ADAPTIVE ORGANIZATIONS: A COMPARISON OF STRATEGIES FOR ACHIEVING OPTIMAL PERFORMANCE

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Abstract

Organizations can adapt to their environment by changing their C^2 structure. Additionally, the organizational members are constantly learning and applying the lessons of experience to new situations. Organizational adaptation may interfere with this process. The question of whether an organization composed of intelligent adaptive agents has the capability of improving its performance through adapting its C^2 structure is addressed theoretically by using a computational model in which personnel learn from experience using a stochastic experiential learning model and the organization adapts by altering its design using a simulated annealing model of architecture adaptation. Using this model it is demonstrated that adaptive organizations are generally stuck in equi-performance plateaus where slight changes in their C^2 structure may dramatically alter performance, but are more likely to result in the same performance. Consequently, standard adaptive practices for altering the C^2 structure may not be sufficient. Additionally, this equi-performance result suggests that CEOs can, within reason, redesign their organization with relative impunity. Moreover, the mere act of redesign is likely to be organizationally advantageous whether or not it improves performance; e.g., the emergent organization may overlook fewer decision factors, and be less redundant in access to resources or task assignments.

° This work was supported by Grant No. N00014-93-1-0793 (UConn FRS 521676) from the Office of Naval Research (ONR), United States Navy.

1. Introduction

Organizations are complex adaptive systems composed of intelligent and adaptive agents. In principle, organizations should be able to locate, evolve, or learn, a design that is better matched to their environment and so improve their performance. In fact, it is generally assumed that over time organizations will evolve those structures best suited to their environments or perish [Hannan and Freeman, 1977]. In principle, the more skilled or more highly trained the personnel in the organization the higher the organizational performance. Organizational adaptation, however, can involve augmenting current staffs with additional personnel, reassigning who is doing what job, and reassigning who is reporting to whom. Such changes might interfere with the individuals' ability to learn and to make use of their previous experience. Thus it is questionable whether adaptive organizations will be able to reap the benefit of individual experience since individuals may be reassigned or brought on board with respect to jobs or positions in which they have had little previous experience. It is questionable whether organizational adaptation will improve performance.

In this paper, I examine whether organizations that automatically restructure in response to changes in their performance evolve a structure that is better suited to their environment. Using a computational model of organizational behavior a series of simulations are run in which the rate of response to changes in performance, and the nature of the response are altered. Two basic questions are addressed. First, as the rate of response to changes in organizational performance increases does organizational performance improve or degrade. Second, what strategy for altering the organization's structure leads to better performance and more or less rigid structures. These strategies vary in terms of whether the organization is most likely to make personnel changes at the top, middle or bottom of the organizational ladder.

2. Basic Model

There is a single organization composed of complex adaptive agents. The organization's life cycle is divided into a series of stages: general operation, evaluate performance, suggest design, evaluate design, select design, alter design. The organization continuously moves through this cycle as it moves from a planning (off line) period to an action (on line) period. Individuals in the organization either make decisions on the basis of their experience or by following standard operating procedures. Organizations have a base staff which they can augment during the planning stage. Time is organized around a sequence of choice tasks which is operationalized as a stylized radar task [Ilgen et al., 1991; Carley and Lin, 1995, 1994; Tang et al., 1992]. The goal is to accurately assess whether the item in the airspace is friendly, neutral, or hostile. Performance is measured across the tasks in that period. Here we examine only performance in the action phase immediately after the planning phase and then later after the organization has been in action for awhile.

The task used is the binary version of the stylized radar task, also referred to as the pattern matching and limited choice task The trinary version of this task was previously used by Carley and Lin (1994). In detection terms, the task is to determine for each problem, whether that problem represents a neutral, or hostile aircraft on the basis of nine aspects. Each aspect, such as speed, can take on a neutral or hostile value. The relationship of the values for all aspects to the right decision is initially unknown by all agents in the organization and must be learned over time. As agents learn these values they are essentially learning how to "weight" the incoming information and the responses of the personnel under them. For managers, this can be thought of as the agents learning whom to trust. As the task changes over time the agents will change these weights.

2.1 Initial Conditions

The organization starts with a particular C^2 architecture chosen at random from the possible set. These organizations have between one and three levels below the CEO, between one and 45 personnel (not counting the CEO), and nine distinct subtasks. The initial determination of size, the command or organizational structure (who reported to whom), the resource access structure (who has access to what resources or performs what subtasks), and how many individuals occupied each organizational level was determined randomly.

The CEO always acts as a majority classifier. All other agents begin knowing nothing and build up their patterns over time. Agents when they have no information to go on, make their decisions by guessing. Individual learning occurs using a stochastic experiential learning process [Carley, 1992]. Overtime, agents build up their experience and begin to act as majority classifiers if they experience an unbiased environment. Each personnel can handle up to seven pieces of information at a time. Given these conditions, no agent in the organization has the capability or sufficient information to make the decision completely unassisted.

2.2 Performance Criteria

Performance is calculated over a sequence of 500 tasks (evaluate performance) as the percentage improvement in accuracy over that expected by chance ((new-old)/old * 100). The level of performance expected by chance is 33.33%. In addition to performance the level of redundancy in access to resources (average number of personnel accessing the same information), average communication links (ties between personnel), and average number of decision making factors that are overlooked (information not attended to) are considered. All averages are calculated over 2000 organizations immediately after planning using a 500 task window, and after sustained action (20,000 tasks) using a 500 task window.

2.3 Adaptive Process

Organizational adaptation is modeled as a simulated annealing process, such that the organization's strategies are the move set. The move set for planning includes: ***augment*** — add n personnel, ***retask*** — move agent i from task s to task j, ***reassign*** — have agent i stop reporting to j and start reporting to agent k. The move set for the action phase includes only retasking and reassigning. The number of personnel changes made at the same time is given by a Poisson distribution. Each of these changes is equally likely. However, over time, the CEO will learn which moves are more likely to improve performance and so will change which adaptive strategies are employed.

Each time period the organization observes the environment (sees a new task). After a sequence of tasks (general operation), performance is calculated over a sequence of 500 tasks (evaluate performance), then an executive suggests a new design (a strategy from the move set), the CEO "looks ahead" and tries to imagine how the proposed new C^2 architecture will impact performance (evaluate design), then the CEO determines whether or not to implement the new design, and then the design may be altered. The limited lookahead is simulated by creating a hypothetical organization with the proposed new design and simulating its performance on a sequence of 100 tasks. After the lookahead, the CEO decides whether or not to accept the new design. The probability of accepting a new design (a strategy from the move set) is based on the Boltzman probability criteria. According to this criteria the CEO always accepts the change if the resulting hypothetical organization is known to be a better performer than the current organization. Otherwise, the risky change is accepted with a probability given by $e^{(-\Delta cost(t)/T)}$ such that cost(t) = 1/performance(t). If the design change is accepted the CEO puts the change in place and then proceeds to process another sequence of tasks at which point another design is considered. If a design change is not accepted the organization goes on as it is for another sequence of tasks. The rate of organizational change is set by the temperature cooling schedule. Temperature (T) will drop each time period as $T(t+1) = \alpha * T(t)$ where α is the rate at which the organization becomes risk averse and t is time. In other words, over time the CEO becomes increasingly risk-averse. Putting this in the context of planning, as it gets closer to the action phase fewer risky changes are made in the planned architecture. During the action phase, the longer the organization has been in the environment the less likely it is to accept a change that is not known to improve performance. This increasingly conservative behavior has been observed in many actual organizations.

2.4 Veridicality

Computational models similar to the one used herein have been shown to provide a reasonably accurate portrayal of the relationship between organizational design and performance [Carley, 1992; Carley and Lin, forthcoming]. In particular, Carley and Lin [1994] demonstrated a strong fit between a comparative statics version of this model and the restructuring behavior of 69 organizations faced with crises. For particular organizational architectures, Carley et al. [forthcoming] demonstrated that the individual learning model is sufficient, given a particular design, for predicting the overall organizational performance of that design. The advantage of the current model is that the process, rather than just the outcome of adaptation, is examined.

3. Virtual Experiment

Four virtual experiments were run using this computational model — organizations adapt their architectures only during planning and personnel follow SOPs, organizations adapt their architectures only during planning and personnel follow experience, organizations adapt their architectures during action and personnel follow SOPs, organizations adapt their architectures during action and personnel follow experience. Recall that during planning organizations can adapt by augmenting their staff; whereas, during the action phase only retasking and reassignment is allowed. When organizations adapt they try to optimize their design for high performance over time in response to environmental feedback. Individuals following SOPs can not learn and instead act as majority classifiers (which is what the majority of them act like when they are able to learn and are given sufficient time to learn). A total of 1000 different organizations were simulated, for each condition, such that the organization's initial design was randomly generated from the set of all possible organizational designs.

The basic task is characterized by a nine bit binary string resulting in a population of 36 distinct tasks. Each organization is simulated for 20,000 tasks (time periods) or until it reaches quiescence whichever comes first. An organization is said to reach quiescence if the approximate probability of accepting a new design drops to 55% (this corresponds to a "freezing" temperature of 0.0345). Initially, temperature is set to 0.433 so that approximately 90% of the changes are accepted.[1] The CE becomes increasingly risk averse with a rate of $\alpha = .975$.

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[1] Initial and final temperature were chosen after the relationship between probability of acceptance and temperature were analyzed for this organizational model. Given a set of 1000 randomly generated organizations each organization was simulated for 100 tasks for an initial partition. The results are shown in the following table. As can be seen, when the partition includes 99% of the theoretical range for the Δ cost, all 100 changes are accepted.

The timing of the various stages in the organization's life cycle is controlled by multiple windows defined as a set of tasks. The 20,000 tasks are divided into a series of 200 cooling windows each composed of 100 tasks. Temperature is dropped after each cooling window. Organizational performance is calculated over the last 500 tasks. The proposed hypothetical design is simulated for 100 tasks and its expected performance is calculated over this look ahead window.

4. Results

The value of organizational adaptation for performance depends on the level of training that the staff has received (see Figure 1). Figure 1 is a contour plot such that darker squares indicate higher performance. Basically there are two strategies that can be followed to achieve high performance, high training and no change in the C^2 architecture or varying levels of training and highly adaptive C^2 architecture.

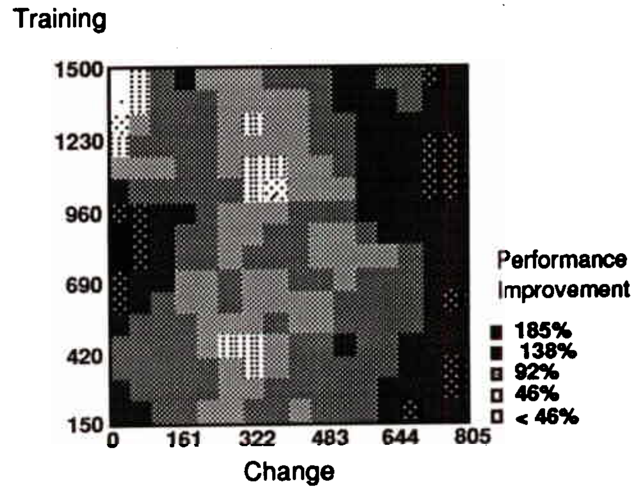

Figure 1. Impact on performance of organizational adaptation and training.

The basic results are as follows: First, it is possible for personnel to be overtrained. Second, organizations can trade of training for redesign. That is, organizations can achieve high performance either by highly training personnel and never changing their design or by engaging in moderate training and then frequently redesigning the organization's structure to meet specific task needs. Finally, while there is a narrow window of training that admits high performance when there is no organizational change (small dark area on left), there is a wider range of tactical options available to the CEO (in terms of the level of training and the level of redesign) for achieving high performance when a high level of redesign is used (larger dark area on right). Organizations that can adapt their C^2 design can often achieve higher performance with less experienced personnel and different organizational designs than those that do not adapt.

In the following analysis, we assume an organization of highly trained personnel (1000 on the previous figure) and examine different types of adaptive strategies. With highly trained

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When the partition was 1e-95 (virtually 0), half of all moves are accepted. This is because the performance space is a large plain and the chances of a move being downhill are 50/50, even for efficient organizations due to the "flatness" of the plain and the inherent randomness in organizational performance.

Initial Partition	Temperature	Ratio of Accepted to Total Moves
.99	199	100/100
1e-1	8.69e-1	96/100
1e-2	4.34e-1	89/100
1e-3	2.9 e-1	87/100
1e-4	2.17e-1	90/100
1e-7	1.24e-1	74/100
1e-10	8.69e-2	64/100
1e-14	6.68e-2	72/100
1e-16	5.43e-2	68/100
1e-20	4.34e-2	69/100
1e-25	3.45e-2	55/100
1e-30	2.9 e-2	53/100
1e-35	2.48e-2	55/100
1e-95	9.14e-3	50/100

personnel, organizations with the ability to adapt their architecture exhibit a 130% to 148% improvement in performance. In First the number and type of changes made under each scenario previously described is discussed. Then the architectures of the emergent organizations, and the impact of various types of changes on performance are described.

4.1 Number of Changes Over Time

As CEO's adapt their organization's C2 architecture we find that over time they stop augmenting their staffs, and the number of retaskings and reassignments first increase then decrease (Figure 1). The pattern is similar for organizations where personnel follow SOPs and where they follow their experience. In marked contrast, during the action phase, organizations tend to retask more than they reassign personnel. Over time, when organizational members follow experience their is a light tendency to increase the number of retaskings and decrease the number of reassignment (Figure 2), and the opposite is the case when personnel follow SOPs. However these trends are very small.

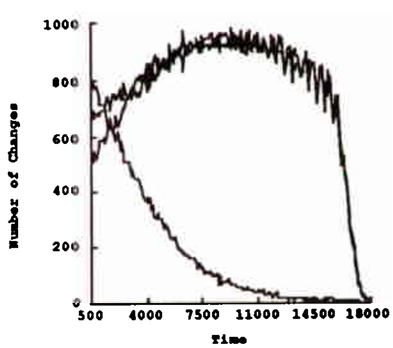

Figure 2. Number of changes over time during planning phase for organizations where personnel follow their experience.

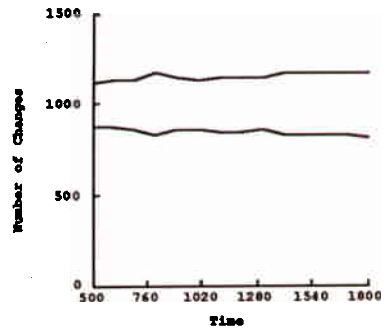

Figure 3. Number of changes over time during action phase for organizations where personnel follow their experience.

4.2 Performance and Types of Adaptation

Organizations, where staff make decisions based on their experience, exhibit the highest performance if they engage in many reassignments and retaskings, and only a moderate number of staff augmentations (see Figure 4). No design, under any condition, exhibits perfect performance. The designs exhibiting the best performance vary dramatically in the number of individuals at each level and the exact pattern by which individual agents are connected. In other words, even for this seemingly simple task there are multiple distinct designs that exhibit high and very comparable performance.

Organizations under each of the scenario's evolve a somewhat different pattern. In Table 1 we see that on average, across organizations, performance is comparable whether personnel are allowed to make decisions on the basis of their experience or when following optimized SOPs. Not surprisingly, performance is better immediately after planning, rather than after the organization has undergone a sustained action phase.

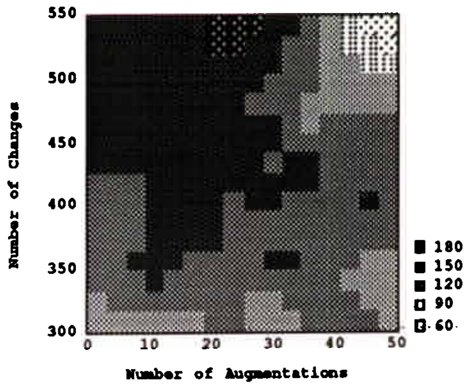

Figure 4. Impact of number of changes and number of staff augmentations during planning on initial performance during action phase.

Prior to planning, organizations have an average redundancy level of 3.77, the average number of factors overlooked is 0.44, and the average number of communication links is 19.87. Planning results in organizations with C^2 architectures which are more redundant in access to resources or task assignments, which overlook fewer factors in making decisions, and have many more communication links. After a period of sustained action redundancy has basically to its pre-planning value. Whereas, there are still fewer factors overlooked than in the pre-planning stage and a comparable number of communication links. Essentially, retaskings and reassignments carried out under sustained action serve to maintain an awareness of the battlespace. Immediately following the planning stage there is less variation in the emergent architectures, than after a period of sustained action. Notice this lack of variation is attributable solely to the ability to augment staffs.

Table 1. Impact of Adaptation on Organization

Adaptation and Decision Making	Performance	Redundancy	Overlook	Communication
Planning and Experience	147.74	5.32	0.037	44.25
Planning and SOPs	147.61	5.30	0.049	44.31
Action and Experience	125.89	3.80	0.399	20.21
Action and SOPs	127.02	3.67	0.399	19.67

N per cell is 2000

Each of these factors (staff augmentation, retaskings, reassignments, redundancy in access to resources or task assignments, and number of communication links) affects organizational performance. Using regression analysis the effects of these factors are simultaneously controlled for (Table 2). Results suggest that the amount of staff augmentation is a critical determinant of the organization's performance immediately following planning; whereas, retasking and reassignment during planning is largely irrelevant. After sustained action, the more retasking and reassignment that occurs the higher the performance. Different patterns of adaptation are needed for high performance immediately after entering the action phase and after sustained action. Additionally, high performing organizations are those that are more redundant in terms of resource access, overlook fewer decision factors, and have communication links among personnel.

Table 2. Regression Analysis of the Impact of Adaptation and Organizational Structure on Performance

	Planning and Experience	Planning and SOPs	Action and Experience	Action and SOPs
constant	83.77**	103.62**	79.19**	57.545**
Augment	0.48**	0.32**	---	---
Retask	0.00	0.01	0.05**	0.12**
Reassign	0.01	0.01	0.07**	0.10**
Redundancy	5.95**	4.64**	2.85**	2.45**
Overlook	-5.86**	-10.01**	-4.00**	-4.18**
Communication	0.39**	0.21**	0.58**	0.50**
R^2	0.23	0.30	0.39	0.32

N is 2000, $p < .001$ **, $p < .01$ *

5. Discussion

Computational models are perhaps uniquely suited to addressing the issue of whether organizations can improve their performance when they attempt to learn both at the individual and the organization level. Field studies of organizational learning have difficulty finding organizations that are sufficiently similar and that are not undergoing periods of adaptation. Lab studies cannot consider organizations of sufficient size. Further, in human organizations performance indicators are difficult to collect. Computational techniques obviate these problems and allow the researcher to build and explore a theoretical model of change. Future empirical studies can then test the predictions that are generated from these computational models.

In this paper, the cost function used was to optimize performance. Alternate cost functions, such as simultaneously optimizing performance and minimizing communication links (which would be useful from an intelligence perspective) could be considered. Work on computational models suggests that changing the cost function can affect the particularities of the results. In this case, it would affect the the number of decision factors overlooked, the level of redundancy, and the tradeoff between accuracy and communication silence. However, changing the cost functions is unlikely to change the basic results that: there are few high performers, that there are equi-performance plateaus, and that small changes in the organization's C^2 architecture can result in dramatic changes in performance. Future studies should investigate alternate cost functions.

Organizations, although altering their structure, are generally stuck in equi-performance plateaus where slight changes in their C^2 structure may dramatically alter organizational performance, but are more likely to result in the same performance. In such an environment, standard procedures for optimizing performance may not be sufficient. Alternate mechanisms for optimizing performance should be examined. Additionally, this equi-performance result suggests that CEOs can, within reason, redesign their organization with relative impunity. Moreover, the mere act of redesign, while it may not generate major improvements in performance is likely to be advantageous to the organization; for example, it may make the organization more efficient by increasing the communication links among the staff, decreasing the number of decision factors that are overlooked, and decreasing redundancy in access to resources or task assignments.

References

[Carley, 1992] Kathleen M. Carley. "Organizational Learning and Personnel Turnover." *Organization Science,* 3(1): 2-46, 1992.

[Carley and Lin, 1995] Kathleen Carley and Zhiang Lin, 1995, "Organizational Designs Suited to High Performance Under Stress," IEEE - Systems Man and Cybernetics, 25(1): 221-230.

[Carley and Lin, 1994] Kathleen Carley and Zhiang Lin. "Relating Shifts in C2 Structure to Performance" in Proceedings of the 1994 Symposium on Command and Control Research.

[Hannan and Freeman, 1977] Michael Hannan and John Freeman, "The Population Ecology of Organizations." *American Journal of Sociology*, 82:940-40.

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

[Tang, et al., 1992] Tang, Zhuang-Bo, Krishnan R. Pattipati, and David L Kleinman, 1992, "On the Role of Confidence of Opinions in Distributed Binary Hypothesis Testing Problems." *IEEE Trans. on Automatic Control,* 632-636.