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# DETERMINING THE BEST LOCI OF KNOWLEDGE, RESPONSIBILITIES AND DECISION RIGHTS IN MAJOR ACQUISITION ORGANIZATIONS

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# Determining the Best Loci of Knowledge, Responsibilities and Decision Rights in Major Acquisition Organizations

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## Abstract

The DoD is a large, bureaucratic, rule-intensive organization that may not be suited well for its environment. Building upon prior research of acquisition centralization and knowledge dynamics, we employ computational methods to assess the behavior and performance of different organizational designs in varying environments. Our results reinforce Contingency Theory and suggest particular characteristics of different acquisition environments make one organizational form relatively more or less appropriate than another. Practically, answers to our research questions have direct and immediate application to acquisition leaders and policy makers. Theoretically, we generalize to broad classes of organizations and prescribe a novel set of organizational design guides.

## Introduction

Acquisition is big business. The US Department of Defense (DoD) alone executes routinely eleven-figure budgets for research, development, procurement and support of weapon systems, for instance. Acquisition is also a rule-intensive business. In addition to myriad laws governing federal acquisition in the US, a plethora of regulations specify—in great detail often—how to accomplish the planning, review, execution and oversight of Government acquisition programs, large and small, sole-source and competitive, military and commercial (Dillard, 2003). Due in great part to the large size and many rules associated with Defense acquisition in particular, the organizations responsible for DoD acquisition activities tend to be large and rule-intensive themselves, reflecting the kinds of centralized, formalized, specialized and oversight-intensive forms corresponding to the classic Machine Bureaucracy from Organization Theory (e.g., see Mintzberg, 1979). The problem is this classic organizational structure is known well to be exceptionally poor at responding to change. In the context of military transformation, such a problem should be clear and compelling. Arguably, one or more, superior, organizational approaches must be available to replace the current acquisition organization. But which, if any, is most appropriate? On what basis should acquisition leaders and policy makers choose between such competing organizational forms? What evidence supports claims of superiority for one organizational approach versus another? Questions such as these are difficult to answer through most research methods employed today to study acquisition organizations (e.g., case study, survey, action).

The bureaucratic nature of the DoD Acquisition Organization did not emerge recently, nor did it materialize by design. Rather, it reflects the cumulative accretion of laws, regulations, rules and hierarchical levels over considerable time. If only the organization could be changed and evaluated—say through assessment of four alternate organizational structures—then one could assess the relative performance of the new organizational designs versus the current form and recommend transformation toward the best performer. But, clearly the set of problems and actors in the changed organizations would differ from those associated with the original and with one another; that is, there is no way to impose controls over such a study (e.g., internal validity is compromised). This is one reason why so many acquisition research projects produce so little new knowledge. Alternatively, such controls can be imposed easily through laboratory experimentation. Yet, the simplified nature and laboratory context of experiments fail to capture the size, scope and complexity of the acquisition organization (e.g., external validity is compromised). This is another reason why so many acquisition research projects produce so little new knowledge. However, by combining the best features of laboratory experimentation (e.g., experimental controls) with field methods (e.g., large-scale and complex behaviors), one can design and conduct a study of acquisition organizations that reflects both internal and external validity.

This is the approach of computational experimentation: using sophisticated and validated computer models of organizations to assess the behavior and performance of different organizational designs. Computational Organization Theory (COT; see Carley & Prietula, 1994) provides a set of methods and tools to enable this approach. In particular, using the methods and tools associated with the Virtual Design Team (VDT) Research Group at Stanford, computational models of organizations are driven by well-accepted organization theory and are validated by extensive and repeated field studies. This validation provides considerable confidence that computational results reflect the likely behaviors and performance of the acquisition organizations they model and emulate.

The research described in this article involves the application of VDT methods and tools to study acquisition organizations. In particular, we model and simulate the behavior of organizations associated with major defense acquisition programs in the DoD. We provide both answers to and insights into how such organizations can be changed to improve performance. Some of the key organizational design variables of interest pertain to the bureaucratic nature of the organization and follow from recent research to investigate centralization (Dillard, 2003). For instance, factors such as *centralization, formalization, specialization, hierarchical layers* and the like can be manipulated—individually as well as in combination—under controlled and replicated conditions to assess the performance of acquisition organizations in different forms. This follows recent, complementary research using computational organization theory in the domain of military command and control (Nissen & Buettner, 2004; Nissen, 2005a, b). Considerations such as the number, frequency and level of acquisition reviews, adaptability and flexibility of acquisition organizations, and risk-versus-project-duration of acquisition programs are primary in this study. The key research question is: How can organizations responsible for major acquisition programs be redesigned to improve performance?

The significance of this approach is twofold. First, answers to the research question have direct and immediate application to acquisition leaders and policy makers. Such answers address a serious and immediate problem, revealing insights into the behaviors of major acquisition organizations that are too complex and dynamic to be understood well or directly. They illuminate the kinds of changes acquisition organizations can make to balance competing performance measures (e.g., adaptability & flexibility vs. project risk & duration). They can explain—in a theoretically grounded manner—many different cases of acquisition success as well as failure. They can also provide overarching theory to help promote the former and obviate the latter in future acquisition programs.

Second, this research project demonstrates the efficacy of a new approach to studying acquisition organizations. It enables leaders, policy makers and analysts to answer “how much” questions such as: How much centralization, formalization and specialization is best? What fraction of commercial off-the-shelf equipment would be ideal? What level of concurrency between development and production provides the best combination of cost, schedule, performance and risk? Such questions are not answered well today in terms of acquisition organizations. This leaves acquisition decision makers today with no reliable means to address such questions.

The balance of the article begins with a focused review of the literature relevant to this study. We follow with discussion of our research design and description of the computation model developed to represent and emulate the acquisition organization. The article turns then to discuss results of our computational experiments. Conclusions, implications and recommendations for future research close the article, along with a rich set of references for deeper exploration into the research on which this article builds and contributes. We also include two appendices to provide details of our computational models.

## BACKGROUND

This focused review of the literature relevant to our study is organized into three parts: 1) the acquisition organization, 2) organization theory, and 3) computational experimentation.

### *The Acquisition Organization*

Of particular interest to the authors is the realm of DoD program management, where research and development dollars are expended to invent or advance warfighting capability. While US weaponry is considered some of the best in the world, the major acquisition projects to acquire them are often fraught with cost and schedule growth. They even fail at times to meet specifications or to provide the capabilities desired. Since implementation of the Goldwater-Nichols Act legislation in the late 1980s, major defense acquisition organizations (e.g., program management offices) have operated under a four-tiered decision structure.

For major acquisitions, the current policy makes clear that the Under Secretary of Defense for Acquisition, Technology and Logistics is the Milestone Decision Authority responsible for the overall program: Described in the DODI 5000.1:

> 3.4 The Milestone Decision Authority (MDA) is the designated individual with overall responsibility for a program. The MDA shall have the authority to approve entry of an acquisition program into the next phase of the acquisition process and shall be accountable for cost, schedule, and performance reporting to higher authority, including Congressional reporting. (USD(AT&L), 2003)

And three levels down the hierarchy, Program Managers (PMs) are described as:

> 3.5.1 the designated individual with responsibility for and authority to accomplish program objectives for development, production, and sustainment to meet the user's operational needs. The PM shall be accountable for credible cost, schedule, and performance reporting to the MDA. (USD(AT&L), 2003)

Thus, the Program Manager and Milestone Decision Authority share responsibility for development and oversight of a program. Further guidance under the DoD Instruction 5000.1 provides:

> 4.3.1.1 There is no *one* best way to structure an acquisition program to accomplish the objective of the Defense Acquisition System. MDAs and PMs shall tailor program strategies and oversight, including documentation of program information, acquisition phases, the timing and scope of decision reviews and decision levels to fit the particular conditions of that program, consistent with applicable laws and regulations and the time-sensitivity of the capability need. (USD(AT&L), 2003)

However, while the wording above might indicate that the MDA and PM plan jointly or collaborate in some way on program strategy, there are, in fact, both a Component Acquisition Executive and Program Executive Officer in the hierarchy between them, and direct communication between MDA and PM is infrequent. The four tiers of major program command and control and typical grade/ranks of positions are shown in Figure 1.

**Figure 1. DoD Decision Hierarchy for Major Defense Acquisition Programs**
(adapted from DAU, 2004)

MDA PMs lead Program Management Offices (PMOs). PMOs vary greatly in size. A typical range of government-assigned workers is generally between 50 and 100 individuals dedicated to the day-to-day efforts. An expanding network of other government agency players, multi-tier industry contractors, and other participants can multiply this figure many times (Dillard, 2004). While all stakeholders represent different parts of the enterprise, here we refer to this central government organizational entity—the government PMO—as the *acquisition organization*.

At the PMO level, several alternatives for the organization exist. In most cases, the offices are comprised of permanently assigned “core” personnel, and temporarily assigned co-located “matrix” personnel on loan from commodity systems commands. These are personnel typically arrayed by functional area within the PMO (as shown in Figure 2). A significant number of on-site support contract personnel may be present as well.

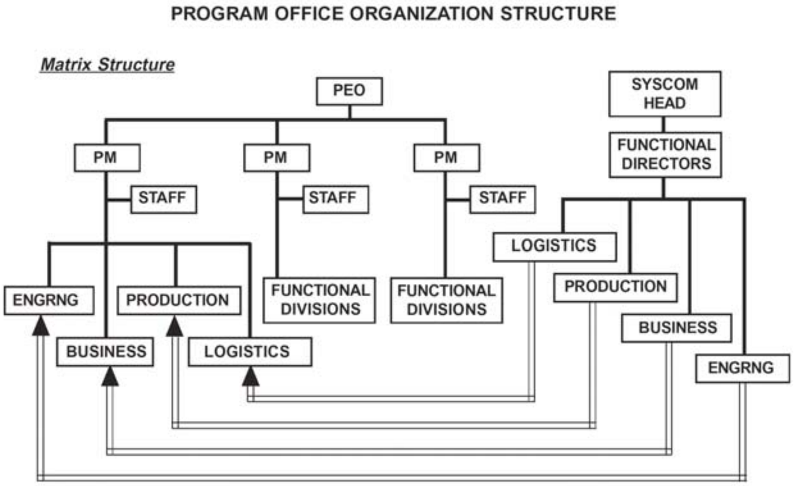


**Figure 2. Typical, Matrixed Program Management Office Structure** (adapted from DAU, 2004)

Somewhat less formally, programs also organize internally in ad hoc teams oriented on specific areas of each project. This stems largely from DoD initiatives over the last 10 years to implement Integrated Product and Process Development (IPPD) using Integrated Product Teams (IPT). This management philosophy emphasizes the potential of collective knowledge via small organizations with cross-functional or multi-disciplinary members (OUSD, 1998). Interestingly, the ideas in this IPPD/IPT philosophy of work implementation and problem solving are also embodied and magnified in emerging thought regarding command and control (C2) in tactical military organizations. The text *Power to the Edge* recognizes the benefit of using information-age technology to transfer knowledge and power to the point of an organization’s interaction with its environment (Alberts & Hayes, 2003).

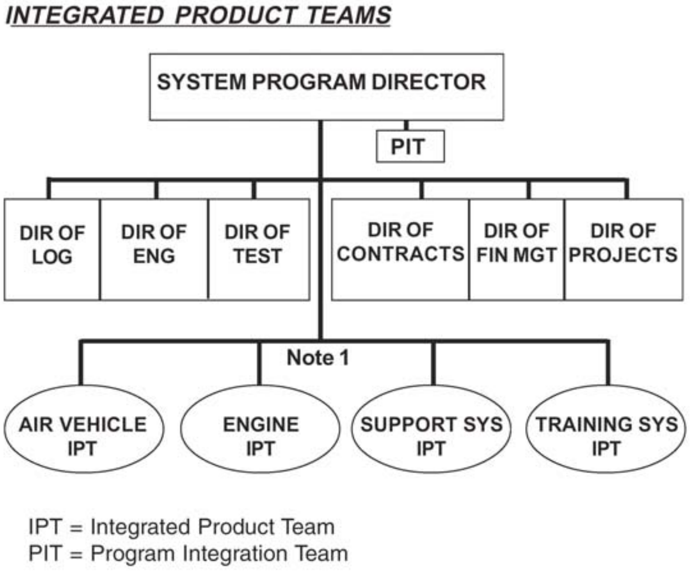


**Figure 3. Example (Aircraft) PMO IPT Structure** (adapted from DAU, 2004)

Another concept pertinent to our introduction is that of work and organizational hierarchy. Nobel Prize winner Herbert Simon argues, from his observation of complexity in things both natural and artificial, that complex systems evolve from simple systems. And they do so more rapidly when there are stable, intermediate forms or sub-systems (like modules or “units of action”). Moreover, he argues the resulting evolution into the complex system will be hierarchic, including systems such as organizations (Simon, 1981). But an important observation is also made by Koestler, who studies hierarchies in social organizations. He notes that sub-systems exist only as entities relative to their positions in the hierarchy. He proposes the word “holon” to describe the hybrid nature of individual organizations within larger organizations/systems. Holons are unique and self-contained wholes to their subordinated parts. But at the same time, they are also dependent parts of the larger hierarchy (or “holarchy,” as Koestler termed structures consisting of them). He views holons as autonomous, self-reliant units which have their own independence, and which cope with contingencies without asking higher authorities for instructions. Yet, they remain subordinate ultimately, subject to control from higher authorities. The term seems somewhat analogous to *edge* in the conceptualization of Edge organizations (Alberts & Hayes, 2003). Such concepts of unit knowledge, empowerment and relative autonomy within organizational structures are key to our design of various organizations for experimentation.

### *Organization Theory*

Classic organization theory holds that organizational structures must change in response to contingencies of size, technology, environment and other factors. Indeed, it is accepted widely that, when faced with uncertainty (a situation with less information than is needed), the appropriate management response should be either to redesign the organization for the task at hand or to improve information flows and processing (Galbraith, 1973). Van Creveld (1985) applies this same principle to command and control of combat elements in war. He argues that the command structure must either create a greater demand for information (vertically, horizontally, or both) and increase the size and complexity of the directing organization, or it must enable the local forces to deal semi-independently with the situation. His central theme is that decentralized control is the superior method of dealing with uncertainty, whether with the task at hand or with transformation of the organization itself. Research by Van de Ven and Delbecq (1986) has shown further that as complexity and uncertainty increase, hierarchical management control and vertical communication strategies are considered inferior to less formal organizations with horizontal communication channels.

Another classical concept of organizational theory is Ashby’s Law of Requisite Variety (Ashby, 1960). This states loosely that, in order to cope with the variety of challenges imposed by it, the internal capabilities of a system must be as diverse as those required by its environment. Organizational evolution and survival are dependent upon requisite variety, particularly in environmental contexts that are dynamic and unpredictable. This suggests, too, that the organization’s structure and control strategy must be matched to its environment to enhance performance. Open and flexible management styles and processes are required often for dynamic market and technological conditions. Further, research by Burrell and Morgan (Morgan, 1997) indicates that any incongruence among management processes and the organization’s environment tend to reduce organizational effectiveness.

What the cumulative research appears to support is that, for large, complex hierarchies such as the Department of Defense—which operate in today’s environment of program complexity, evolving requirements, and rapidly changing technology—decentralized control and empowerment should be an organizational strength. Notwithstanding such cumulative research, however, organizational hierarchies persist (Leavitt, 2004). Indeed, for DoD acquisition in particular, the command structure has remained relatively stable since the late 1980s. Although the current command structure is arguably flatter and more streamlined now than it was in the Seventies and before, it remains fundamentally hierarchical, centralized and rule-driven. Only through the major reform initiatives of the 1980s and 1990s did the acquisition organization's "chain of command" become as streamlined as it now is (Packard Commission, 1986).

### *Computational Experimentation*

Drawing heavily from Nissen and Buettner (2004), we assert that throughout the era of modern science, a chasm has persisted between laboratory and field research. On one side, the laboratory provides unparalleled opportunity for controlled experimentation. Through experimentation, the researcher can manipulate only a few variables of interest at a time and can minimize the confounding associated with the myriad factors affecting complex systems and processes in the field (Box et al., 1978; Johnson & Wichern, 1992). However, limitations of laboratory experimentation are known well (Campbell & Stanley, 1973) and are particularly severe in the domain of acquisition. In acquisition experimentation, such limitations center on problems with external validity. Laboratory conditions can seldom replicate the complexity, scope and scale of the physical organizations and systems of interest for research. Experiments also include problems with generalizability. Many experiments utilize samples of convenience (esp. university students) instead of working professionals. This practice calls into question how closely the associated experimental results are representative of acquisition behavior in operational organizations. These same concerns pertain also to analytical methods (e.g., mathematical analysis, optimization; see Chiang, 1984; Lapin, 1985). Most such methods use theoretical concepts as variables, not operationalized constructs. And, of course, analytical models do not involve real people, systems and organizations.

On the other side, field research provides unparalleled opportunity for realism (Denzin &, Lincoln, 1994). The researcher in the field can study full-scale artifacts in operational environments (Yin, 1994) and can minimize the abstraction away from working people, systems and organizations (Glaser & Strauss, 1967). However, limitations of field research are also known well (Campbell & Stanley, 1973) and are particularly severe in the acquisition domain. In acquisition field research, such limitations center on problems with internal validity. Field research affords little opportunity for controlled experimentation (cf. Cook & Campbell, 1979). Also, confounding data often results from the myriad influences on complex systems and organizations that cannot be isolated in the field. This diversity makes it difficult to identify and trace the causes of differential behaviors—better as well as worse—in acquisition.

As implied by the name, computational experiments are conducted via computer simulation. As such, they offer all of the cost and time advantages of computational analysis. But, computational experiments go beyond most simulations. Rigorous experimental designs are employed to capture the benefits of laboratory experimentation. The variables affecting physical systems and organizations in the field can be isolated and examined under controlled conditions. This type of analysis also addresses the internal validity and confounding limitations of field research. Yet, computational experiments can be conducted at a fraction of the cost and time required to set up and run experiments with human subjects in the laboratory. Further, through external validation, computational models can demonstrate fidelity emulation of the key qualitative and quantitative behaviors of the physical systems and organizations they represent. This ability addresses the problems with external validity and generalizability noted above.

It is important to note: computational modeling and simulation are not new techniques for the study of acquisition. For instance, a major DoD initiative called simulation-based acquisition has sought to educate the workforce about modeling and simulation (DSMC, 1998). And DoD policy has called for extensive use of modeling and simulation techniques in program planning and execution (Gansler, 1998). But, simulation-based acquisition has suffered to date from problems with internal and external validity alike. Such problems are not inherent to simulation methods or tools per se. Rather, they stem from models lacking theoretically rooted behaviors, externally validated results, and experimental controls. Our approach to computational experimentation obviates such problems deliberately.

Figure 4 illustrates the essential elements of computational experimentation as a research method. The top of the figure includes a shape to depict the bridge metaphor associated with this method, as it spans a wide gap between laboratory and field methods. From the left side of this "bridge," two arrows represent inputs to describe the behaviors of computational models. Organization theory, which is predicated upon many thousands of studies over the last half century, provides the basis for most such behaviors. Behaviors pertaining to organizational factors such as centralization, division of labor, task interdependence, function, coordination, formalization, technology and information processing from organization theory are captured well. Where extant theory does not address well a behavior of interest (e.g., knowledge flows), ethnographic and like immersive field studies (Bernard, 1998) are conducted to understand the associated organizational behaviors. Because organization theory is general and not based on any single organization, the associated behaviors have broad applicability across organizations in practice. This provides for the generalizability attainable through the method of computational experimentation.

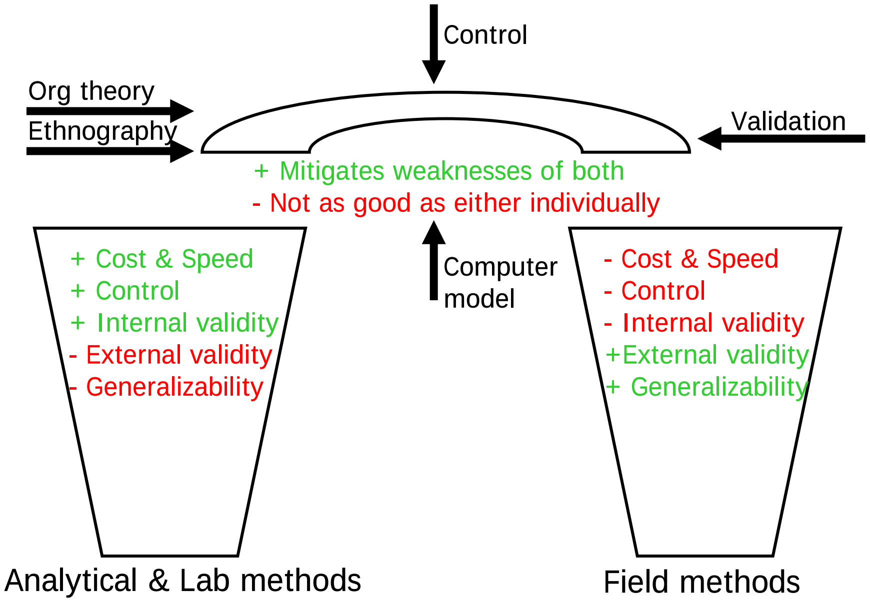


**Figure 4. Bridge Method** (adapted from Nissen & Buettner, 2004)

From the bottom of the “bridge,” an arrow represents the use of computer models to represent organizations and to emulate their key behaviors. Some variety exists in terms of specific implementations, but most computer models adhere to standards, norms and conventions associated with the COT field. The central goal is to develop computer models that emulate the key behaviors of organizations and to use such models to examine alternate methods of organization and coordination. As such, COT shares with acquisition a focus on many factors of importance.

From the right side of the “bridge” in the figure, one arrow represents a requirement in our approach for model validation. Through validation, the organizational behaviors emulated by computer models are examined and compared with those of operational organizations in the field. We view this comparison as essential, for it provides confidence that the behaviors emulated by the computer model have sufficient fidelity to mirror faithfully the behaviors of the operational organizations they represent. This provides for the external validity attainable through computational experimentation. It is important to note, not all COT models are subjected to such validation. Many researchers use computational models to conduct theorem-proving studies, which are valuable in their own right to demonstrate various aspects of organization theory. But without validation, researchers have difficulty making claims that such theory mirrors the behavior of organizations in the field. Hence, validation represents an important characteristic of distinguishing computational experimentation (as the research method described specifically in this article) from COT in general.

Finally, from the top of the “bridge,” an arrow represents the use of experimental controls in research. Following the same, rich set of experimental designs available to laboratory researchers (e.g., full-factorial, Latin Squares, blocking with replication), computational experimentation as a research method can be used to control myriad factors and to manipulate just one or a few variables at a time (e.g., searching for causality relations). Further, the same experimental design and setup can be replicated any number of times—for instance, using Monte Carlo techniques or other computational approaches to introduce variation. This provides for the internal validity attainable through computational experimentation. The combination of these “bridge” inputs—organization theory and ethnography, computer models, validation and control—allows the method of computational experimentation to be understood in terms of, and to indeed inherit, the various properties of its constituent elements.

Figure 4 illustrates also the bridging nature of computational experimentation as a research method. On the left side, we depict analytical and laboratory methods and we summarize their key advantages (e.g., low-cost & fast studies, good experimental control & internal validity) and disadvantages (e.g., poor external validity & generalizability). On the right side, we depict field methods in similar fashion to summarize their key advantages (e.g., good external validity and generalizability) and disadvantages (e.g., high cost & time consuming, poor experimental control & internal validity). Notice from their relative advantages and disadvantages how the two classes of research methods complement one another. Field methods are strong in the areas where analytical and laboratory methods are weak, and vice versa. As an alternate research method, computational experimentation mitigates weakness of both classes. For instance, it enables good experimental control and internal validity as in laboratory methods. It also promotes good generalizability and external validity as in field methods.

Nonetheless, every research method is flawed in some respects. In our present case, when used in isolation, computational experimentation is not as good as either method at its best. For instance, because computational experimentation uses computer models of people in organizations instead of real people, it is weaker in this respect than laboratory experimentation is. This same use of computer models instead of real people also makes computational experimentation weaker than field methods are. This is why we describe computational experimentation as a *bridge method*: it bridges the chasm between experimental and field research methods; yet, it serves best to complement, not to replace, such methods.

## RESEARCH DESIGN

This discussion of the research design is organized into three parts: 1) agent-based modeling environment, 2) computational acquisition organization model, and 3) experimental design.

### *Agent-Based Modeling Environment*

In this section, we build upon current advances in VDT research to describe the agent-based modeling environment used here for computational experimentation. Drawing heavily from Nissen and Levitt (2004), we first summarize the stream of research associated with VDT and then describe its modeling environment.

#### Virtual Design Team Research

The VDT Research Program (VDT, 2004) reflects the planned accumulation of collaborative research over two decades to develop rich theory-based models of organizational processes. Using an agent-based representation (Cohen, 1992; Kunz et al., 1998), micro-level organizational behaviors have been researched and formalized to reflect well-accepted organization theory (Levitt et al., 1999). Extensive empirical validation projects (e.g., Christiansen, 1993; Thomsen, 1998) have demonstrated representational fidelity and have shown how the emulated behaviors of VDT computational models correspond closely with a diversity of enterprise processes in practice.

The VDT research program continues with the goal of developing new micro-organization theory and of embedding it in software tools that can be used to design organizations in the same way that engineers design bridges, semiconductors or airplanes: through computational modeling, analysis and evaluation of multiple, alternate prototype systems. Clearly, this represents a significant challenge in the domain of organizations. Micro-theory and analysis tools for designing bridges and airplanes rest on well-understood principles of physics (e.g., involving continuous numerical variables, describing materials whose properties are relatively easy to measure and calibrate), and analysis of such physical systems yields easily to differential equations and precise numerical computing.

In contrast, theories describing the behavior of organizations are characterized by nominal and ordinal variables, with poor measurement reproducibility, and verbal descriptions reflecting significant ambiguity. Unlike the mathematically representable and analyzable micro-behaviors of physical systems, the dynamics of organizations are influenced by a variety of social, technical and cultural factors, are difficult to verify experimentally, and are not as amenable to numerical representation, mathematical analysis or precise measurement. Moreover, quite distinct from physical systems, people and social interactions—not molecules and physical forces—drive the behavior of organizations. Hence, such behaviors are fundamentally non-deterministic and difficult to predict at the individual level. Thus, people, organizations and business processes are qualitatively different from bridges, semiconductors and airplanes. And it is irrational to expect the former to ever be as understandable, analyzable or predictable as the latter. This represents a fundamental limitation of the approach.

Within the constraints of this limitation, however, we can still take great strides beyond relying upon informal and ambiguous, natural-language textual description of organizational behavior (e.g., the bulk of extant theory). For instance, the domain of organization theory is imbued with a rich, time-tested collection of micro-theories that lend themselves to qualitative representation and analysis. Examples include Galbraith's (1977) information-processing abstraction, March and Simon’s (1958) bounded rationality assumption, and Thompson’s (1967) task-interdependence contingencies. Drawing from this theory base, we employ symbolic (i.e., non-numeric) representation and reasoning techniques from established research on artificial intelligence to develop computational models of theoretical phenomena. Once formalized through a computational model, the symbolic representation is “executable,” meaning it can emulate the dynamics of organizational behaviors.

Even though the representation is qualitative (e.g., lacking the precision offered by numerical models), through commitment to computational modeling, it becomes semi-formal (e.g., different people viewing the model can agree on what it describes), reliable (e.g., the same sets of organizational conditions and environmental factors generate the same sets of behaviors), and explicit (e.g., much ambiguity inherent in natural language is obviated). Particularly when used *in conjunction with* the descriptive natural language theory of our extant literature, this represents a substantial advance. Further, once a model has been validated to emulate accurately the qualitative behaviors of the field organization it represents, it can be used to examine a multitude of cases (e.g., many more and diverse than observable in practice) under controlled conditions (e.g., repeating the same events multiple times, manipulating only one or a few variables at a time through repeated trials, stopping the action for interpretation). These features alone offer great promise in terms of theory development and testing.

Additionally, although organizations are inherently less understandable, analyzable and predictable than physical systems are, and the behavior of people is non-deterministic and difficult to model at the individual level, it is known well that individual differences tend to average out when aggregated cross-sectionally and/or longitudinally. Thus, when modeling aggregations of people in the organizational context (e.g., work groups, departments, firms), one can augment, with certain aspects of numerical representation, the kind of symbolic model from above. For instance, the distribution of skill levels in an organization can be approximated—in aggregate—by a Bell Curve; the probability of a given task incurring exceptions and requiring rework can be specified—organization wide—by a distribution; and the unpredictable attention of a worker to any particular activity or event (e.g., new work task, communication, request for assistance) can be modeled—stochastically—to approximate collective behavior. As another instance, specific organizational behaviors can be simulated hundreds of times—such as through Monte Carlo techniques—to gain insight into which results are common and expected versus those that are rare and exceptional.

Of course, applying numerical simulation techniques to organizations is nothing new (e.g., see Law & Kelton, 1991). But this approach enables us to *integrate* the kinds of dynamic, qualitative behaviors emulated by symbolic models with quantitative aggregate dynamics generated through discrete-event simulation. It is through such integration of qualitative and quantitative models—bolstered by strong reliance upon well-established theory and commitment to empirical validation—that our approach diverges most from extant research methods and offers new insight into the dynamics of organizational behavior.

### VDT Modeling Environment

Here we provide a brief overview of the VDT modeling environment. The development and evolution of VDT has been described in considerable detail elsewhere (e.g., Cohen, 1992; Christiansen, 1993; Jin & Levitt, 1996; Thomsen, 1998; Kunz et al., 1998; Levitt et al., 1999; Nogueira, 2000; VDT, 2004), so we do not repeat such discussion here. The VDT modeling environment has been developed directly from Galbraith's information-processing view of organizations. This information-processing view has two key implications (Jin & Levitt, 1996). The first is ontological: we model knowledge work through interactions of *tasks* to be performed, *actors* communicating with one another and performing tasks, and an *organization structure* that defines actors' roles and that constrains their behaviors. In essence, this amounts to overlaying the task structure on the organization structure and to developing computational agents with various capabilities to emulate the behaviors of organizational actors performing work.

Figure 5 illustrates this view of tasks, actors and organization structure. As suggested by the figure, we model the organization structure as a network of reporting relations which can capture micro-behaviors such as managerial attention, span of control and empowerment. We represent the task structure as a separate network of activities, which can capture organizational attributes such as expected duration, complexity and required skills. Within the organization structure, we further model various *roles* (e.g., marketing analyst, design engineer, manager), which can capture organizational attributes such as skills possessed, level of experience and task familiarity. Within the task structure, we further model various sequencing constraints, interdependencies and quality/rework loops—which can capture considerable variety in terms of how knowledge work is organized and performed.

As suggested also by the figure, each actor within the intertwined organization and task structures has a queue of information tasks to be performed (e.g., assigned work activities, messages from other actors, meetings to attend) and a queue of information outputs (e.g., completed work products, communications to other actors, requests for assistance). Each actor also processes such tasks according to how well the actor's skill set matches those required for a given activity, the relative priority of the task, the actor's work backlog (i.e., queue length), and how many interruptions divert the actor's attention from the task at hand. Collective task performance is constrained further by the number of individual actors assigned to each task, the magnitude of the task, and both scheduled (e.g., work breaks, ends of shifts, weekends and holidays) and unscheduled (e.g., awaiting managerial decisions, awaiting work or information inputs from others, performing rework) downtime.

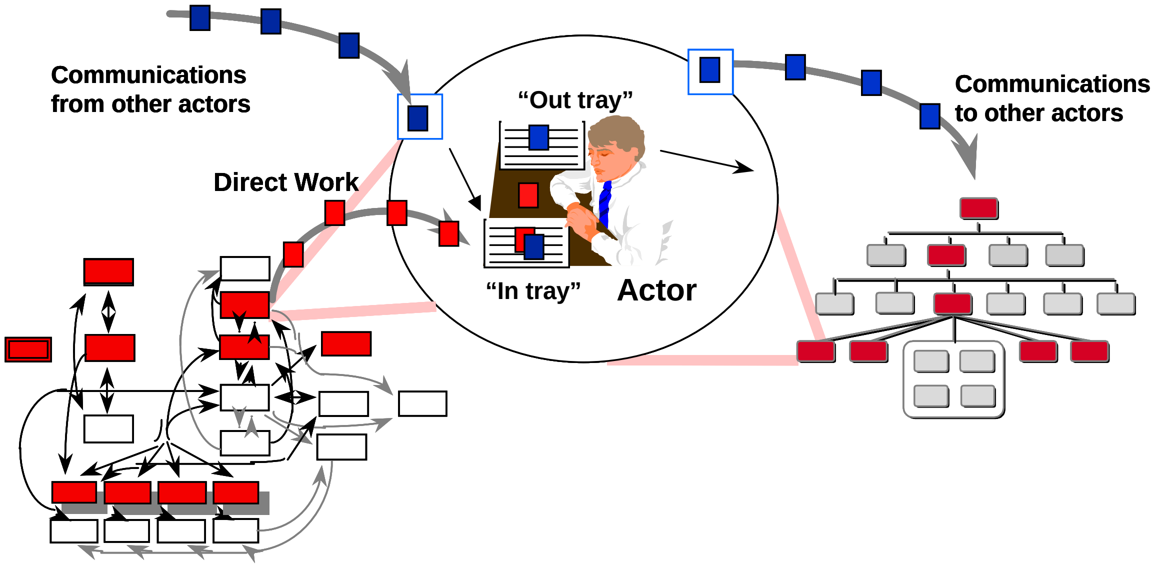


**Figure 5. VDT Information Processing View of Knowledge Work** (adapted from Nissen & Levitt, 2004)

The second implication is computational: both primary work (e.g., planning, design, management) and coordination work (e.g., group tasks, meetings, joint problem solving) are modeled in terms of *work volume.* This construct is used to represent a unit of work (e.g., associated with a task, a meeting, a communication) within the task structure. In addition to symbolic execution of VDT models (e.g., qualitatively assessing skill mismatches, task-concurrency difficulties, decentralization effects) through micro-behaviors derived from organization theory, the discrete-event simulation engine enables (virtual) process performance to be assessed (e.g., quantitatively projecting task duration, cost, rework, process quality).

Clearly, quantitative simulation places additional burden on the modeler in terms of validating the representation of a knowledge-work process, which generally requires fieldwork to study an organization in action. The VDT modeling environment benefits from extensive fieldwork in many diverse enterprise domains (e.g., power-plant construction and offshore drilling, see Christiansen, 1993; aerospace, see Thomsen, 1998; software development, see Nogueira, 2000; healthcare, see Cheng & Levitt, 2001; others). Through the process of "backcasting"—predicting known organizational outcomes using only information that was available at the beginning of a project—VDT models of operational enterprises in practice have demonstrated dozens of times that emulated organizational behaviors and results correspond qualitatively and quantitatively to their actual counterparts in the field (Kunz et al., 1998).

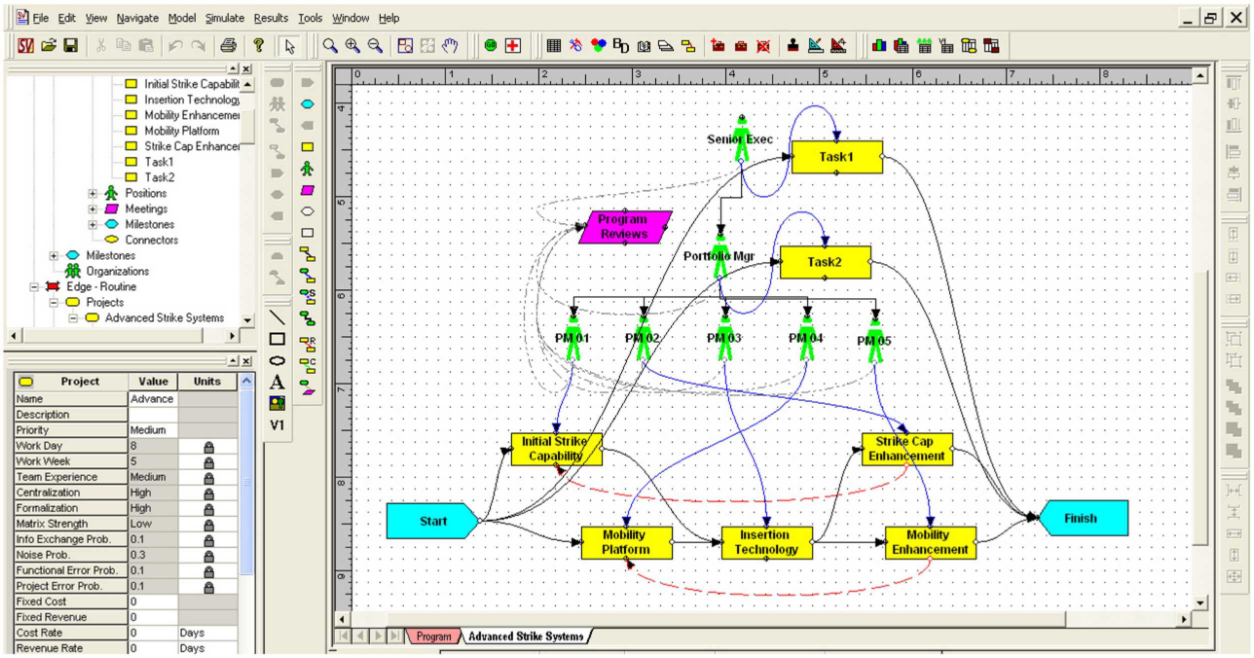
Viewing VDT as a validated model of project-oriented knowledge work, researchers have begun to use this dynamic modeling environment as a "virtual organizational testbench" to explore a variety of organizational questions, such as effects of distance on performance (Wong & Burton, 2000) or to replicate classic empirical findings (Carroll & Burton, 2000). Thus, the VDT modeling environment has been validated repeatedly and longitudinally as representative of both organization theory and enterprises in practice. This gives us considerable confidence in its results. Moreover, VDT is designed specifically to model the kinds of knowledge work and information-processing tasks that comprise the bulk of acquisition processes.

### *Computational Acquisition Organizational Model*

In our experimental efforts, we use the VDT modeling environment to represent work associated with a three-tier acquisition organization. This follows our discussion above, and it is representative of many DoD service-level environments today (e.g., where several project offices report into one program executive “Portfolio Manager” and then up to a Component Acquisition Executive, and often into yet another level of decision-making). VDT is capable of modeling large, complex, operational organizations in great detail; it has been demonstrated repeatedly to emulate well the associated behaviors of organizations in the field. But, using a high-level model as such helps us to maintain the focus of this expository article on techniques of VDT modeling and computational experimentation (which represents one of our primary contributions), and not to get lost in the details of the organization itself. We first describe the VDT representation and then illustrate how a full-factorial computational experiment can be performed upon it.

## VDT Acquisition Model

Figure 6 presents a screenshot of the VDT acquisition program model. The model is comprised of five developmental system acquisition projects (i.e., denoted as lightly colored boxes). Both concurrent and sequential projects/tasks are depicted in the model, and interdependencies are represented among them. The model depicts a simple and abbreviated series of coordinated research and development efforts which are aligned to deliver an Advanced Strike capability integrated into a mobile platform and, subsequently, are enhanced with an evolutionary block of capability. It is but a representative subset of what could be a larger, more complex, and more detailed representation of such a program.



| Project | Value | Units |
|---|---|---|
| Name | Advance | |
| Description | | |
| Priority | Medium | |
| Work Day | 8 | 🔒 |
| Work Week | 5 | 🔒 |
| Team Experience | Medium | 🔒 |
| Centralization | High | 🔒 |
| Formalization | High | 🔒 |
| Matrix Strength | Low | 🔒 |
| Info Exchange Prob. | 0.1 | 🔒 |
| Noise Prob. | 0.3 | 🔒 |
| Functional Error Prob. | 0.1 | 🔒 |
| Project Error Prob. | 0.1 | 🔒 |
| Fixed Cost | 0 | |
| Fixed Revenue | 0 | |
| Cost Rate | 0 | Days |
| Revenue Rate | 0 | Days |

**Figure 6. VDT Acquisition Model Screenshot**

The coordination links (i.e., denoted by light dashed lines) connecting the coordinated tasks or projects denote reciprocal task interdependencies (Thompson, 1967), which suggest they must be coordinated closely in both planning and execution. For example, integration of strike capabilities into a mobile platform requires coordination among engineers for interface and configuration control of hardware, software, and other factors. VDT emulates the added coordination effort associated with such reciprocal task interdependencies. The rework links (i.e., denoted by dark dashed lines) connecting tasks from different mission phases denote sequential task dependencies, which suggest the predecessor activities must be accomplished effectively in order for the successors to perform well. Strike and Mobility Enhancements, for instance, depend heavily upon success of the Initial Strike and Mobility Platform efforts. To the extent that such predecessor work is not completed or not accomplished effectively, certain aspects may have to be reanalyzed to correct any major deficiencies.

The people icons depict organizations and are arranged in terms of the command-and-control, or decision-making, hierarchy. People icons represent one or more human resources, specified in Full Time Equivalents (FTEs), which have particular capabilities, skill levels and roles. Where a skilled actor's capability matches that required for an acquisition task, the resource is likely to perform it competently and within the time required. If the actor has greater or lesser skill, the time required to perform the task can be appreciably shorter or longer, and the competency of performance can be notably better or worse, respectively. Where an actor does not possess the required capability at all, the task will be in jeopardy. Such relationships are appealing intuitively and reflect well many organizational behaviors.

A Senior Executive actor sits atop the acquisition organization model and has a Portfolio Manager reporting to it. Reporting to the Portfolio Manager are five individual PMOs (01 through 05) with different roles and capabilities within them. For example, the icon labeled "PM 02" is responsible for the technological enhancement of the initial Strike Capability. Notice the VDT representation includes a work task structure and an organization structure. The assignment links (i.e., delineated by solid lines) denote which organizational actors are responsible for the various work tasks. Finally, a dark trapezoid box is used to depict recurring meetings (e.g., coordination meetings, technical reviews, milestone reviews) that must be attended by the actors connected by links. Meetings consume actors' resources, but they also contribute toward coordination.

All of the structural elements (e.g., work tasks, requirements and interdependencies, actor capabilities, skill levels and roles, organization structure, task structure and meeting requirements) of this VDT model are developed by the authors. Such structural elements would clearly be different for each unique organization and process model. VDT also includes several dozen environmental variables with "normal" values determined empirically by prior field research. These include factors such as the level of uncertainty and noise associated with a project, the inherent propensity of an organization to make errors, and relative concern for performance quality associated with actors at different levels of organizational hierarchy. These and other environmental variables can be changed where appropriate to reflect a wide variety of different organizations and contexts. Other factors can be changed to reflect different organizational designs. For instance, the level of centralization and formalization can be varied by changing design variables. The corresponding VDT model behaviors have been developed empirically. We capitalize upon such empirically developed behaviors to design and compare new acquisition organization models and subject them to changing environments.

VDT also includes several performance variables for comparison. In addition to standard simulation measures such as project duration and cost, VDT also includes measures such as levels of rework, coordination and delay, in addition to risk measures keyed to various attributes of importance (e.g., tasks left undone, missed communications, project-level errors). Some of these performance variables are correlated often with one another, whereas others highlight tradeoffs that must be made. In other words, where a project is running behind schedule but on budget, a leader or manager can decide to employ more resources. This often has the effect of increasing the rate of progress while also increasing the rate of expenditure. Other tradeoffs such as those between cost and risk or schedule and coordination require balance in a similar fashion. It is important to note again the extensive and longitudinal validation of VDT provides considerable confidence that the organizational behaviors emulated by our computational model will reflect well those of operational organizations in the field.

### *Experimental Design*

As is appropriate for the cumulative accretion of knowledge through research, this study builds upon prior work using VDT methods and tools to examine alternate organizational designs and environmental conditions. For instance, Kim and Burton (2002) use VDT to model projects with varying levels of task uncertainty and centralization, measuring the effects on cost, schedule and risk as dependent performance variables. They find a relationship between organizational structure and performance. And they examine project risk, measuring the likelihood that outputs from a project will not be integrated at completion, or that the integration will have defects. The study calls attention to the impact of centralized control on organizational performance in light of task uncertainty. It also suggests that managers should pay attention to such aspects of organizational structure and should consider the importance of project quality in addition to profitability alone. In another instance, Nissen and Buettner (2004) use VDT to model command and control in military missions. They model organizations having varying levels of bureaucracy, coordination and knowledge, measuring the effects on mission duration and risk as dependent, performance variables. They find a similar relationship between organizational structure and task performance and overall risk, and they suggest that organizational leaders must choose and balance the performance measures that are most relevant to the project's environment and desired outcomes.

In this study, we emulate the behaviors of three different modeled organizations which vary in degrees of hierarchy, centralization and formalization, and which are subjected to different levels of environmental stress. Briefly, our three designs of organizations have the same amount of work volume to perform, with the same level of team experience and individual skills involved. What differs among them is their degree of autonomy and empowerment, specified by several VDT constructs. Therefore, we build upon the kinds of prior research noted above, and we extend such prior research to address the acquisition domain. We also extend prior research through the greater number and variety of organizational design changes and degrees of environmental stress examined in this study.

Figure 7 reflects today's acquisition organization (labeled "Typical") with high centralization, formalization and three layers of decision hierarchy, somewhat like an ACAT II program or set of projects within the DoD.

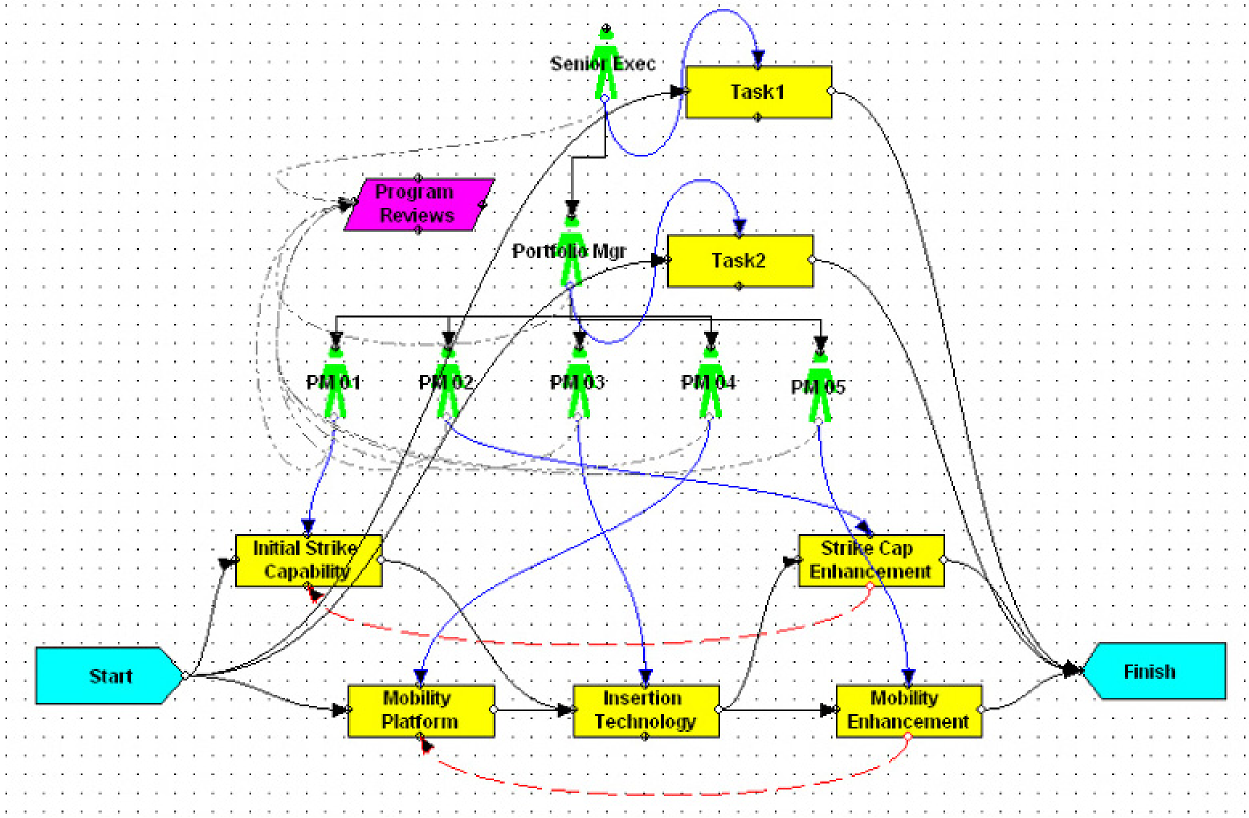


**Figure 7. Typical Acquisition Organization Design and Project Work**

In contrast to the typical organization, Figures 8 and 9 depict two alternate organizations with fewer layers of decision hierarchy and lower centralization and formalization. The first organization (labeled "Decentralized") has less hierarchy and control overhead in its management structure. Note the removal of the "Senior Executive" position in the representation, whose VDT role of PM has been delegated lower to the Portfolio Manager, now labeled as "Leader." As in reality, the supervision structure in the VDT model is an exception-handling hierarchy. It is the chain of command for information and decision about problems discovered in the course of a project. Positions of PM 01, 02, and others still act within the VDT simulation as Subteam Leaders who handle some exceptions and pass others up the hierarchy for resolution.

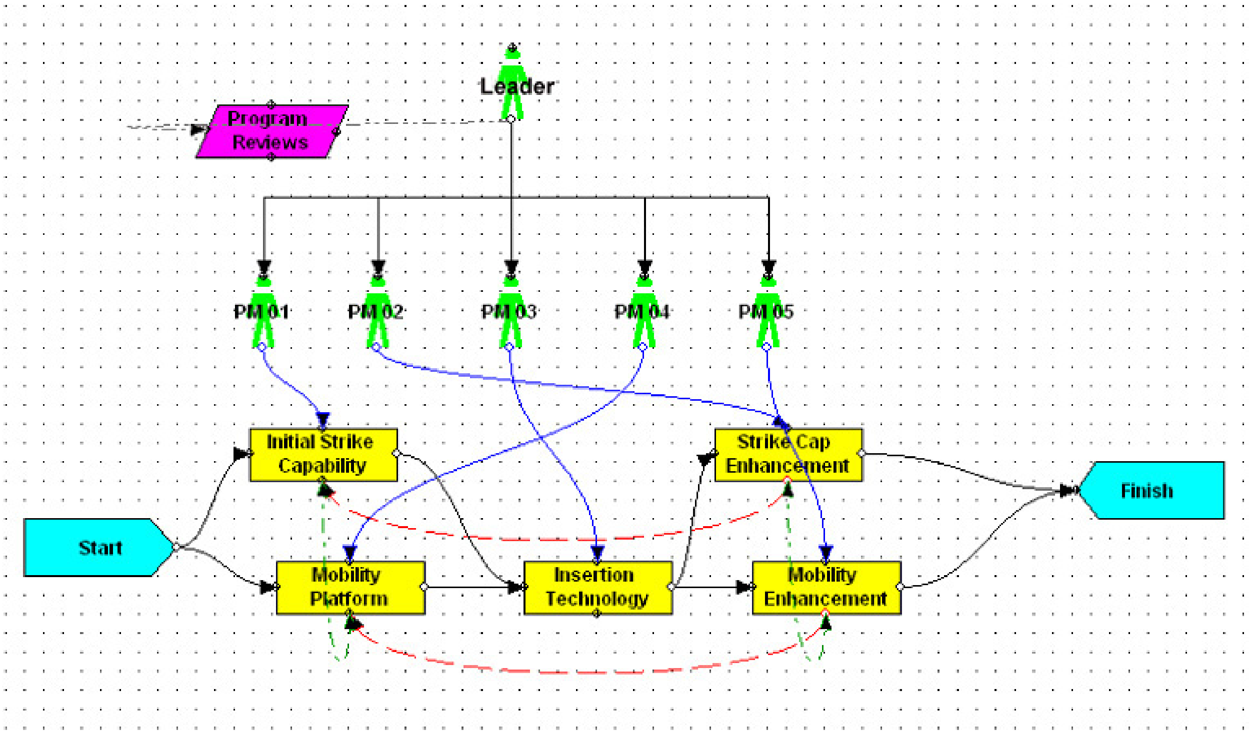


**Figure 8. Decentralized Organizational Design and Project Work**

The second organization, depicted in Figure 9 (labeled "Holonistic") has no overhead management structure at all. Here, each PM position in the figure remains designated a Subteam Leader within the VDT tool. The various PMs communicate with one another directly. Table 1 shows the VDT settings for organizational parameters to be tested. Additional modeling detail on organizational design parameters is found in Appendix A.

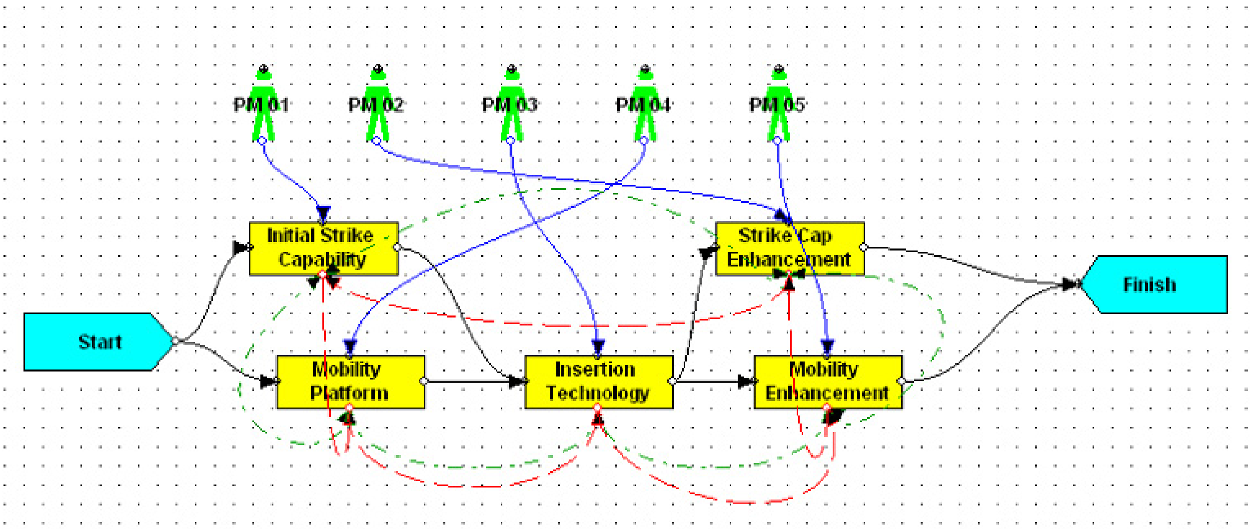
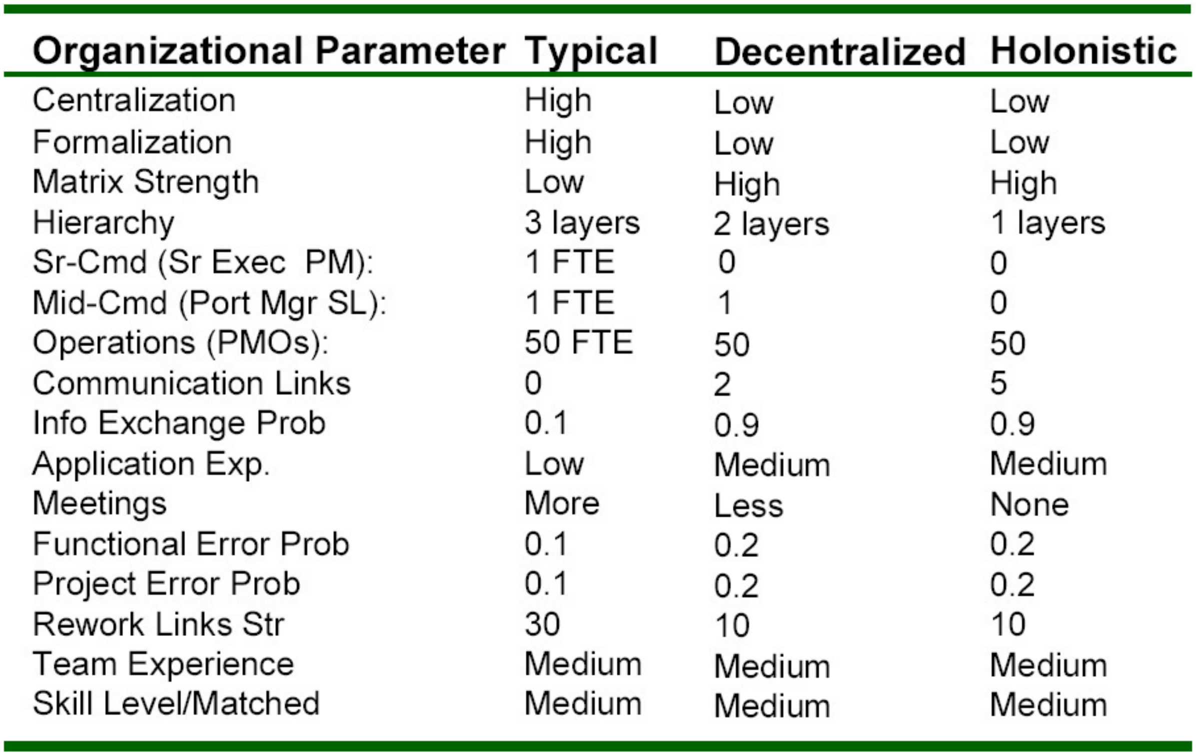


**Figure 9 . Holonistic Organizational Design and Project Work**

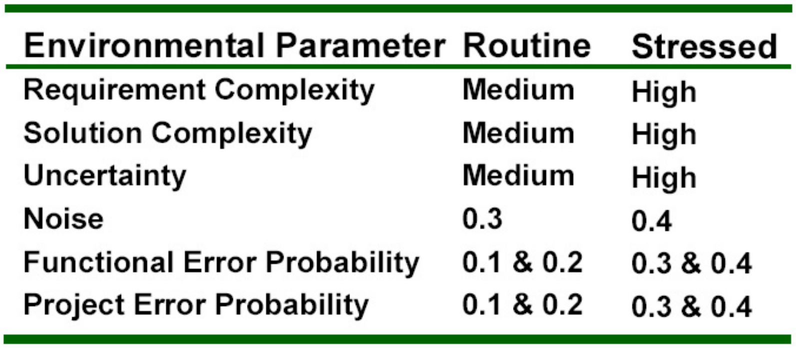
**Table 1. Organizational Design Parameters**



| Organizational Parameter | Typical | Decentralized | Holonistic |
|---|---|---|---|
| Centralization | High | Low | Low |
| Formalization | High | Low | Low |
| Matrix Strength | Low | High | High |
| Hierarchy | 3 layers | 2 layers | 1 layers |
| Sr-Cmd (Sr Exec PM): | 1 FTE | 0 | 0 |
| Mid-Cmd (Port Mgr SL): | 1 FTE | 1 | 0 |
| Operations (PMOs): | 50 FTE | 50 | 50 |
| Communication Links | 0 | 2 | 5 |
| Info Exchange Prob | 0.1 | 0.9 | 0.9 |
| Application Exp. | Low | Medium | Medium |
| Meetings | More | Less | None |
| Functional Error Prob | 0.1 | 0.2 | 0.2 |
| Project Error Prob | 0.1 | 0.2 | 0.2 |
| Rework Links Str | 30 | 10 | 10 |
| Team Experience | Medium | Medium | Medium |
| Skill Level/Matched | Medium | Medium | Medium |

Environmental stress is applied to our three organizational designs via the VDT constructs *requirement complexity, solution complexity,* and *task uncertainty* (appropriate to environments that project offices often face with technology maturity, interoperability requirements, etc.) as well as higher noise (distractions) and increasing functional- and project-error probabilities. For the experiment, each of these three factors is specified at two levels: routine and stressed, shown in Table 2 below. Hence, a full-factorial design consists of six trials (i.e., three alternate organizational designs x 2 different environmental conditions), which we designate according to the levels corresponding to a set of environmental factors. Additional modeling detail on environmental parameters is presented in Appendix B.

**Table 2. Environmental Parameters**



| Environmental Parameter | Routine | Stressed |
|---|---|---|
| **Requirement Complexity** | **Medium** | **High** |
| **Solution Complexity** | **Medium** | **High** |
| **Uncertainty** | **Medium** | **High** |
| **Noise** | **0.3** | **0.4** |
| **Functional Error Probability** | **0.1 & 0.2** | **0.3 & 0.4** |
| **Project Error Probability** | **0.1 & 0.2** | **0.3 & 0.4** |

We examine the dependent variables of particular interest in the acquisition domain: *cost, schedule duration* and *project risk*. We also make note of the maximum position backlog, rework volume, coordination volume, and decision wait time, as these have implications for managers to consider. Schedule is important to project managers, and time is often viewed as money because of the staff that must be paid as long as they are retained—whether productive to the project or not. Project cost is measured in $K, and pertains to staffing costs only, as no material costs are modeled in our experiment. Project risk, as mentioned above, is represented as the likelihood of an incomplete project outcome, which relates directly to project quality. While every task within a project may not be critical to project quality, more tasks incomplete or defective place the overall project at risk for failure. Where lives are at stake, such as in new pharmaceutical compounds, new passenger aircraft, or defense weapon systems involving lethality and survivability, overall project risk may be a difficult trade for managers also concerned with project cost and schedule.

## EXPERIMENTAL RESULTS

In this section, we report on the results of our computational experiment. Summarized in Table 3 is each of the six trials in this full-factorial experiment. The table includes measures for project cost, schedule and risk, in addition to other metrics that can provide insight into organizational dynamics (rework volume, coordination volume and decision wait).

**Table 3. Experimental Results**

| **Measure** | **Typical Organization in Routine** | **Decentralized Organization in Routine** | **Holonistic Organization in Routine** | **Typical Organization Under Stress** | **Decentralized Organization Under Stress** | **Holonistic Organization Under Stress** |
|---|---|---|---|---|---|---|
| Duration (dys) | 556 | 428 | 407 | 580 | 604 | 458 |
| Cost $K | $8,085 | $4,674 | $4,565 | $8,561 | $6,708 | $4,973 |
| Project Risk | 0.41 | 0.54 | 0.76 | 0.37 | 0.55 | 0.76 |
| Max Backlog (dys) | 26 | 12 | 12 | 30 | 27 | 19 |
| Work Volume (dys) | 4800 | 4500 | 4500 | 4800 | 4500 | 4500 |
| Rework Volume (dys) | 124 | 866 | 465 | 401 | 2747 | 740 |
| Coordination Volume (dys) | 3051 | 423 | 742 | 3205 | 952 | 976 |
| Decision Wait | 20 | 54 | 0 | 67 | 186 | 0 |

Examining these results, we see that the baseline organization—the Typical Organization in Routine environment—completes the series of projects in 556 days, at a cost of $8,085(K), with a project risk index of 0.41. While these are the three primary success measures of any project, the VDT simulation provides more insight in terms of position backlog (e.g., one actor got 26 days behind in work at one point during the project). The tool can also identify when this occurs so that planners can split tasks or assign more resources for specific tasks. Work volume refers to the amount of effort expected to complete all project tasks under ideal conditions (e.g., no noise, errors or miscommunications). Rework Volume refers to the simulated time needed for all positions on a project to perform required rework. Coordination volume is the cumulative time positions spend during a project processing information requests from each other, attending meetings, and other coordinative tasks. Decision Wait measures the cumulative time spent by positions waiting for decisions to be made in a project. These values for our baseline case provide a basis for comparison with results for alternate organizational designs and environmental conditions.

Comparing these results with those obtained by the Decentralized and Holonistic Organizations in the Routine environment, key differences are apparent. Decentralized and holonistic organizations fare considerably better (in terms of both cost and schedule) in the routine environment than their more typical counterpart organizational design does. Program schedule or duration is reduced some 23% (from 556 to 428 days) with the Decentralized Organization and 27% (from 556 to 407 days) by changing organizational structure toward more Holonistic. Program cost is reduced similarly by 42% (from $8085 (K) to $4674 (K)) with Decentralized and 44% (from $8085 (K) to $4565 (K)) with Holonistic in the successive design iterations. However, project risk increases appreciably in both alternate organizations, going up to 54% and then to 76%, respectively, in decentralized and holonistic designs. Here, we find that Decentralized and Holonistic organizational forms offer a combination of advantages (e.g., shorter schedule duration, lower cost) and disadvantages (e.g., higher risk) with respect to the Typical acquisition organization in a routine environment.

Upon examination of these organizational designs under stress environments, we find the Typical Organization suffers cost and schedule growth in the 4-5% range (i.e., 580 days, $8561K), with a slight decline in project risk (0.37). Decentralized and Holonistic organizations under stress perform better in the cost realm with 22% ($6708K) and 42% ($4973K) reductions compared with the Typical. The Decentralized design reveals longer schedule duration (604 vs. 580 days), but the Holonistic organization shows a 21% decrease (458 vs. 580 days). Again, project risk climbs in stress environments to 55% for Decentralized and to 76% for the Holonistic.

Figure 10 illustrates graphically the dynamic relationship we find between cost and organizational design. Notice, in the routine environment, project cost decreases abruptly with a shift from a Typical to a Decentralized organizational form. But, negligible additional improvement accrues to the Holonistic design. Alternatively, in the stressed environment, the Decentralized organization performs better than the Typical does, and the Holonistic organization performs better still. Notice also how costs are higher for every organizational form in the stressed environment than they are in the routine one.

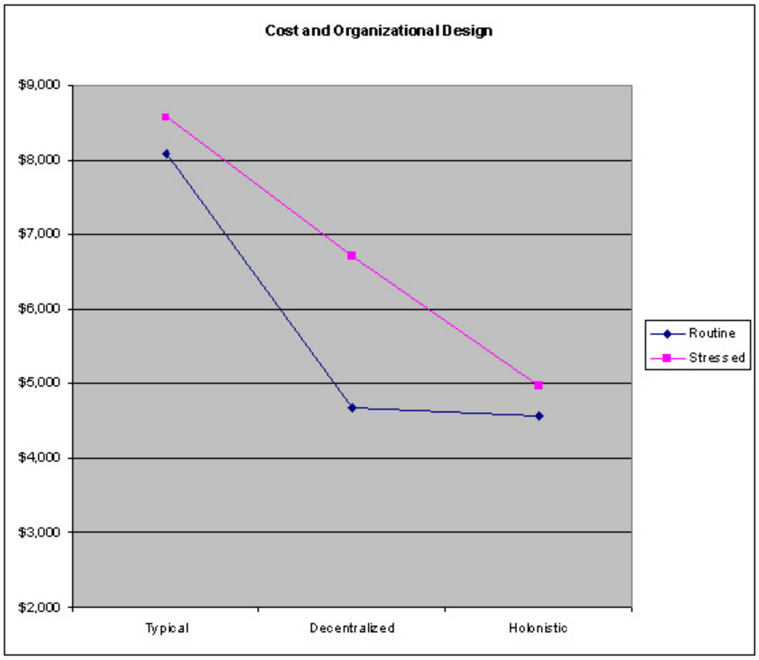


Figure 10. Relationship between Cost and Organizational Design

Figure 11 illustrates the relationship between risk and organizational design. Here, we observe a monotonic increase in risk corresponding to progression in organizational form from Typical, through Decentralized, to Holonistic. As costs decrease across these alternate organizational forms, risk increases in lock step. Unlike the cost results, however, the stressed environment appears to exert little influence in terms of risk.

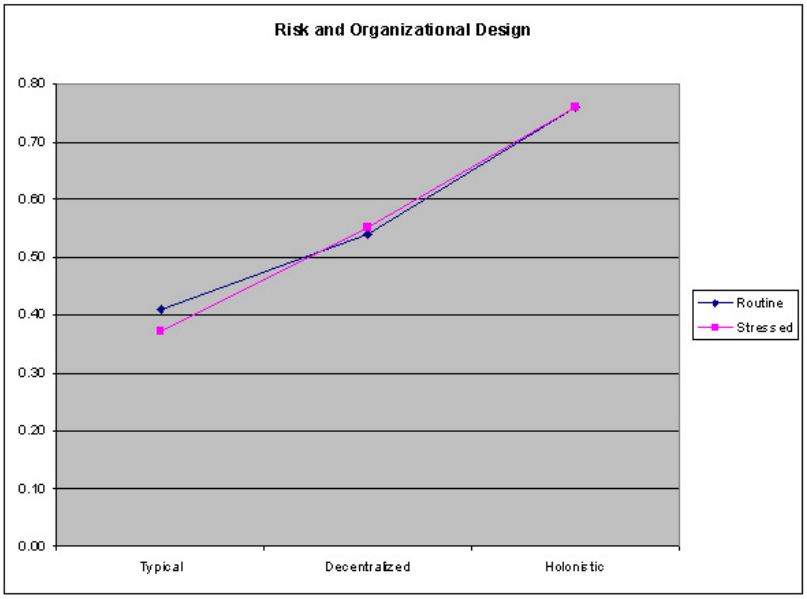


Figure 11. Relationship between Risk and Organizational Design

Interpreting these results, the researchers found that the less centralized, formalized and hierarchical organizational designs perform better in terms of cost and schedule than other designs, but with accompanying project-quality risk. Interpreting these results further, in which schedule and cost are of primary concern to all project managers, decentralized control (especially in stressed environments) may provide a more cost-effective approach. Alternatively, where project risk or quality is paramount, formalized procedures, vertical information flows, and centralized decision-making typical of bureaucratic organizational forms can be seen as superior. This reflects a fundamental tradeoff between performance measures and organizational design, as conceptualized generally in terms of Contingency Theory (Lawrence & Lorsch, 1967). And as Kim and Burton (2002) noted, the theory is actually extended by the evidence of risk coming into play with a more rapid and inexpensive project solution afforded by empowered actors with relevant information at their organizational edge.

The DoD, like sponsors of projects in the FDA's pharmaceutical arena and in the FAA's commercial aviation arena, is averse generally to risk due to the safety and survivability aspects of many of its developmental systems. Indeed, the modeling here can be viewed as confirmation of the DoD's varying levels of decision hierarchy correlating to estimated program dollar thresholds (stratification of acquisition categories I though IV) as a means of addressing cost risk. However, and just as important to illustrate, high levels of bureaucracy place considerable stress on acquisition organizations and come at their own cost. Are 40% program cost growth and 25% schedule growth commensurate with 20 – 50% program risk reduction? Might a commensurate amount of risk be alleviated through a less-expensive means? Clearly, tools such as VDT provide a new way of gaining insights into these important program considerations, particularly when forming organizations for the management of weapon system developments.

## CONCLUSION

The DoD is a large, bureaucratic, rule-intensive organization that may not be suited well for its environment. Building upon prior research on acquisition centralization and knowledge dynamics, we employ computational methods to assess the behavior and performance of different organizational designs in varying environments. Our results reinforce Contingency Theory and suggest particular characteristics of different acquisition environments that make one form relatively more or less appropriate than another. Practically, answers to our research questions have direct and immediate application to acquisition leaders and policy makers. Theoretically, we generalize to broad classes of organizations and prescribe a novel set of organizational design guides.

In this study, we use the VDT modeling environment to represent and emulate the behavior of an acquisition organization. Although the Typical acquisition organization modeled in this study is representative of such organizations in practice, we do not claim to have experimented—even computationally—with an operational organization. Rather, we experiment computationally with a high-level organizational model, illustrating the method, use and utility of our approach for exposition. We then conceptualize and model two alternate acquisition organizations, manipulating key factors of their organizational designs. We subject them to two environmental contexts, routine and stressed, comparing their performance in terms of cost, schedule and risk.

In routine circumstances, our experimental decentralized and holon-type organizations out-perform typical hierarchies in measures of cost and schedule. Under high stress from task uncertainty, noise, and error probability, our decentralized and holon-type organizations completed their same project work volume as well, faster, and for less cost than their centralized counterpart. In both environments, however, our less formal organization structures yield a higher project-quality risk.

Our findings are similar to those of other VDT researchers who find the relationship between organizational performance improvements and increasing project risk from decentralization in environments of uncertainty (Kim & Burton, 2002) and worker knowledge (Nissen & Buettner, 2004). They offer an extension of contingency theory to include risk as a dependent variable for organizational structures and project outcomes. Our results reveal the same relational patterns of performance capabilities among the three organizational designs and across differing stress environments. They underscore complex interactions between organizational design factors, and suggest fundamental tension and decision tradeoffs between important performance measures such as project cost, schedule and quality/risk.

The results provide several implications for managerial practices and application of organization theory regarding the relationships between organizational structure and performance. Understanding when the bureaucracy is relatively beneficial and how this rigid organizational form can negatively influence project cost (and positively impact project risk) is important for acquisition practitioners today. The apparent implications are that adopting a decentralized structure in accordance with contingency theory may not lead to higher unit performance, since it might instead produce poorer project quality. But, we suspect it is insufficient to only assume that more bureaucracy alleviates risk with attendant costs, or that managers must simply choose either fast and cheap, or better quality results.

In the early 1990’s, with a goal of shortening development times, reducing cost, and increasing numbers of scientific missions flown, NASA adopted a “Faster, Better, Cheaper” approach to project management. This management philosophy was implemented in spite of an old project management adage that project managers could have any two of these performance outcomes, but not all three (Spear, 2000). This maxim is supported somewhat by the findings of Lin and Carley (1997) regarding decision accuracy in organizations under time pressure. After the several unmanned mission failures, and ultimately the February 2003 Columbia disaster that claimed the lives of seven astronauts, an analysis of NASA failures blamed a more risk-tolerant culture as an organizational cause of the accident.

The DoD, having large complex systems with inherent risk of their own, is particularly averse to risk in its decision structure and perhaps even its organizational culture. With growing federal budget deficits and base re-alignments, it is also particularly cost-constrained. And with accelerating obsolescence rates of weapon system technology, the DoD remains under considerable pressure to reduce project schedules as well. Even with simple models, we show that project performance can be examined with various organizational designs and under differing environments. Perhaps for the first time—or at least to an extent unachievable heretofore—we show how managers can gain fundamental insights into the inherent project tradeoffs *in advance of making project decisions*. The practical significance should be apparent immediately.

These experiments support propositions that information processing is a primary organizational activity and is associated with project cost and duration (i.e. the more information processing a project requires, the more costly and lengthy the project becomes). Certainly, there is attendant benefit to the information processed as well. However, the additional measure of project-quality risk is critical for many types of projects, and its emerging relationship from these studies and our most recent work begin to shape a new hypothesis: that perhaps there is an optimal organizational design solution, relative to cost, duration *and* risk. If managers can ascertain early on the criticality (and tolerable level) of project-quality risk, they can perhaps select along a continuum the level of organizational hierarchy and centralization needed to control project outcomes. Or, reframing the question, how much will added bureaucracy cost to alleviate risk? The key point is: the answer will differ—necessarily—for every project. A one-size-fits-all acquisition policy is naïve given such knowledge and our ability to emulate organizational performance as illustrated in this article.

Building upon the VDT constructs introduced in this article, one day researchers may even develop techniques for design optimization based on project objectives (e.g., speed vs. risk) and environment. Leaders, managers and researchers may develop the capability to design organizations, work processes and technologies using computational techniques comparable to those employed for designing airplanes, bridges and computers. That day is not yet here. But, through research along these lines, we can both foresee and accelerate its arrival. Meanwhile, the centralized control that dominates current acquisition thinking and policy merits re-examination in light of this study. Such control imposes costs as well as accrues benefits. We know now how to measure and compare them: via computational experimentation.

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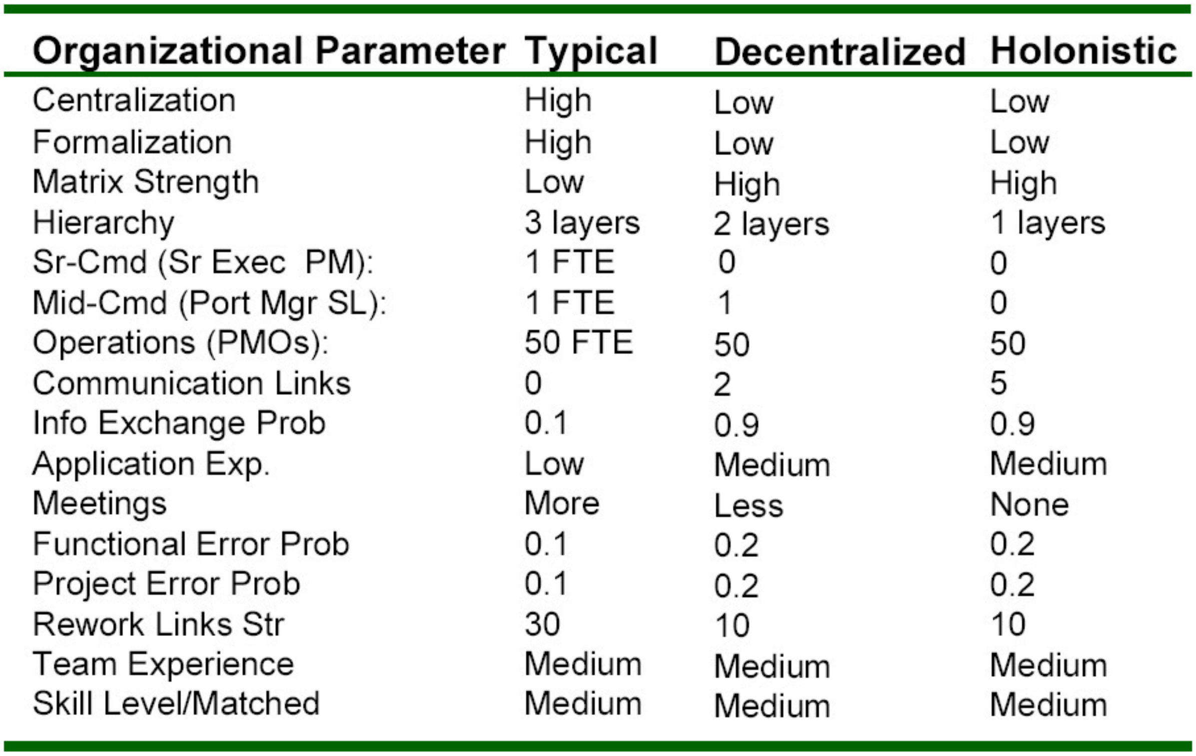
# APPENDIX A: DESIGN OF ORGANIZATION MODELS

This appendix provides additional detail about the design of our experimental acquisition organization models. Table 1 above specifies design parameters and VDT simulation settings for all three of our organizational designs: Typical, Decentralized and Holonistic. We reproduce the information below as Table 4 and discuss the various design parameters.

**Table 4. Organizational Design Parameters**



| Organizational Parameter | Typical | Decentralized | Holonistic |
|---|---|---|---|
| Centralization | High | Low | Low |
| Formalization | High | Low | Low |
| Matrix Strength | Low | High | High |
| Hierarchy | 3 layers | 2 layers | 1 layers |
| Sr-Cmd (Sr Exec PM): | 1 FTE | 0 | 0 |
| Mid-Cmd (Port Mgr SL): | 1 FTE | 1 | 0 |
| Operations (PMOs): | 50 FTE | 50 | 50 |
| Communication Links | 0 | 2 | 5 |
| Info Exchange Prob | 0.1 | 0.9 | 0.9 |
| Application Exp. | Low | Medium | Medium |
| Meetings | More | Less | None |
| Functional Error Prob | 0.1 | 0.2 | 0.2 |
| Project Error Prob | 0.1 | 0.2 | 0.2 |
| Rework Links Str | 30 | 10 | 10 |
| Team Experience | Medium | Medium | Medium |
| Skill Level/Matched | Medium | Medium | Medium |

Our experiments simulate the acquisition efforts of five small project-management offices oriented on an initial strike capability (such as one provided by a missile or direct-fire weapon), integration into a mobile platform (such as a ground or air vehicle), and followed by block enhancements to both sets of capability from insertion of technology. These types of effort are common within program executive office portfolios across the military services. To simulate the completion of these projects, we design three different organizations with similar resources, but varying parameters of organizational control.

Centralization, Formalization and Matrix Strength comprise a group of variables that work together in our modeling tool to characterize levels of bureaucratic organizational control. Low Centralization settings in the Decentralized and Holonistic models mean decisions are made by the individual responsible positions. Centralization reflects decision-making in the organization—either by senior project positions or by “decentralized” individuals. With high Centralization, there is more communication required. Formalization measures how formal the communication is in an organization, with high Formalization meaning that communication tends to occur in formal meetings (despite the many informal communication occurring in any typical project office), and low settings reflecting informal communication among positions. Matrix strength characterizes the probability that workers will attend to exchanges of information—

whether via meetings, communications about tasks, or noise. It conveys “connectedness” and can correspond to geographical collocation of workers. Typical major program acquisition organizations have workers and decision makers distributed across the country, and there is a greater need for meetings. The low setting for Typical acquisition organizations, however, reflects high meeting quality and complements high Formalization. Conversely, high Matrix Strength, which complements low Formalization, characterizes our flatter, more Decentralized or Holonistic organizations. In the “Typical” model, we use a three-level management hierarchy with two different full-time equivalents (FTE) in two management positions, acting as portfolio manager and senior executive. We reduce to two, and then one in the other derivations. The PM and SL designations beside their positions are VDT designations, which connote decision-making. The 50 FTEs aside—Operations represent project management office personnel in five distinct project work areas that are interdependent, and become more strengthened with communication links, used as such by the VDT. In the Typical DoD acquisition organization, we have observed it is common for individual project offices within a PEO to communicate infrequently, though there is a great deal of vertical communication within the hierarchy, evidenced in the model with Meetings. We also reduce the number of meetings in the successively flatter organizational designs.

Correspondingly, hierarchical communication is also depicted via a low setting (0.1) of Information Exchange Probability for the Typical Organization and growing much higher (0.9) in the flatter designs. This is characteristic for a project involving mostly routine daily jobs performed by skilled workers (Typical design). A higher value is given the designs with more highly interdependent tasks that are being performed by very busy workers.A low setting of Application Experience for the Typical organization, and set at the entire program level, describes how many new R&D projects the positions may have worked on before, in spite of relative individual skill levels (which are all presumed as Medium and Matched to the work tasks assigned across all three designs). The Decentralized and Holonistic learning organizations are envisioned as learning organizations, with the benefit of some Application Experience (set at medium), from less complicated information processing and learning.

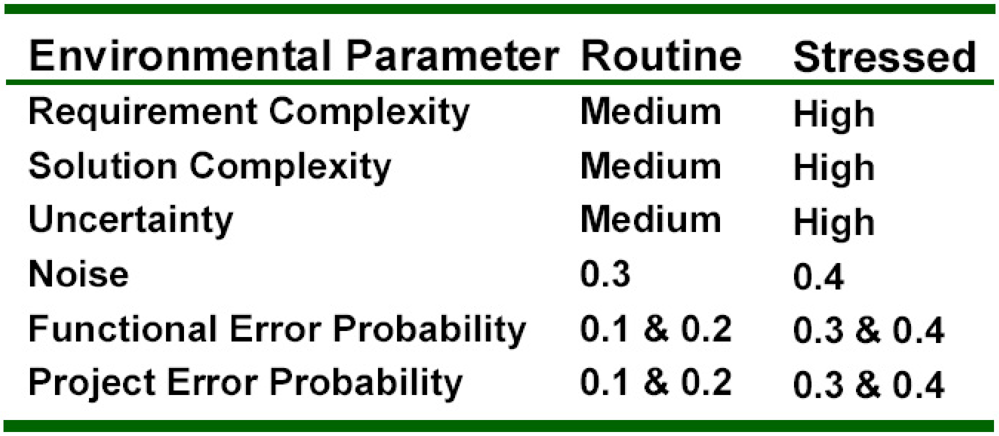
Five Rework links connect all tasks in the Holonistic design, given the lack of an overhead hierarchy as an integrative function. This is opposed to two links in the Decentralized and Typical designs. Likewise, Rework Strength designations shift to reflect success/failure dependency as higher in the Decentralized and Holonistic, and lower in the Typical hierarchy, commensurate with associated task interdependency. In much the same way, the stove-piped, independent efforts within the Typical organization hierarchy are represented in lower Functional and Project Error Probability settings. Higher settings for the flatter organizational designs convey the challenge of integration and alignment they must face without an overarching control entity.

The total simulated work task effort of all organizational designs is the same, except that layers of management in the Typical configuration have their own management tasks that run about 25% of the duration of the project’s planned timeline. The team experience value in the VDT tool affects the amount of information exchange on the project and the way a position’s information processing speed is calculated. Team Experience for the work effort is set to medium for all organizations, representing a measure of how successfully the team has performed related projects.

# APPENDIX B: ENVIRONMENTAL PARAMETERS

This appendix provides additional detail about the environmental scenarios that our experimental acquisition organization models were subjected to. Table 2 above specifies environmental parameters and VDT simulation settings for both of our environmental conditions: Routine and Stressed. We reproduce the information below as Table 5 and discuss the various parameters.

**Table 5. Environmental Parameters**



| Environmental Parameter | Routine | Stressed |
|---|---|---|
| Requirement Complexity | Medium | High |
| Solution Complexity | Medium | High |
| Uncertainty | Medium | High |
| Noise | 0.3 | 0.4 |
| Functional Error Probability | 0.1 & 0.2 | 0.3 & 0.4 |
| Project Error Probability | 0.1 & 0.2 | 0.3 & 0.4 |

Requirement Complexity describes the degree of task complexity, which is relative to the total number of project requirements that the task must satisfy. Representative of current DoD acquisition environments are state-of-the-art technologies and interoperability requirements. As such, there is a common environment of at least a medium setting within our VDT tool for organizations under even routine circumstances. An even more highly optimized design could have many tasks with a high requirement complexity, and is appropriate for our “stressed” settings.

Solution Complexity represents the number of solutions to which a task contributes. The degree of complexity reflects the effect a task has on the tasks that depend on it. Thus, for routine circumstances, we use “medium” and “high” for stressed scenarios.

Uncertainty is a setting regarding the amount of communication across links needed for a task’s (and its dependent tasks’) completion. Task uncertainty reflects the effect that other tasks can have on each other within the project. Task Coordination volume and the number of communications increase with higher uncertainty, so we selected “medium” for routine and “high” for stressed environments.

Noise Probability describes the interruptions or distractions that detract from work on project tasks. The probability of noise is set at 0.3 for our routine scenarios and 0.4 for stressed.

Functional error probability is the probability that a task will fail and require rework. Functional errors are localized to an individual task and, thus, only cause rework in that task. Functional errors could be discovered via self-check, a project-review meeting, or a supervisory review. Depending on the level of centralization and hierarchy in the project, an exception can be handled by the responsible position or someone up the hierarchy. When a functional error is detected, an exception is sent to the responsible position or to a supervisor, generating either rework of the task, a quick fix, or feigned ignorance of the problem. Project error probability is the probability that a task will fail and generate rework for all dependent tasks connected to it by rework links. The more rework links there are in a project, the more rework is generated by the exceptions that occur. We select 0.1 as our routine setting for the Typical organization and 0.2 for our Decentralized and Holonistic designs, reflecting their decreasing management potential for intervention. For stressed scenarios, we use 0.3 for our Typical organization and 0.4 for our Decentralized and Holonistic designs.

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