments using human subjects on decision making by Kathleen Carley and Michael Prietula of Carnegie Mellon University. In the experiment each subject processes 120 problems in about 40 minutes, which is about 20 seconds for each problem. For every problem, a subject reads three pieces of information (3 units), makes experiential decision (6 units), and passes the decision (1 unit). Thus if we let x as the seconds in each time unit, we have $3x + 6x + x = 20$, or $x = 2$.

[11]This decision is made based on the persistence of belief model (Carley, 1991b). The persistence of belief rule is as follows: if the difference between the new decision and the old decision is two away (either friendly versus hostile, or hostile versus friendly), then the new decision will not replace the old decision unless the confidence level of the new decision is 20% higher than that of the old one. If the difference between the new decision and the old decision is one away, then the new decision will not replace the old decision unless the confidence level of the new decision is 10% higher than that of the old one. If there is no difference between the new decision and the old decision, then there is no update of decision, but the confidence level increases if the confidence of the new decision is higher than that of the old one.

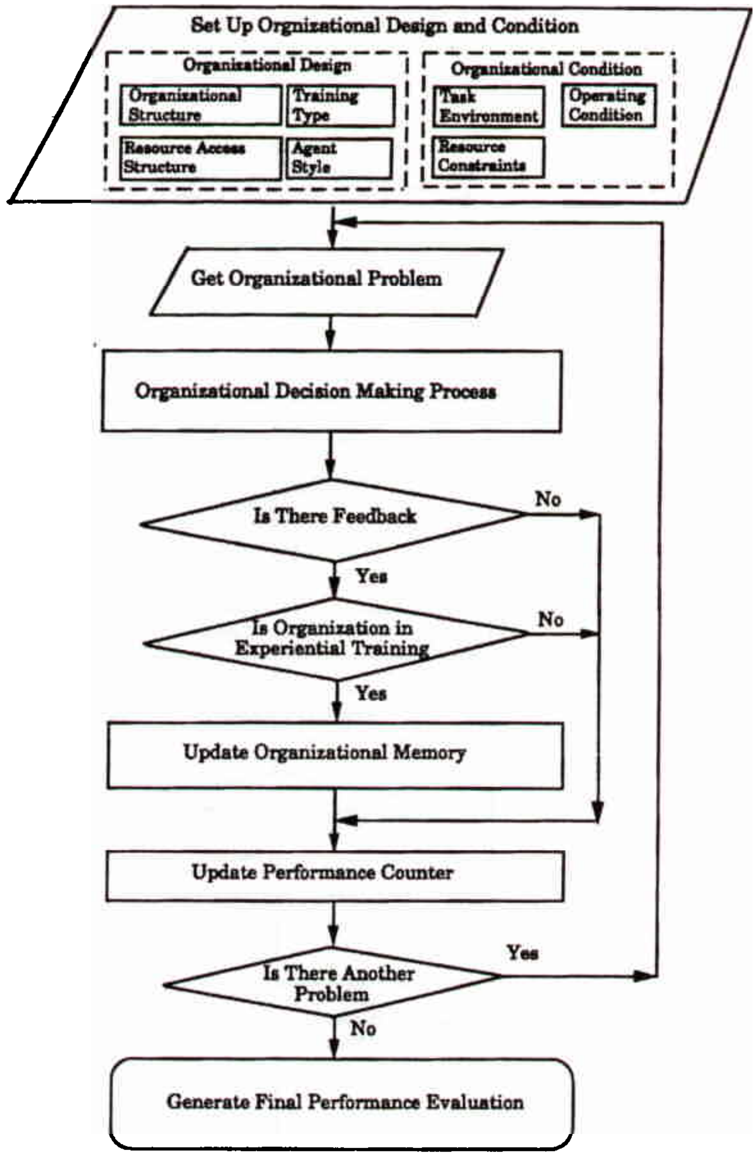


FIGURE 1. Top level description of the organizational decision making process.

asking for further information, or reading decision information based on the availability of information (Figure 2). The top-level manager begins by examining the time remaining to make an organizational decision. This is the number of time units allotted given the time pressure minus the amount of time already spent examining the problem. Then, if there is no time and there is no previous decision the top-level manager simply guesses the solution. If there is time the top-level manager initiates the decision process. If the problem has come to the must be solved stage the top-

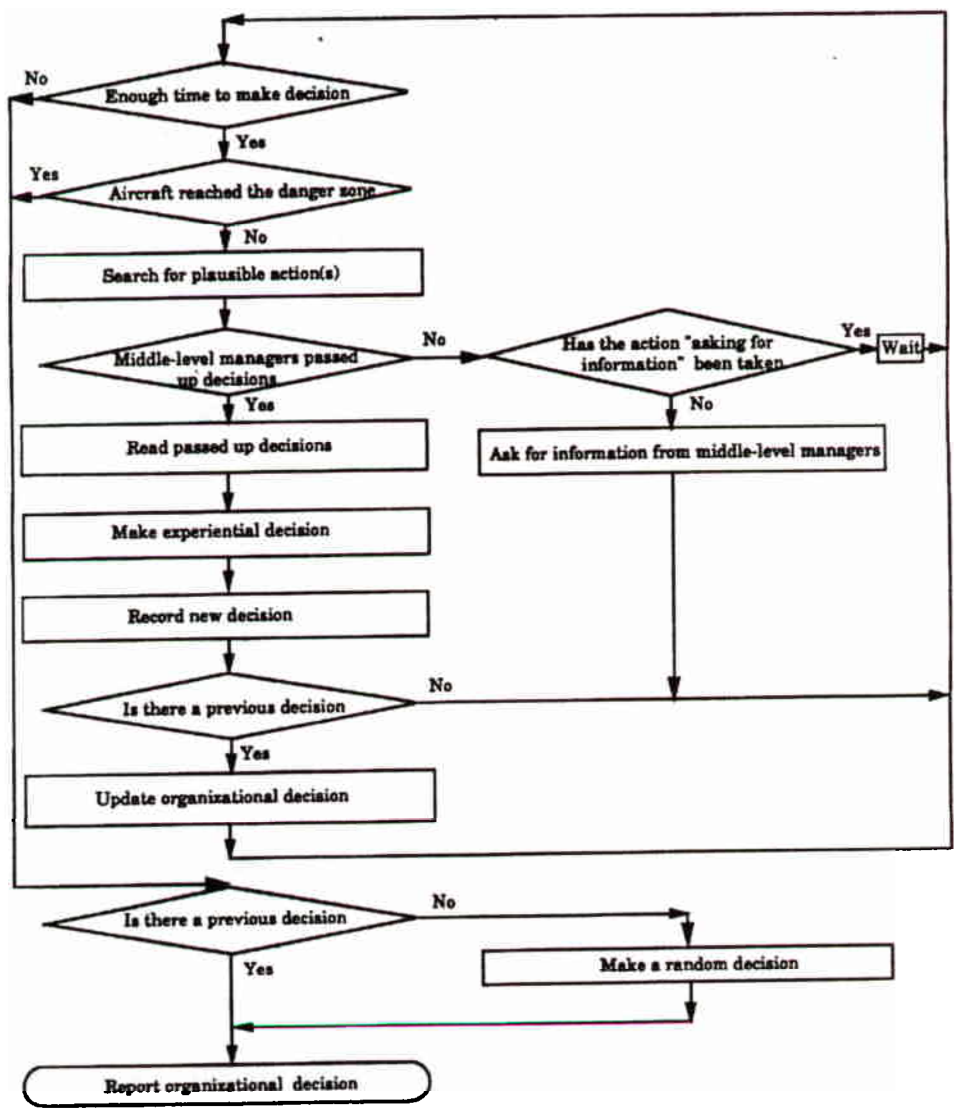


FIGURE 2. Level 2 description of organizational decision making process (top-level manager).

level manager stops the process and proceeds to make the organizational decision. Otherwise, the top-level manager searches for plausible actions—those actions that are currently possible. Then the top-level manager will look to see whether his or her subordinates have passed up their decisions. If they have not then the top-level manager, acting in a proactive information, will ask for information (if he or she had not previously asked). Once the middle-level managers have passed up their decisions then the top-level manager can read these decisions, and because he or she is trained experientially, will follow the experiential decision process and then record the decision (thus updating the agent's mental model). If the top-level manager had gone through this process before then there will exist a previous decision. The top-level manager may then take the new decision, compare it with the old, and update the decision using the beliefs rule (Carley, 1991b). Note, the decision that "counts" as the organizational decision is the last decision made following this process prior to the point at which there is no more time to make a decision.

Middle-level managers go through a process similar to the top-level managers (Figure 3). However, the actions of middle-level managers have a time lag behind those of top-level managers. Middle-level managers also receive instructions from and pass up decisions to the top-level manager. Middle-level managers check to see if there is enough time to make a decision and if so search for plausible actions. The decision passed up by the middle-level manager to the top-level manager is the last decision that they made prior to the point where either the top-level manager interrupts them and asks them to pass up a decision or where the middle-level manager realizes there is not enough time to make a decision. The middle-level manager, if there is no decision, will simply make a guess as to what the solution should be. The middle-level manager can be interrupted at any point. Since the middle-level manager is a proactive agent the agent begins by searching for actions, and then asking for information from the analysts if they have not already responded. For the middle-level manager, which analysts it requests information from and receives information from depends on the organizational structure.

Analysts also go through a similar process (Figure 4). Analysts, because they are proactive, begin the search for actions prior to a request from a middle-level manager and begin to read information even before they receive a request from a manager. Analysts continue to take actions such as read information and pass up decision information until there is not enough time to make a decision or until the analyst is interrupted by a middle-level manager. Analysts respond to middle-level manager requests by passing up a decision. The decision passed up by the analyst is the last decision made by the analyst. The analyst, if there is no previous decision, will simply make a guess about the solution.

All agents' actions are subject to resource constraints and agents select actions relative to these constraints and their preference functions (Figure 5). This is done by searching for plausible actions. Each action is considered, sequentially. Actions are plausible if the agent is not engaged in another action, there is time to complete them, and their prerequisites have been met. If the agent is currently engaged in that action then it is plausible and no others are plausible.

We have so far considered only the proactive agents. The diagrams shown in Figures 2 through 5 will change if the agents are reactive. For example, if the agents are reactive, then the agents will not voluntarily pass up their decisions to their managers unless they receive requests from a superior. Due to time constraints, the interactions among the hierarchical levels may be limited. If the time available for the organizational decision process is short, the top-level manager may not have time to wait until the decision is passed up by reactive agents. In this case, the top-level manager will simply guess. Given sufficient time, there can be multiple exchanges of information among the hierarchical levels, and the top-level manager

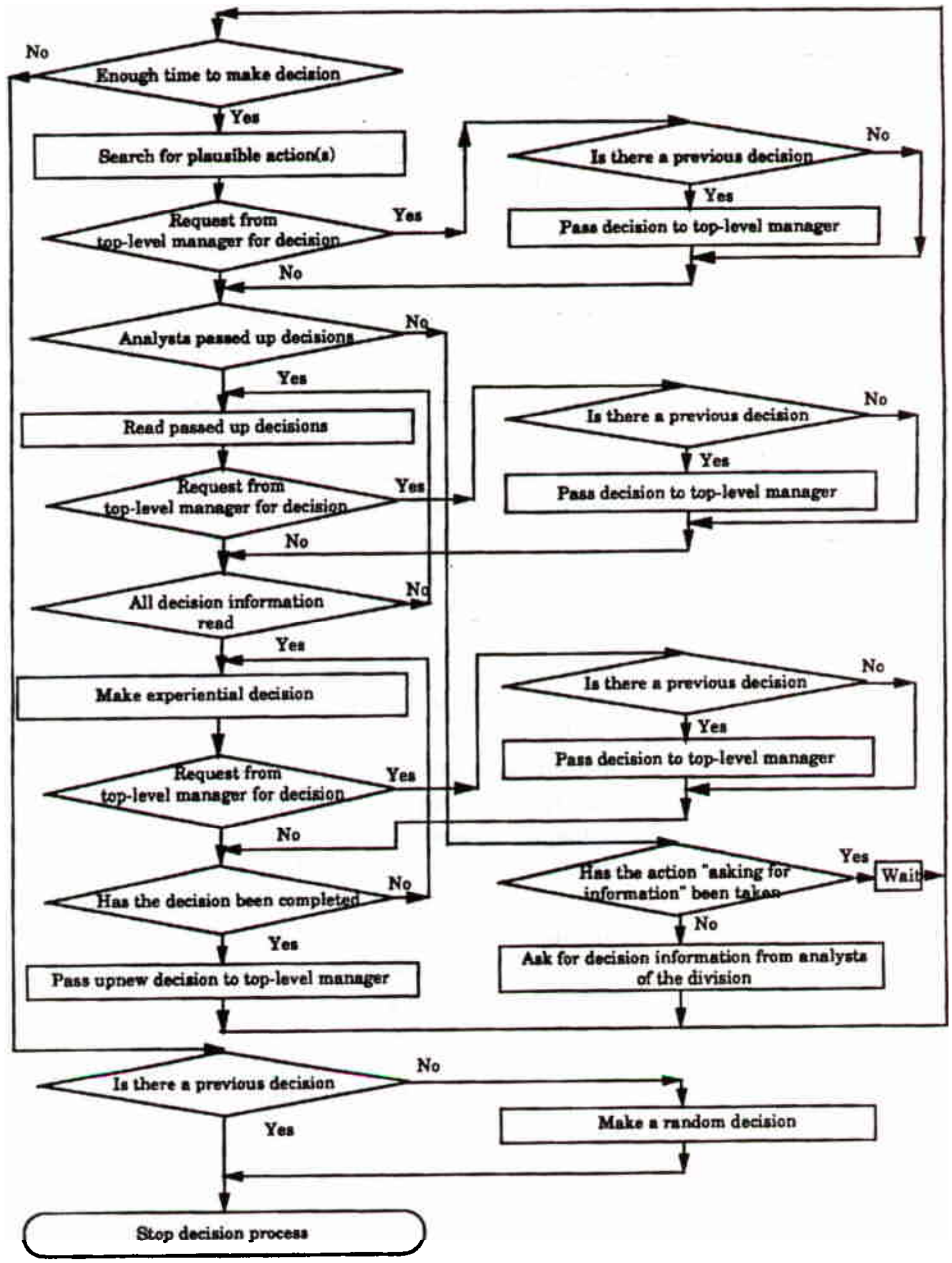


FIGURE 3. Level 2 description of organizational decision making process (middle-level managers).

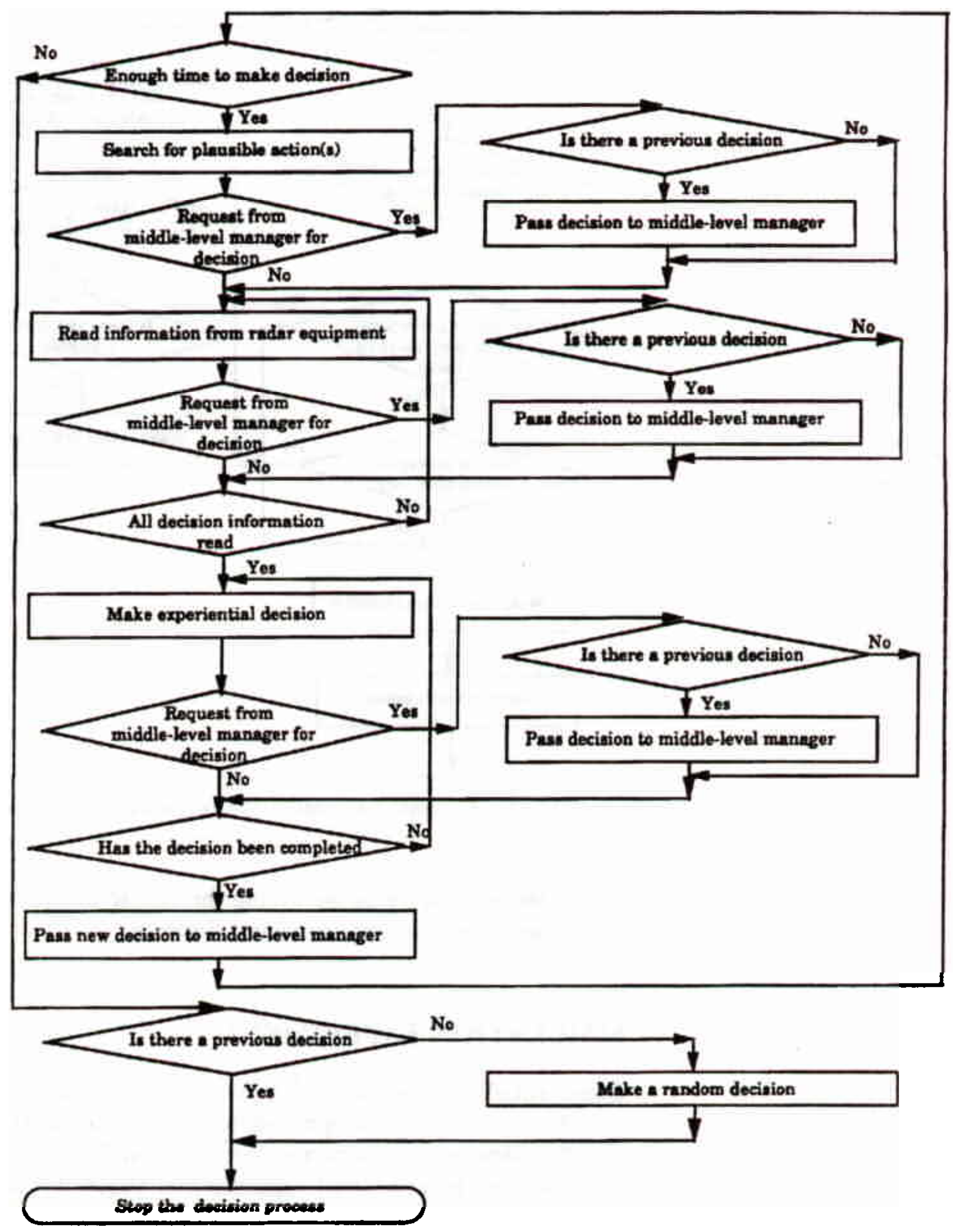


FIGURE 4. Level 2 description of organizational decision making process (analysts).

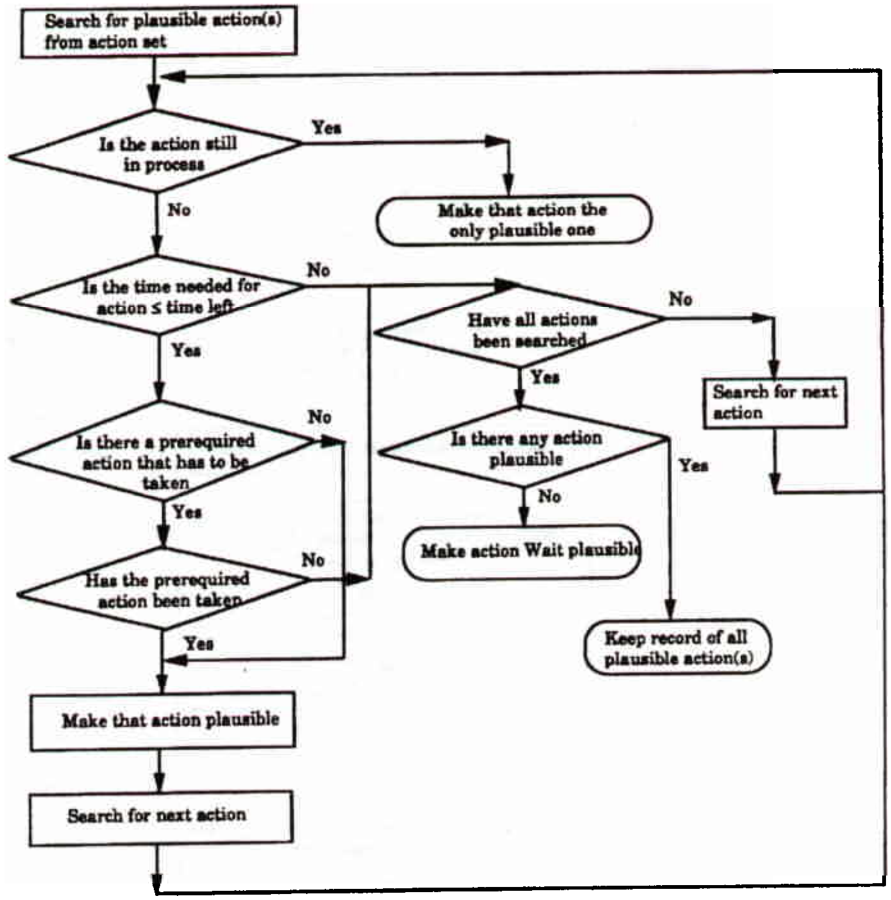


FIGURE 5. Level 3 description of action search process according to resource constraints.

may make several decisions during the course of the problem, from which he or she can choose the final organizational decision.

SIMULATION EXPERIMENT

Experientially trained organizations are expected to exhibit greater flexibility and therefore to outperform operationally trained organizations particularly in hostile or rapidly changing environments. Such "hostile" environments are often characterized by high time pressure and high internal stress. We examined this expectation using DYCORP. We simulated a series of organizations varying in whether the agents are trained experientially or operationally. We considered different levels of "hostility" by varying the time pressure and the presence or absence of all five types of murphies. We averaged across different organizational structures and different task environments.

Stylized Radar Task

The task used by DYCORP is a stylized radar detection task.[12] The static version of this task, i.e., one where the aircraft do not move, has been described in Carley and Lin (1992). We now present a brief description of a dynamic version of this task where the aircraft move and the analysts, depending on the time pressure, may examine the aircraft multiple times.

There exists a physical air space that is being scanned by the organization on the ground. In the organization there are always nine and only nine analysts (or radar operators) working in front the radar detection equipment. The organization may have other agents whose responsibilities are different as will be discussed later. The organization faces a sequence of radar-detection problems. Each problem is defined as a single aircraft moving through the airspace. Thus, within the airspace, at any one time, there is a single aircraft. This aircraft, however, is moving and it is moving in a straight line. This aircraft has a true state; i.e., it is 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 *a* time limit set by the organization has been met, whichever 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 and a new problem (i.e., aircraft) occurs.

Each aircraft has nine characteristics. These are: Speed, Direction, Range, Altitude, Angle, Corridor Status, Identification, Size, and Radar Emission Type. Each characteristic can take on a certain range of values and may be either continuous or discrete (Table 3). For example, Speed is a continuous variable from 200 miles per hour to 800 miles per hour, while Radar Emission Type is a discrete variable from 0 to 2. Each analyst can interpret each characteristic from the values they read from the radar equipment into one of the three categories: low (friendly), medium (neutral), or high (hostile).[13] The three categories are assumed to be divided evenly.[14] For example, when Speed is within 200 to 400 miles per hour, then it is interpreted as having a low or friendly characteristic, when Speed is within 400 to 600 miles per hour, then it is interpreted as having a medium or neutral characteristic, when Speed is within 600 to 800 miles per hour, then it is interpreted as having a high or hostile characteristic. For Radar Emission Type, if the value is 0 (civilian), then it

[12]This task is also being used by Al Lesgold, John Levine and Kathleen Carley in a series of human experiments focused on determining hierarchical performance under stress. We choose this stylized task for the following reasons: First, this task has similarities in the real world. It has been widely examined in situations as such as air-traffic control. Second, in this task, the true decision can be known, feedback can be provided and so issues of learning can be addressed. Third, the task is sufficiently complex that multiple agents can be used to work on different aspects of the task, thus enabling us to examine organizational decision making in a distributed environment. And finally, this task can be expanded to include many other factors, such as communication of different types of information or different process rules or learning rules or training orientations, later with relative ease.

[13]As will be discussed later, such interpretations may not always be correct, thus causing murphies.

[14]We may relax this assumption in our future research. To do so now, we may further complicate the task environment.

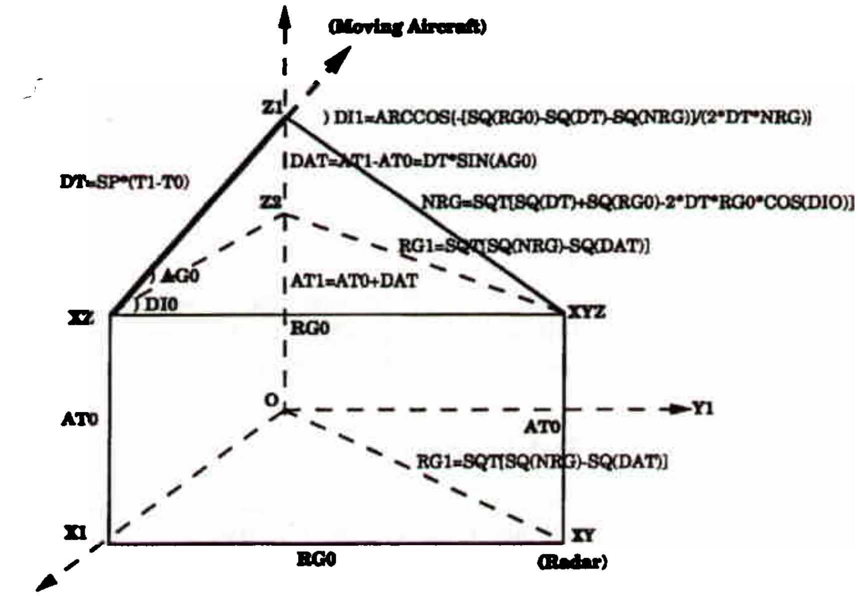
TABLE 3
Characteristics of a Moving Aircraft

Name	Range	Categorization of Criticality		
		Low	Medium	High
Speed (F1)	200–800 miles/hour	200–400	401–600	601–800
Direction (F2)	0–30 degrees	21–30	11–20	0–10
Range (F3)	1–60 miles	41–60	21–40	1–20
Altitude (F4)	5,000–50,000 feet	35k–50k	20k–35k	5k–20k
Angle (F5)	(−10)–10 degrees	4–10	(−3)–3	(−10)–(−4)
Corridor Status (F6)	0 (in), 1 (edge), 2 (out)	0	1	2
Identification (F7)	0 (friendly military), 1 (civilian), 2 (unknown military)	0	1	2
Size (F8)	0–150 feet	100–150	50–100	0–50
Radar Emission Type (F9)	0 (weather), 1 (none), 2 (weapon)	0	1	2

Note:
Speed (F1) indicates the speed of the aircraft. It is a continuous variable, and is assumed constant once detected.
Direction (F2) indicates degrees of deflection by which the flight path deviates from a direct route to the asset. It is a continuous variable. It changes as a function of speed, range, and altitude.
Range (F3) indicates the distance from the location o the plane to the point immediately above the radar center. It is a continuous variable. It changes as a function of speed, direction, and angle. Before Range is less than or equal to 1 mile, the organization has to make a decision.
Altitude (F4) indicates the vertical distance of the aircraft to the ground. It is a continuous variable, and change as a function of speed, direction, and angle. The organization will be unable to detect the aircraft if the altitude is less than 5,000 ft.
Angle (F5) represents a changing altitude. It is a continuous variable and is assumed constant throughout the flight.
Corridor Status (F6) represents whether the aircraft is in, on the edge of, or out of the corridor. It is a categorical variable, and is assumed constant once detected.
Identification (F7) represents whether the aircraft is friendly military, civilian, or unknown military. It is a categorical variable, and is assumed constant once detected.
Size (F8) represents the size of the aircraft. It is a continuous variable, and is assumed constant once detected.
Radar Emission Type (F9) represents whether the emission type of aircraft is weather, none, or weapons. It is a categorical variable, and is constant once detected.

is interpreted as having a low or friendly characteristic, if the value is 1 (unknown), then it is interpreted as having a medium or neutral characteristic, and if the value is 2 (military), then it is interpreted as having a high or hostile characteristic (see Table 3 for a detailed explanation of other characteristics). The indication of a specific characteristic may not reflect the true state of the whole aircraft. For example, while the aircraft may have weapons (2), and so the characteristic Radar Emission Type may appear hostile, the aircraft when all characteristics are considered may actually be friendly. The number of possible unique aircraft or problems is thus the number of all possible combinations of the different levels (low, medium or high) of the nine characteristics, which is 19683 (3^9).

As the aircraft moves in a straight line, some of the characteristics remain constant. Speed, Angle, Corridor Status, Identification, Size, and Radar Emission Type remain constant throughout the airspace, while Direction, Range, and Altitude change as the aircraft moves through the airspace (see Figure 6). In this sense, the organization actually faces a series of sub-problems given each starting state. In the static version of this task the aircraft does not move and its starting state is its final



T0	— Time at XZ
T1	— Time at Z1
SP	— Speed of the aircraft
DT (XZ-Z1)	— Distance between T1 & T0
AG0	— Angle at T0
AG1	— Angle at T1
AT0 (Z1-O)	— Altitude at T0
AT1 (XZ-X1)	— Altitude at T1
RG0 (X1-XY)	— Range at T0
RG1 (Z2-XYZ)	— Range at T1
DI0	— Direction at T0
DI1	— Direction at T1

Altitude=f(Speed,Angle):

Altitude[i]=Altitude[0]+Speed*(Time[i]-Time[0])*SIN(Angle[0])
Range=g(Speed,Angle):
Range[i]=SQT[SQ(NRG)-SQ(Altitude[i]-Altitude[0])]
Direction=h(Speed, Angle):
Direction[i]=ARCCOS(-[SQ(Range[0])-SQ(Speed*(Time[i]-Time[0]))-SQ(NRG)]/[2*Speed*(Time[i]-Time[0])*NRG]),

where NRG=SQT[SQ[Speed*(Time[i]-Time[0])]+SQ(Range[0]) -2*[Speed*(Time[i]-Time[0])]*Range[0]*COS(Direction[0])]

FIGURE 6. Dynamics of the characteristics of the aircraft.

state. Thus each organization made only one decision per aircraft (Carley and Lin, 1992). In contrast, in the dynamic task used herein the aircraft moves away, linearly, from its starting state. The organization can track the aircraft and can make a series of decisions about the state of the aircraft. Though some of the characteristics of the aircraft may change during the flight, the true state of the aircraft cannot change and is defined relative to the characteristic of the aircraft at the starting state.[15]

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 times

[15]Analysis reveals that for the aircraft examined and the defining rule used for characterizing the true state of the aircraft, the true state of the aircraft does not shift during each problem.

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 problem/aircraft, the number of time units assigned can vary from 1 to 60, and the actual number is assigned randomly. For each aircraft, the number of time units until it enters the danger zone depends on its speed, direction, angle, and altitude.[16] The position of the aircraft at any point in time is calculated based on the equation shown in Figure 6.

In DYCORP the organization will face a sequence of problems. The content of this sequence depends on the task environment. Regardless of the task environment the problems in this sequence are independent of each other.

Task Environment

The aircraft is "truly" 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. Such true states are often a product of the technology. For example, within the radar environment aircraft that are moving very fast, are within the corridor, are carrying weapons, and have an unknown identification, typically are hostile. Using DYCORP the researcher can manipulate the "true state of the world" in order to examine different types of tasks, yet remain within the radar scenario. By altering the "reality" faced by our organizations, the user is altering the definition of what constitutes a truly friendly, neutral, or hostile aircraft. Based on the literature, two types of manipulations of the task environment were built into DYCORP. These are: the extent to which the task is decomposable (Simon, 1962; Roberts, 1990) and the extent to which it is concentrated (Aldrich, 1979; Hannan and Freeman, 1977).

Regardless of the task environment there are 19683 unique aircraft. The nature of the task environment determines which of the possible states (friendly, neutral, or hostile) is the true state for each aircraft. This classification involves first combining the values of all nine characteristics and then categorizing the aircraft (based on the combined value) as either friendly, neutral, or hostile. Let X_i be the value of feature i such that $1 \leq i \leq 9$ and $X_i = 1, 2,$ or 3. The true state of the aircraft is defined using some algorithm that combines these X_is and then categorizes the aircraft based on this combination. Decomposability and concentration affect the combination and categorization rule. Based on these two manipulations, four different "realities" or

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

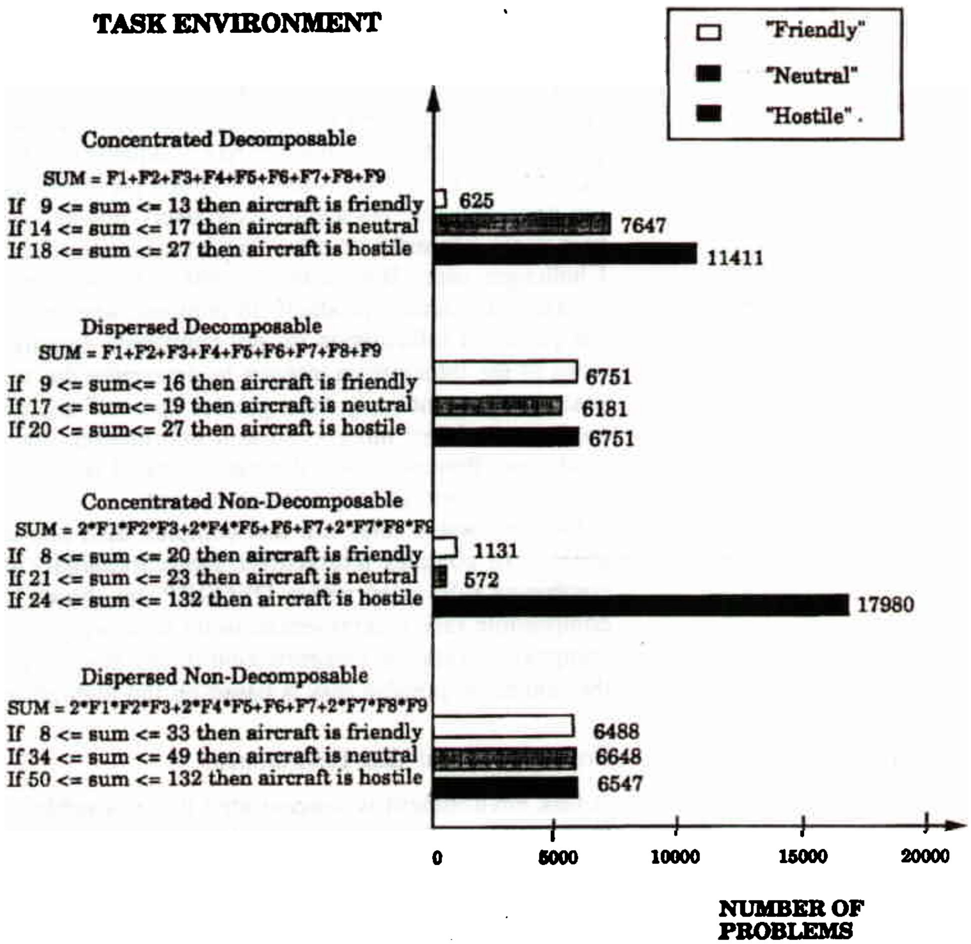


FIGURE 7. Stylized task environments.

environmental situations can be examined in DYCORP. These four environments define the true state of each aircraft. These environments are shown in Figure 7 where they are listed from the least complex to the most complex.

As a final caveat, it is important to understand that the task environment defines the true state of all aircraft. However, the organizations do not know, nor do the individuals within them know, exactly which environment they face. Indeed, the organizations have only a vague understanding of the environment. No agent knows, a priori the rule selected by the researcher using DYCORP to characterize the task environment. Depending on their ability to learn, the agents (and so the organization) may be able to learn this rule or a similar rule. This difference reflects the fact that in real organizations, organizations have only their history, and their understanding of their current technology to guide them, and so rarely have a completely accurate mapping of the environment.

Decomposability of Task Environment

A task environment is decomposable if there are no complex interactions among components that need to be understood in order to solve a problem. In a decomposable task each component has a separable, identifiable and additive effect in determining the problem solution. Each piece of information contributes equally to the final decision. No agent has greater "power" simply by virtue of having access to a more powerful or more important piece of information. For example, in the Challenger case (Rogers et al., 1986), the work was mainly a combination of numerous contractors' products. In contrast, when the task is non-decomposable then the pieces of information do not contribute equally to the final decision, and portions of the information interact to determine the true nature of the aircraft. In this case, some agents may have greater "power" simply by virtue of having access to more powerful or more important information. For example, in the Three Mile Island case (Perrow, 1984), the basic work of the nuclear plant was not all separable from each other, as they were all related.

Decomposable tasks are less complex than non-decomposable tasks due to the absence of complex interactions. Decomposability affects the combining rule. The combining rules used within DYCORP are shown in Figure 7. In DYCORP a decomposable task is represented using an unweighted additive rule. That is, in a decomposable task the categorization of the aircraft is based on $\sum_{i=1}^{9} X_i$. In contrast, the nondecomposable task is based on the multiplicative rule.

Concentration of Task Environment

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. For example, during war time one might see many more hostile than friendly aircraft. In a dispersed environment approximately one third of the 19683 aircraft (6568) are hostile and one third of the aircraft are friendly. This environment can be thought of as an uncertain environment because the chances of all three outcomes are almost identical. In contrast, concentrated environments are more certain simply because the most common aircraft is hostile. Concentrated tasks thus are less complex than dispersed tasks due to the preponderance of a particular solution. In a dispersed environment one third of all aircraft are truly friendly, another third are truly neutral, and another third are truly hostile. Concentration affects the categorization rule. The categorization rules used within DYCORP are shown in Figure 7.

Each organization was given a sequence of 1,000 randomly generated problems. The time limit associated with each problem was randomly generated from 1 to 60 units. Murphies were located randomly. Each organization examined faced the same 1000 problems, had the same time limit for the same problem, and faced the same pattern of murphies.

The Effect of Training Type

Contrary to the expectation, operationally trained organizations perform slightly better on average than experimentally trained organizations (Table 4). However,

TABLE 4
Performance by Training Type

Training Type	Level of Time Pressure			
	All Levels of Time Pressure	High Time Pressure	Medium Time Pressure	Low Time Pressure
Experientially Trained	46.09 (0.20)	33.26 (0.05)	43.61 (0.20)	61.41 (0.36)
Operationally Trained	47.84 (0.17)	33.69 (0.05)	53.64 (0.21)	56.19 (0.25)
N	7680	2560	2560	2560

Note: Performance is the percentage correct. Standard errors are in parentheses below the performance.

these results vary as we consider time pressure. Under high time pressure, there is virtually no difference in the performance of the experientially and the operationally trained organizations. Both basically have so little time to gather information that they are reduced to guessing. Under medium time pressure, operationally trained organizations outperform experientially trained organizations. This is due to the relatively simpler and less time consuming decision procedure employed by operationally trained organization. The simpler procedure allows them to go through more decision rounds and so improve their overall performance. However, when the time pressure is low, experientially trained organizations outperform operationally trained organizations. This suggests that the advantage of experience only comes into play when there are no time constraints.

The Effect of Murphies

Both experientially and operationally trained organizations exhibit a degradation in performance as murphies occur. In general, this degradation is less severe for experientially trained than for operationally trained organizations (see Table 5). However, the impact of the different types of murphies depends on the training scenario. For example, experientially trained organizations, are most affected by agent turnover, with incorrect information having the second largest impact (Table 5). When experience matters it is important to retain personnel. In contrast, operationally trained organizations suffer most when they are faced with incorrect information or missing information. When decisions are made using SOPs the accuracy of the information on which the decision is based becomes critical. These results hold regardless of the time pressure. These results suggest that organizations relying on personnel experience should expend resources on retaining personnel, and those organizations relying on SOPs should expend resources on information gathering technology.

DISCUSSION AND CONCLUSION

The DYCORP framework is general. In DYCORP organizations are modeled as open systems with a particular design and composed of intelligent, and possibly

TABLE 5
Performance by Murphy Type

Experientially Trained	Level of Time Pressure: All Levels of Time Pressure	High Time Pressure	Medium Time Pressure	Low Time Pressure
Murphy				
Missing Information	46.67	33.22	43.97	62.83
	(0.44)	(0.11)	(0.46)	(0.82)
Incorrect Information	46.19	33.29	43.78	61.51
	(0.44)	(0.11)	(0.47)	(0.85)
Agent Unavailability	46.61	33.20	44.01	62.62
	(0.44)	(0.11)	(0.47)	(0.78)
Communication Channel	46.64	33.24	44.05	62.62
Breakdown	(0.43)	(0.11)	(0.46)	(0.78)
Agent Turnover	44.37	33.33	42.27	57.49
	(0.39)	(0.11)	(0.41)	(0.76)

Operationally Trained	Level of Time Pressure: All Levels of Time Pressure	High Time Pressure	Medium Time Pressure	Low Time Pressure
Murphy				
Missing Information	47.16	33.62	52.64	55.21
	(0.33)	(0.11)	(0.42)	(0.51)
Incorrect Information	44.73	33.69	49.37	51.13
	(0.29)	(0.11)	(0.41)	(0.48)
Agent Unavailability	48.63	33.77	54.76	57.37
	(0.35)	(0.12)	(0.43)	(0.52)
Communication Channel	48.63	33.58	54.82	57.48
Breakdown	(0.36)	(0.12)	(0.43)	(0.52)
Agent Turnover	50.05	33.79	56.60	59.77
	(0.42)	(0.12)	(0.55)	(0.68)
N	1536	512	512	512

Note: Standard errors are in parentheses below the performance.

adaptive, agents. In building DYCORP we broadened the concept of organizational design to include aspects of task environment, training, and agent style, in addition to structure. DYCORP can be used to examine organizational performance in general or under stress from a combined task environment, organizational design, and stress perspective. This makes it possible to discover relationships among these factors. Initial analyses of organizational performance using DYCORP suggest that there are systematic relationships between task environment, organizational design, and stress that affect performance. DYCORP can be used to develop a theory of organizational design and to suggest strategies for mitigating stress consistent with the organizational goals. For example, this study demonstrates that more information does not always result in better decisions. Rather, decision making performance depends on the training procedure, the location of communication links, and the task environment characteristics. A policy implication of this is that organizations should be very careful expanding or altering their organizational or task decomposition structures during crisis situations.

DYCORP can be used to address many issues in organizational design other than those addressed in this paper. One such issue is the relationship between training and performance. Different training orientations such as training for friendly environments may affect performance. Future studies using DYCORP could be done to develop a better understanding of how training in situation "x" affects performance in situation "y". Another such issues is organizational shifts. It is often suggested that organizations when faced with external crises, should restructure themselves. This analyses presented sugest that the structure that is best under crises may not be the best in general; however, they do not provide insight into whether the process of shifting structures would degrade organizational performance. Further studies could examine whether this restructuring is beneficial given that personnel are trained on the old (non-crisis) structure.

There are important ways in which, without changing the basic framework, DYCORP can be expanded to admit further organizational studies. For example, alternate organizational designs and task environments could be examined within this general framework. For example, DYCORP currently defines the task environment using two dimensions: concentration and decomposability. Another dimension is task complexity which can be modeled simply as the number of task components. Future work could expand this framework to include this and other elements.

The DYCORP framework uses computer simulation. Computer simulation has been used in many areas such as military training, business administration, and theory developing. Computer simulations can grasp the fundamental nature of human information processing behavior (Simon, 1973). Compared with experiments using human subjects, computer simulations are easier to control, more flexible, more objective, with less noise, and thus can examine more factors within less time. As pointed out by Ostrom (1988), computer simulation offers a third symbol system in studying social science, besides natural language and mathematics, because "computer simulation offers a substantial advantage to social psychologists attempting to develop theories of complex and interdependent social phenomena." Computer simulations are limited by the simplified assumptions, as well as the computer technologies. Such simulations do not always capture difference due to individual cognition. Thus, when facing a task environment requiring more subjective judgments, our framework may need to be modified. Nevertheless, these simulation experiments provide a series of hypotheses which we can test both with human experiments and by using real organizational data. Since human experiments are costly to run, and it is often improbable to obtain sufficient large quantities of data on real organizations, these simulation experiments help us develop organizational theory and determine which parameters are most important to explore in other settings.

REFERENCES

Aldrich, H. E. (1979) *Organizations and Environment*, Englewood Cliffs, NJ: Prentice Hall.

Blumberg, R. L. (1987) *Organizations in Contemporary Society*, Englewood Cliffs, NJ: Prentice-Hall.

Burton, R. M. and Obel, B. (1990) Devising expert systems in organization theory: The organizational consultant, in Masuch, M. (ed.) *Organization, Management, and Expert Systems*, Berlin: Walter De Gruyter.

Carley, K. M. (1990) Coordinating for success: Trading information redundancy for task simplicity. *Proceedings of the 23rd Annual Hawaii International Conference on System Sciences*.

Carley, K. M. (1991a) Designing organizational structures to cope with communication breakdowns: A simulation model. *Industrial Crisis Quarterly* 5: 19–57.

Carley, K. M. (1991b) On the persistence of beliefs. Working Paper, SDS/Carnegie Mellon University.

Carley, K. M. (1992) Organizational learning and personnel turnover. *Organization Science* 3 (1): 2–46.

Carley, K. M. and Lin, Z. (1992) Maydays and Murphies: A study of the effect of organizational design, task, and stress on organizational performance. Working paper, CMU-SDS.

Cohen, M. D., March, J. B. and Olsen, J. P. (1972) A garbage can model of organizational choice. *Administrative Science Quarterly* 17 (1): 1–25.

Davis, S. M. and Lawrence, P. R. (1977) *Matrix*, Reading, MA: Addison Wesley Publishing Company, Inc.

Hannan, M. T. and Freeman, J. (1977) The population ecology of organizations. *American Journal of Sociology* 82: 929–964.

Houskisson, R. E. and Galbraith, C. S. (1985) The effect of quantum versus incremental *M*-form reorganization on performance: A time series exploration of intervention dynamics. *Journal of Management* 11: 55–70.

Lin, Z. and Carley, K. (1993) Proactive or reactive: An analysis of the effect of agent style on organizational decision making performance. *International Journal of Intelligent Systems in Accounting, Finance, and Management* 2: 271–287.

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

March, J. G. and Simon, H. A. (1958) *Organizations*, Wiley.

March, J. G. and Olsen, J. P. (1976) *Ambiguity and Choice in Organizations*, Bergen: Universitetsforlaget.

Means, B., Salas, E., Crandall, B. and Jacobs, T. O. (1992) Training decision makers for the real world, in Klein, G., Orasanu, J., and Calderwood, R. (eds.) *Decision Making in Action: Models and Methods*, Norwood, NJ: Ablex Publishing Corp.

Mintzberg, H. (1983) *Structures in Five: Designing Effective Organizations*, Prentice Hall Inc.

Ostrom, T. M. (1988) Computer simulation: The third symbol system. *Journal of Experimental Social Psychology* 24: 381–392.

Perrow, C. (1984) *Normal Accidents: Living with High Risk Technologies*, Basic Books, Inc.

Peters, L. H., O'Connor, E., Pooyan, A. and Quick, J. C. (1984) The relationship between time pressure and performance: A field test of Parkinson's law. *Journal of Occupational Behavior* 5 (4): 293–299.

Roberts, K. (1989) New challenges to organizational research: High reliability organizations. *Industrial Crisis Quarterly* 3 (3): 111–125.

Roberts, K. (1990) Some characteristics of one type of high reliability organizations. *Organization Science* 1 (2): 160–176.

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

Rothstein, H. G. (1986) The effects of time pressure on judgment in multiple cue probability learning. *Organizational Behavior and Human Decision Processes* 37 (1): 83–92.

Schoonhoven, C. B. (1981) Problems with contingency theory: Testing assumptions hidden within the language of contingency theory. *Administrative Science Quarterly* 26: 349–437.

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

Simon, H. A. (1962) The architecture of complexity. *Proceedings of the American Philosophical Society* 106 (6): 467–482.

Simon, H. A. (1973) Applying information technology to organizational design. *Public Administrative Review* 33: 268–278.

Staw, B. M., Sandelands, L. E. and Dutton, J. E. (1981) Threat-rigidity effects in organizational behavior: A multilevel analysis. *Administrative Science Quarterly* 26: 501–524.

Thompson, J. D. (1967) *Organizations in Action*, New York: McGraw-Hill.

Zey-Ferrell, M. (1979) *Dimensions of Organizations: Environment, Context, Structure, Process, and Performance*, Santa Monica, CA: Goodyear Publishing Company, Inc.