# CHAPTER 9

# HOW WELL DID IT WORK?

## Measuring Organizational Performance in Simulation Environments

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***"We are confronted with insurmountable opportunities..."***

**—Pogo (Walt Kelly)**

**ABSTRACT**

Immersive "virtual" simulations offer an opportunity to gain insight and experience in new, innovative organizational structures. Assessing the performance of these new organizations represents a considerable challenge due to the myriad of complex interrelated factors that may contribute to the outcomes observed in the simulation. Theories and models, often in the form of "constructive" simulations of organizational performance, can guide the development of empirical performance measures by linking detailed behaviors to overall outcomes for organizations. Constructive simulations can be used to create meaningful test conditions for immersive performance measurement, to identify those aspects of performance that are most critical to measure, and to predict the effects of organizational structures on performance. Translating theoretical measures into a form that can guide empirical data collection is a considerable challenge, however. This chapter provides examples of the use of theories and constructive simulations to structure empirical data collection for organizational performance, and discusses the lessons learned from these efforts. The focus is on organizational structures for military command and control, including innovative structures associated with the new and rapidly evolving concept of "network-centric warfare."

## THE CHALLENGE OF UNDERSTANDING ORGANIZATIONAL PERFORMANCE

The “bottom line” performance of multi-person teams and organizations, as measured through outcomes such as successful mission completion for military organizations or through profit or productivity measures for business organizations, results from the complex interaction of a myriad of interrelated factors. Organizational performance is a complex, dynamic, stochastic phenomenon. There are a multitude of individual attitudes, behaviors, decisions, and actions—all potentially measurable—that may contribute to successful outcomes for the entire organization. This complexity creates a major challenge for understanding and measuring organizational performance. Without a strong theory to guide the measurement and analysis, a mountain of seemingly unrelated and uninterpretable data can quickly overwhelm the analyst.

Because of the complexity of organizational performance, computational models have come to play a key role in understanding organizational structure and behavior. Hulin and Ilgen (2000) have suggested that computational modeling is a “third scientific discipline” for understanding complex socio-technical systems, supplementing the more traditional approaches of correlational analysis of real-world data and controlled laboratory experimentation. They characterize computer simulations of organizational behavior as “experiments done ‘in silica’ rather than ‘in vitro.’”

Hulin and Ilgen argue that computational organizational models supply an essential capability lacking in other approaches. Controlled experimentation is limited in the number of variables it can consider. Correlational studies are dependent on the existence of a sufficient range and variability of data about the phenomena of interest. Both methods are severely limited in their ability to consider dynamic causal effects over time, depending either on static “snapshots” of isolated points in time or on arbitrarily selected measurement time periods that are often not dictated by the time cycles of the effects that are to be analyzed.

Models are tools for “illuminating the interface between theory and data” (Hulin and Ilgen, p. 11). Models can act as “dynamic theories” or “dynamic hypotheses” by making testable predictions about how multiple variables will interact to produce measurable outcomes. By making predictions across a theoretical space that includes a wide range of variables and conditions, only a few of which can be tested empirically, models can serve as a bridge between organizational theory and empirical data collection.

Models allow analysts to explore uncharted organizational territory. Computational models can make predictions about the performance of organizations that do not yet exist, under circumstances that have not yet been observed. Further, models can be used to concentrate empirical data collection in the most informative parts of an unexplored organizational space. These capabilities are essential if we wish to create and evaluate new and innovative organizational structures. The need to develop new organizational structures and to understand and predict their effectiveness before they are fully implemented seems especially important at the present time, as information network connectivity changes the face of the organizational landscape.

## NETWORK CONNECTIVITY ENABLES NEW ORGANIZATIONAL STRUCTURES

Network connectivity is rapidly changing the information flow and communication constraints that have shaped human organizations for millennia. Physical location is becoming increasingly less critical for information exchange—it has become possible to obtain information from around the world in seconds. New communication technologies make it possible to create “virtual organizations” that can pull together expertise in a variety of locations to address a specific need and then disband as rapidly as they have formed.

Within the military, this change is reflected in a focus on “network-centric warfare” (Cebrowski, 2003; Alberts and Hayes, 2003) that asks how information technology can be used to gain both a strategic and tactical advantage in battle. Network connectivity has removed many of the limitations on information flow that shaped the organizational structure of Napoleon’s command center, but a definitive replacement for that structure has yet to emerge. Almost instantaneous information flow seems able to support the formation of flexible, adaptive organizations that can change direction quickly in response to emerging events, but the full potential as well as the limitations of this concept are yet to be explored. At the heart of network centric warfare is the challenge of creating new organizational forms and structures that can use the rapid movement of information to create and maintain a strategic and tactical advantage in military conflicts.

How will we know if these new organizational forms will provide us with the advantages that we seek? How will we know that we have developed organizational structures and procedures that take maximum advantage of new technology for information flow? Organizational models and constructive simulations[1] provide us with a means to test our ideas at a much more rapid pace than the traditional methods of small incremental changes and trial-and-error learning—punctuated by flashes of genius—that have characterized organizational learning in the past. The creation and use of these constructive simulations to test

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[1] We use the widely accepted term “constructive simulation” in this chapter to describe “third party” models and simulations that do not involve real-time human-in-the-loop participation by live human test subjects. We use the term “virtual simulation” to describe the use of simulations to create an environment in which live humans interact with the simulation and with each other.

new organizational concepts does not free us from the need to collect data through empirical human-in-the-loop testing, however.

## HUMAN-IN-THE-LOOP TESTING OF ORGANIZATIONAL STRUCTURES

In the midst of the explosion in information connectivity, human attention spans, perceptual and cognitive capabilities, and processing speeds are unchanged. Although new skills may be developed, fundamental human information processing abilities remain the same. The massive increase in the amount of information available without a fundamental change in the way that human beings attempt to process that information has resulted in the often-cited "information overload" problem for complex distributed operations such as modern warfare. Information overload has replaced information scarcity as the predominant problem of warfare, and the "fog of war" now results more frequently from too much information than from too little.

Although much progress has been made in understanding and modeling human perceptual and cognitive capabilities, models are still far away from capturing the complex decision-making expertise that underlies a successful military operation and the complex person-to-person interactions that characterize an effective organization. Human-in-the-loop testing with live in-the-flesh decision makers thus remains an essential tool for determining whether humans can use new technology to accomplish their goals and whether they can function effectively in new and innovative organizational structures. Constructive models and simulations can provide insight into how new organizational structures can and should function, and can make predictions about the potential associated with the effective use of new technology, but human-in-the-loop testing is still needed to ensure that abstract ideas about how to use technology and how to alter organizational structures will really "play" as envisioned when used by real people in the real world.

Virtual simulation environments provide a means to construct "artificial worlds" in which multiple individuals can experience new technologies, new concepts of operations, and new organizational structures in a realistic interactive environment. These environments can be used for innovation, exploration, and training. The degree of control and observability that is feasible in these environments, while much less than that associated with traditional experimentation, is still much greater than that possible in real-world settings. It is possible, for example, for multiple teams to "play" the same scenario with different CONOPS (concepts of operation) or technologies, or to test the effectiveness of an organizational structure in circumstances designed specifically to create different types of stress on the organization. Although a complex scenario involving multiple players in a virtual environment does not ever play out in exactly the same way over multiple trials, virtual simulations provide much more testing control and replication than would otherwise be possible.

But how do we know whether a new organizational structure, coupled with new technology, is working as intended when we test it in a virtual simulation environment? What should we measure to gauge success? Overall outcome measures are often not very illuminating. Outcomes may prove to be insensitive to the variations in structure and technology that are being tested within the specific environment and scenario chosen for the test, and it is almost impossible to conduct tests that capture all of the variations in the environment that may affect outcomes. "Finer-grained" measures are needed that can capture how and why organizational structures and new technologies change the processes and behaviors of the organization in ways that lead to desired outcomes in a specific environment. If detailed process and behavior measures can be linked to desired outcomes and to the specifics of the external events that occur in the scenario, then empirical results can be extrapolated to make testable predictions about other environments and scenarios.

## MODELS PROVIDE A FRAMEWORK FOR EMPIRICAL TESTING

It is relatively easy to obtain massive amounts of data from simulation-based exercises, but it can be difficult if not impossible to interpret these data in a meaningful way without a theory, framework, or model that links detailed measurable behaviors to overall results. A framework is needed both to focus the empirical data collection and to aid in finding the patterns of interest in the results.

Executable organizational models serve as dynamic theories to guide the collection and analysis of empirical performance data in virtual human-in-the-loop simulations. Constructive simulations and models can be used to design the scenarios to be "played out" in virtual simulations; to select the behaviors to be measured, based on predictions about the relationship of those behaviors to outcomes; and to analyze and interpret the empirical data once it is collected. Models make predictions by linking measurable processes to measurable outcomes, and these predictions serve to guide both the collection and the analysis of the empirical data. Further, models "enable surprise" in analyzing complex phenomena.[2] By specifying and instantiating expectations, models allow us to know when we have found the unexpected.

This chapter focuses on analysis of the communication patterns that underlie organizational performance as an example of the use of organizational models to develop process measures that are linked to outcomes, serving to guide the

[2] We are indebted to Gary Klein for this apt phrase.

collection and interpretation of empirical data from experiments conducted in virtual simulations. Communication in an organization is easy to observe and measure, but difficult to interpret. For example, communication rates (e.g. message exchange rates between nodes in an organization) are relatively easy to measure quantitatively, but the results can be meaningless without a model or theory that makes predictions about the relationship of these communication rates to the goals of the organization and the outcomes of the mission.

## ORGANIZATIONAL MODELING APPROACH

Over the past several years, we have been involved in a series of collaborative studies with the University of Connecticut (MacMillan, Paley, Levchuk, Entin, Serfaty, and Freeman, 1999; Levchuk, Pattipati, and Kleinman, 1998, 1999) to develop models that predict organizational performance and to test and validate those models through empirical experiments. Figure 1 shows the conceptual framework underlying our modeling approach. Organizational models capture the dynamic relationship between the mission to be accomplished (the tasks to be performed), the resources needed to perform those tasks (sensor and weapons systems as well as the information needed for each task), and the human decision makers who use the resources to perform the tasks. The organizational structure is modeled as a three-way matching of humans, tasks, and resources. Based on the interdependency of the tasks in time (some tasks must be completed before others can be undertaken) and the resources required for each task, it is possible to optimally schedule the use of scarce resources to accomplish a mission. Typically there is substitutability among some of the resources (several ways to do the same task), with differences in the projected success of the task depending on which resources are used. As human decision makers are matched to resources and tasks, human capabilities and workload limitations must be taken into account by setting constraints on the number and type of tasks that can be performed simultaneously by each individual. If the workload associated with a task exceeds the capabilities of an individual, then multiple individuals must work together to perform the task. Splitting tasks across individuals, and the interdependencies that exist among different tasks (e.g., one task must be completed before another one can be initiated) create the need for coordination among the individuals in the organization. The need for coordination spawns the need for communication among the individuals who must coordinate. The organizational structure instantiated in the model thus captures the roles played by each individual in the organization (who does what) and predicts the communication patterns that will be associated with those roles (who talks to whom).

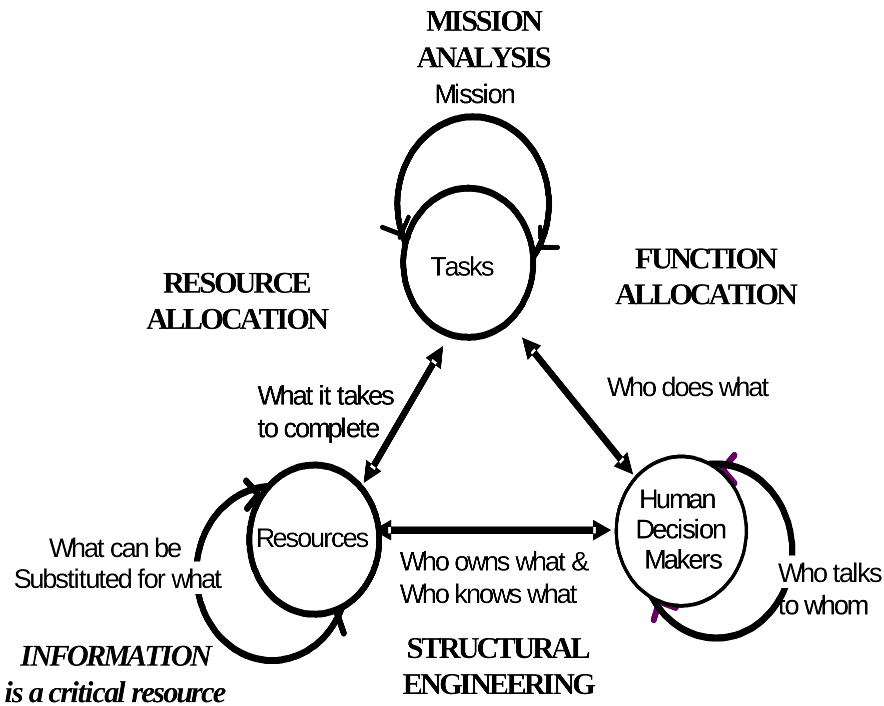


**FIGURE 1.** Conceptual Framework for Organizational Modeling

## COMMUNICATION BEHAVIOR AS A MEASURE OF ORGANIZATIONAL PERFORMANCE

In order for an organization or a team within an organization to act "in concert" to achieve common goals, the team must have information both about the external situation and about the other team members. Some information will be relevant to the entire organization, while other information is relevant only to individuals or sub-groups within the organization. The need for shared information depends on the nature of the mission and the specifics of the organizational structure. Although some of the needed information can be shared through common displays or gathered through observation of what other teams members are doing, effective organizational performance almost always requires explicit communication—

messages, discussions, directions, and orders—to achieve the necessary sharing of information.

Explicit communication has a cost, however—an “overhead” associated with the exchange of information among team members. Communication requires both time and cognitive resources, and, to the extent that communication can be made less necessary or more efficient, team performance can benefit as a result. Reductions in the “communication overhead” associated with coordinated action have been found to result in more efficient and more effective organizational performance (Entin and Serfaty, 1999; MacMillan, Serfaty, and Entin, 2004).

The volume of communication in an organization, taken in a vacuum without considering any other factors, has no natural directionality. Is more communication good? Or is less communication good? The answer depends on the demands of the tasks to be performed, the organizational structure, and the situation in which the organization finds itself. The effective team or organization should *communicate as much as necessary,* but no more. Constructive organizational modeling can provide insights and predictions concerning *how much communication should be necessary* in order for the team to perform effectively for a specific mission in a specific scenario.

The nature of the mission to be performed and the organizational structure of the team interact to determine the communication patterns that will be associated with successful outcomes. For a military mission, the tasks to be performed will have certain requirements for resources, the amount and types of resources needed will depend on the specifics of the scenario, and the structure of the organization will determine how the needed resources are assigned and controlled.

For example, in a simulated amphibious assault scenario recently used to evaluate alternative organizational structures for a Joint Task Force command team (Entin, Diedrich, and Rubineau, 2003; Diedrich, Entin, Hutchins, Hocevar, Rubineau, and MacMillan, 2003), an assault on an airbase might require both strike assets (e.g., cruise missiles) and the support of a Special Forces team. Following this attack, the Special Forces team may then be needed for an assault on a nearby port, and thus the attack on the airbase must be accomplished in time for the Special Forces to deploy to the port. In this case, the amount of coordination required between commanders or command nodes, and therefore the communication required, will depend on who controls which assets. If the strike assets and the Special Forces team are under the control and direction of a single node (commander) in the organization, then little or no inter-person or inter-node communication will be needed to achieve the assault. If, however, the strike assets and the Special Forces team are controlled by different commanders, then extensive inter-person or inter-node communication will be necessary for the assault to be successful. Hence, the fit or match between the organization and the task requirements influences the coordination and communication needed to achieve a successful outcome.

An organizational model that captures the interdependencies among tasks and the way that these interdependencies interact with the control of resources in alternative organizational structures can thus predict how much communication will be needed for successful completion of a mission under each structure. These predictions can then be tested through empirical data collection in a virtual simulation environment.

## EMPIRICAL RESULTS: MODEL-BASED PREDICTIONS OF COMMUNICATION BEHAVIOR

We have conducted a number of experimental studies, working with colleagues at the University of Connecticut and the Naval Postgraduate School, that examine how mission structure and organizational structure interact to produce communication behaviors that are associated with effective performance for a command and control organization. In each of these experiments, the interdependence of the tasks being performed and the team structure—the control of resources and the assignment of task responsibilities—generates the need for coordination. This need for coordination then drives the need for communication among team members. Detailed results for these experiments are reported elsewhere (Diedrich et al., 2003; MacMillan, Entin, and Serfaty, 2004; Entin, 1999) but we review them briefly below to show how constructive organizational simulations can serve as a framework to shape empirical data collection in virtual simulations, can guide the analysis and interpretation of organizational performance results, and can enable us to find and interpret the unexpected in our results.

### Experiment 1. Can Organizational Structure Be Optimized for a Mission?

This experiment compared both mission outcomes and organizational processes for two different organizational structures (Entin, 1999). The mission involved an air- and sea-based operation to regain control of an allied country that had been taken over in a hostile invasion by a neighboring country. One of the organizational structures tested was a relatively traditional Joint Task Force (JTF) structure, developed by subject matter experts, in which all resources of a similar type (e.g., air strike assets or amphibious landing forces) were controlled by the same node in the organization without explicit consideration of the need to coordinate the use of those resources in the mission. The second structure tested was "optimized" for the mission using an approach originally developed at the University of Connecticut (Levchuk, Luo, Levchuk, Pattipati, and Kleinman, 1999; Levchuk, Pattipati, and Kleinman, 1998, 1999) in which a model of the activities required to complete the mission was developed and an organizational structure was designed based on a model of how resources could be most efficiently employed during the mission. The optimized organizational structure developed for the experiment was based primarily on two optimization objectives—simultaneously minimizing the coordination required to accomplish the mission and balancing workload across the team. These multiple objectives act to constrain each other, since the workload-balancing objective prevents the assignment of all tasks to only a few team members in order to minimize the coordination requirements.

The model predicted that teams using the optimized structure would perform the mission more successfully. But—most importantly—the model predicted *how and why* teams using the optimized structure would be more successful. Specifically, the model predicted that teams using the optimized structure would need to coordinate less, and therefore would need to communicate less frequently, because each node in the optimized organization controlled all or many of the resources needed to perform the tasks to which they had been assigned. In the optimized structure, it was predicted that the command nodes would be able to achieve the coordinated use of resources to carry out mission tasks without the need for extensive, explicit communication among nodes.

These predictions were tested in an experiment conducted in a virtual simulation with 10 six-person teams of Navy officers (Entin, 1999). The results were as predicted by the model. The teams using the optimized structure accomplished the mission more successfully as judged by outcome measures such as the successful completion of mission tasks, the speed with which mission tasks were completed, and the efficiency of resource usage. More interestingly, the model also successfully predicted differences in the coordination and communication patterns for the two team structures. Teams using the optimized structure coordinated less and communicated less frequently (lower communication rate). Other differences observed for the two structures were not directly predicted by the model, but could be derived from the differences that were "designed in" to the two structures (MacMillan, Entin, and Serfaty, 2004). Because teams using the optimized structure needed to communicate less frequently to accomplish the mission (lower "communication overhead"), they were predicted to experience a lower subjective workload during the mission -- measured with the NASA TLX questionnaire (Hart & Staveland, 1988) -- and this prediction was borne out by the data.

We also found an effect not predicted by the models—associated with less communication and a lower workload under the optimized structure was a more accurate awareness of what other team members were doing measured via periodic questionnaires about major activities at the other nodes (MacMillan, Entin, and Serfaty, 2004). This finding that less need for coordination and a lower communication rate was associated with a more accurate understanding of others' tasks was both interesting and unexpected. One might have predicted that teams who communicated more frequently would have a more accurate understanding of each other's tasks and situation. Instead, it seems possible that the workload associated with communication may counteract the expected positive effects of that communication on each team member's awareness and understanding of the activities of others. This idea is supported by the finding that teams using the optimized structure were better able to anticipate each other's needs for information, as measured by an "anticipation ratio" (Entin, 1999; MacMillan, Entin, and Serfaty, 2004) that counts the number of transfers of information relative to the number of requests for information across team members.

This experiment illustrates how an organizational model can be used to shape the collection and interpretation of empirical organizational performance data in two ways. First, the model can make explicit predictions about performance that can then be tested experimentally—in this case, a prediction that teams using an optimized organizational structure would be able to accomplish a mission more successfully while coordinating less and communicating less frequently than teams using a traditional JTF structure. Second, the theoretical structure instantiated by the model supports additional theory development and hypothesis formulation that builds on the model to generate new predictions—in this case, the finding that a lower communication rate was apparently associated with a higher level of mutual awareness and understanding among team members. This effect was not predicted by the model, but can be factored into theory formulation and model development in the future. Thus, models not only help us know what to look for in empirical data collection, they can also provide a structure that allows us to find and recognize the unexpected—they "enable surprise" and help us to understand and interpret that surprise.

### Experiment 2. Does the Benefit of Collaborative Planning Vary Under Alternative Organizational Structures?

In another experiment (Price, Miller, Entin, and Rubineau, 2001; Miller, Price, Entin; Rubineau, and Elliott, 2001) we examined the effects of using an electronic collaboration tool—a shared whiteboard—during pre-mission planning, and the subsequent effects of that planning on a team's ability to carry out a coordinated mission under two different organizational structures. The mission to be performed was a humanitarian assistance/airlift mission that required the coordinated delivery of food and medical supplies to refugee sites, combined with the need to use defensive weapons to protect the planes making the deliveries. Teams were able to pre-plan this mission based on information about the delivery sites and their respective needs, but other sites and needs that could not be anticipated in advance emerged during the mission.

Three-person teams planned and carried out the mission under two different organizational structures. In a "functional" structure, each team member controlled assets of only one type—medical supplies, food supplies, or defensive weapons. The simultaneous "delivery" of the needed supplies to a site thus required all three team members to work together to meet the requirements for the mission. In a "divisional" structure, each team member controlled a portion of all three types of resources. In the divisional structure, each member of the team could perform a successful delivery to a site without coordinating with the other team members if he or she had the quantity of resources that were required by the site. In the scenarios that were used in the experiment, some, but not all, of the sites could be serviced independently by individuals under the divisional structure, while all sites required coordination under the functional structure. Thirty-six university students participated as subjects in the experiment, in 12 three-person teams.

The outcome measures used in this experiment were based on the team's ability to deliver exactly the right amount of resources to each site ("task accuracy"). For example, percent task accuracy was measured by the percentage of times that the team managed to deliver 100 percent of the needed supplies to each of the refugee sites. One might have expected, based on a model that predicts more effective performance if less coordination is required, that the teams using the divisional structure would perform at a higher level of task accuracy than teams using the functional structure. In fact, the opposite was found. Overall performance was significantly better for the teams using the functional structure.

In this experiment, our model "enabled surprise" by making a prediction that was not borne out by the data. It also gave us an indication of "where to look" in order to understand the results. The performance problems for the divisional teams arose in those tasks for which coordination *was* required. Teams using the divisional structure needed to coordinate much less frequently than the teams using the functional structure, but when they *did* need to coordinate they did so poorly. For example, a coordination success measure (the percentage of required team members who participated in each task) was significantly higher for the functional structure than for the divisional structure.

These results tell us that a model that simply predicts that "teams who need to coordinate less frequently will perform better" is inadequate. If teams vary in their need to coordinate—sometimes they can act independently and sometimes they need to coordinate—then those teams that know how to coordinate will be at an advantage when coordination is needed. So the overall performance levels for the "divisional" teams who are usually able to act independently will depend on how frequently coordination is needed.

The experiment also examined the effects of using a shared whiteboard for collaborative planning, with teams in one condition using the electronic whiteboard (with a map background) and teams in the other condition conducting their planning using paper maps. There was an overall positive effect of the use of the collaborative whiteboard during planning on mission success (task accuracy), but, interestingly, use of the whiteboard appears to have been more advantageous to the teams using the functional structure than to the teams using the divisional structure (MacMillan, Serfaty, and Entin, 2004). Teams that used the electronic whiteboard collaborated more intensively during the planning process, as measured by the number of collaborative communications that occurred during the planning phase (Miller et al., 2001), and this collaboration during planning seems to have been especially beneficial to the functional teams that needed to coordinate intensively during the mission.

Neither the more intensive collaboration that occurred when the electronic whiteboard was used for planning nor the advantage that this more collaborative planning gave to the high-coordination functional teams during the mission were directly predicted by models or theories prior to the experiment. However, the theoretical framework that distinguishes functional and divisional organizational structures helped us to understand these unexpected results.

The experiment was designed, based on theory, to create organizational structure conditions that differed in the amount of coordination that was required for successful mission execution. At the time the study was designed, we did not predict the difficulty of coordination for teams that needed to coordinate less frequently. However, these results seem consistent with recent studies showing that teams find it more difficult to move from a divisional to a functional structure than vice versa (Hollenbeck et al., 1999; Moon et al., 2000). Teams who are experienced in acting independently seem to find it difficult to learn to coordinate, while teams experienced in coordination find it relatively less difficult to learn to act independently. Given this expectation, it is not surprising that more intensive collaboration during the planning phase was associated with more successful coordination during mission execution. What remains a "surprise" that requires more investigation is why the use of the electronic whiteboard during planning was associated with more intensive collaborative communication. Theory and models that link organizational structure to performance have thus enabled us to identify the "most surprising" results of the study and the most promising areas for future investigation.

## Experiment 3. What Happens When the Structure of an Organization Is Incongruent with Its Mission?

A third, recently completed, experiment illustrates how constructive organizational models can be used both to design scenarios that stress specific organizational structures and to collect and interpret empirical performance data for organizations using those structures (Diedrich et al., 2003). The focus of the experiment was to understand and predict the performance of organizations that find themselves "out of synch" with the mission they are performing. The fundamental concept is that it is possible to mathematically define the degree that an organizational structure is "congruent" with the mission that the organization is performing, and that organizations using structures that are more congruent with a mission will perform that mission more effectively than organizations using structures that are less congruent.

In order to test this concept experimentally, it was necessary to define the organizational structures to be tested in detail and to develop mission scenarios that would provide congruent and incongruent test conditions for those organizations (Kleinman, Levchuk, Hutchins, and Kemple, 2003). The organizational structures for the experiment were developed to correspond roughly to the theoretical divisional and functional structures discussed above, with adjustments made as needed to create an organizational structure that was credible for a Joint Task Force (JTF) in a military context. Two structures were developed for a six-person JTF command team: (1) a functional structure in which all or most of the assets of a specific type (e.g. strike aircraft) were under the control of one commander, and (2) a divisional structure in which all or most of the assets on a specific platform in a geographical area were under the control of one commander.

A model of the divisional (D) and functional (F) structures was developed and used to develop and refine scenarios for the experiment (Kleinman, Levchuk, Hutchins, and Kemple, 2003). Essentially, the test scenarios for the experiment were “reverse engineered” by using the model to evaluate the amount of “incongruence” predicted to exist between the two organizational structures and the two different types of mission scenarios. One scenario type (d) was designed to be “tuned” to the divisional structure but mismatched to the functional structure, and the other scenario type (f) was designed for the reverse effect. The major scenario-design factors manipulated to create congruence and incongruence between structures D and F and scenarios d and f were the amount of coordination required to perform the scenario tasks and the spatial-temporal loading of the individual decision makers.

The focus of the experiment was to develop and test model-based predictions about organizational performance in the congruent conditions (Dd and Ff) and the incongruent conditions (Df and Fd). Overall performance as measured by successful mission outcomes was, of course, expected to be higher in the congruent conditions, but it was also of great interest to be able to predict and understand in more detail the organizational behaviors that were affected by the incongruence between the structure and the mission. The experiment was conducted at the Naval Postgraduate School with eight six-person teams composed primarily of Navy officers.

As expected, performance was higher in the congruent conditions as measured by the mean percentage of tasks completed (Diedrich et al., 2003) as well as by an “accrued task gain” measure that weighted task completion by the value of the task (Levchuk, Kleinman, Ruan, and Pattipati, 2003). Also, as expected, the subjective workload experienced by participants was lower in the congruent than in the incongruent conditions (Diedrich et al., 2003).

The congruent and incongruent conditions were designed so that the requirements for coordination were greater in the incongruent than in the congruent conditions. Communication rates were therefore expected to be higher in the incongruent conditions because the team’s primary mechanism of coordination was through verbal communication. As predicted, there was a significant effect of congruence on communication frequency (Diedrich et al., 2003). However, as shown in Figure 2, there was an asymmetry in the effects of

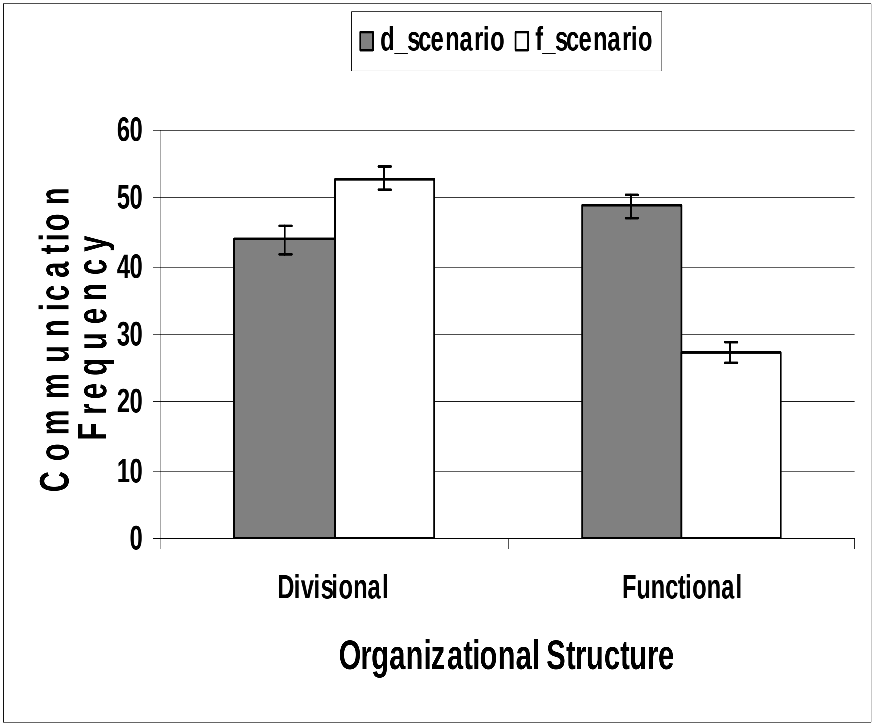


**FIGURE 2.** Communication Frequency in Congruent and Incongruent Conditions

congruence on communications that had not been predicted by the models. The effect of incongruence on the need to communicate was much greater in the F than in the D organization. Communication rates in the two incongruent conditions (Df and Fd) were roughly the same, while communication rates were much higher in the Dd congruent condition than in the Ff congruent condition.

The unexpected finding that congruence effects on overall communication were quite different for the two organizational structures led us to perform a more detailed analysis of the nature of the communications in the two conditions (Diedrich et al., 2003; Entin, Diedrich, and Rubineau, 2003). Using a categorization of utterances by type, we analyzed changes in the patterns of verbal communication—who talked about what—as the two organizational structures moved between congruent and incongruent scenarios.[3] Teams using the D structure increased their communication in almost all communication categories in the incongruent scenarios as compared to the congruent scenarios. In the D structure, teams talked more overall in the incongruent condition, but there was little change in the *pattern* of those communications. Teams using the F structure, in contrast, showed major changes in their communication patterns between the congruent and incongruent conditions, with some categories of communication increasing greatly while others decreased, and with some positions on the team talking more while others talked less. Team members in the F structure not only talked more in the incongruent condition, they also talked *differently*.

These organizational differences in the amount, type, and nature of communications between congruent and incongruent conditions were not predicted by the model, suggesting that they result from factors not taken into account in the model-based definition of "congruence" in the experiment. Communications in the functional organizational structure looked quite different in both amount and type in the congruent and incongruent conditions, while communications in the divisional structure increased in volume without changing in pattern. The effect of incongruence on mission outcomes, in contrast, was roughly symmetrical, with both structures suffering about the same decrement under incongruent conditions.

Based on these results, one might argue that the divisional structure was more "robust" across the congruent and incongruent conditions, if we define robustness as the ability to cope with incongruence without making major changes in organizational communication patterns. The functional structure, in contrast, seems to have been able to take advantage of the congruent conditions to be more efficient (much lower communication rates) and to exhibit more flexibility in changing communication patterns under incongruent conditions. Without more detailed communication-pattern predictions from the model, however, we cannot say to what extent the change in communication patterns shown by teams using the functional structure was necessitated by the coordination requirements that resulted from the combination of the functional structure and the incongruent scenarios. Were the functional teams simply "doing what they had to do" to try to maintain performance under incongruent conditions? Or was there something about the functional structure that resulted in a greater ability to change communication patterns—more adaptability—in response to changing mission requirements? Additional modeling and experimentation is needed to address this issue.

The models in this experiment played a key role in defining the test conditions and in setting the expectations for the experiment, allowing us to be "surprised" by the differences in the effects of incongruence on communication patterns under the two structures. Understanding the implications of this difference in

[3] The direction of movement from congruent to incongruent scenarios was counterbalanced for the two organizational structures.

communications under incongruence for the two structures will require further investigation as well as enhancement of the models.

## CONCLUSIONS

Our experience in measuring and analyzing organizational performance using a combination of constructive and virtual simulations suggests that simulation technology is entering an innovative period of the “S curve” with regard to understanding organizational behavior. As the capabilities for virtual simulation of multi-node organizations have advanced through efforts such as the Air Force’s Distributed Mission Operations training program, the capabilities for constructive simulation and computational modeling of organizations have advanced in parallel. We argue that these two capabilities are complementary, and, further, that they are both essential for developing new organizational structures that exploit new information technology and connectivity. Organizational performance is complex, and formulating expectations about that performance requires taking into account the interaction of a multitude of variables. Computational models provide a valuable tool for understanding this complexity, allowing us to understand what to measure in virtual simulations, how to construct conditions for data collection, and how to interpret the results of the evaluation.

As technology alters the possibilities for organizational structures, we need new methods for developing effective organizations that move beyond incremental trial and error learning. The ability to combine the capabilities of constructive and virtual simulation puts us at a new threshold for building innovative and effective organizations. Computational models can help us to design new organizational forms that can be experienced in virtual simulations, and can help us evaluate those new organizations by creating model-based expectations that let us know when we have found the unexpected.

The studies reviewed in this chapter suggest that computational organizational models can be extremely useful in creating and using immersive simulation environments to develop and test new organizational forms and structures, as envisioned in the OrgSim environment. Models have three major uses in OrgSim

- Designing organizational structures to be tested in virtual human-in-the-loop simulations
- Designing scenarios (external events) for the simulation environment that will stress the organizational structure in predictable ways
- Suggesting performance measures for human-in-the-loop testing that will indicate whether an organizational structure performs as predicted

Constructive models can provide a theoretical framework that ensures that the best possible use is made of experiences in immersive OrgSim testbeds.

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