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Hypothesis Testing of Edge Organizations: Simulating Performance under Industrial Era and 21st Century Conditions[1]

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Abstract

The *Edge* represents a fresh approach to organizational design. It appears to be particularly appropriate in the context of modern military warfare, but also raises issues regarding comparative performance of alternate organizational designs. Building upon prior C2 research, we seek to understand the comparative performance of the Edge and *all* organizational forms, across 21st Century and *all* mission-environmental conditions, and hence characterize the entire *organization design space* systematically. Leveraging recent advances in computational organization theory, we extend our campaign of experimentation to specify six, diverse, archetypal organizational forms from theory, and to evaluate their comparative performance empirically. Results confirm that no single organizational form is “best” for all circumstances; highlight contingent circumstances for which the Edge and other kinds of organizations perform relatively better than one another; and elucidate seven specific performance measures that provide multidimensional insight into different aspects of organizational performance. This research grounds the Edge organization firmly in well-established organization theory, and provides empirical support for and against claims regarding this novel organizational form, particularly in terms of *agility*. We discuss the model, experimental setup and results in considerable detail, which offer theoretical implications for the organization scholar and actionable guidance for the C2 practitioner.

INTRODUCTION

The *Edge* (Alberts and Hayes 2003) represents a fresh approach to organizational design, which appears to be particularly appropriate in the context of modern military warfare. It proposes to capitalize upon fully connected, geographically distributed, organizational participants by enabling shared awareness, and by moving knowledge and power to the edges of organizations. This highlights promising opportunities for enterprise efficacy, but it also raises issues in terms of comparative performance with respect to alternate organizational designs. Modern military organizations in general have adapted and evolved over many centuries and millennia, respectively. Command and control (C2) through bureaucratic, hierarchical organizations in particular have been refined longitudinally (e.g., through iterative combat, training and doctrinal development) to become very reliable and effective at the missions they were designed to accomplish. In contrast, the many putative benefits and comparative advantages proposed for Edge organizations have since their origin remained untested hypotheses at best and naïve speculations at worst.

The research described in this article addresses such putative benefits and comparative advantages directly, through a campaign of experimentation to assess the relative performance of Edge and other organizations across a diversity of mission-environmental contexts. This work builds directly upon prior C2 research that employs the methods and tools of computational experimentation to examine organizational performance empirically. For recent instance, Nissen and Buettner (2004) articulate the promise of computational experimentation toward this end, and elaborate a unique, complementary role that the associated research methods and tools can play in conjunction with other, more established methods (e.g., analytic modeling, laboratory experimentation, fieldwork). As another instance, Nissen (2005) compares and analyzes more than 25, diverse organizational forms from the organization studies literature, and shows how the Edge organization is theoretically distinct and uniquely differentiated from other organization forms described over the past half century. This prior research succeeded in grounding the Edge firmly in organization theory for the first time, which provides a noteworthy contribution to new knowledge. With this, organization scholars can now understand the theoretical characteristics of this new organizational form, and can make informed comparisons and contrasts with other, more familiar forms (esp. the Hierarchy). Also, C2 leaders and policy makers can now identify and understand the kinds of classic organizational forms that exhibit both similarities and differences with respect to the Edge. This prior research allows unprecedented, mutually informed conversations between organization scholars and C2 practitioners to take place now.

Moreover, this prior research also offers a theoretical discussion, and develops a set of testable research hypotheses, about the performance of Edge and Hierarchy organization forms under two, contrasting, mission-environmental conditions: Industrial Era and 21st Century. Consistent with well-established Contingency Theory (e.g., see Lawrence and Lorsch 1967 for seminal work, Donaldson 2001 for contemporary review), this prior research demonstrates that *no single organizational form—not even the Edge—is “best” for every mission-environmental context*, and it elucidates the key mission-environmental contingencies that impact the performance of these two, contrasting organizational forms.

With this, organization scholars can now assess the comparative performance of Edge organizations empirically, and can evaluate the Edge's relative fit, across contrasting mission-environmental contexts, with respect to that of the Hierarchy. Also, C2 leaders and policy makers can now identify the kinds of mission-environmental conditions in which their predominant organizational form—the Hierarchy—is likely to suffer from performance degradation, and can appreciate the kinds of organizational changes required to become more edge-like. This offers a contribution to Organization Theory and C2 practice alike, and it provides a well-grounded baseline for our campaign of experimentation to understand—theoretically and empirically—the relative strengths and weaknesses of alternate organizational forms across different mission-environmental conditions.

The present research continues this experimentation campaign, but expands it greatly to understand the comparative performance of *all* organizational forms, across *all* mission-environmental conditions. Through this campaign of experimentation, we are progressing systematically toward instantiation and analysis of the entire *organization design space* (i.e., in a contingency-theoretic sense) of organizational forms and mission-environmental contexts. Although such instantiation and analysis is clearly not exhaustive, by including a diversity of classic organizational archetypes from theory, and by examining them across contrasting and current mission-environmental contexts, this design space should be representative, and the results should be applicable across a wide diversity of organizations and environments in practice. This computational, organization studies research is theoretically grounded yet empirical in nature—thereby augmenting the largely atheoretic, speculative characterization of Edge organizations to date—and it targets theoretical development as well as practical application—thereby informing organization scholars and C2 practitioners alike.

As reported in our prior research, however, few, if any, research methods—aside from computational experimentation—offer potential to even address this problem of organizational design space depiction and elaboration. Indeed, only through recent advances in computational organization theory (e.g., see Burton et al. 2002, Carley and Lin 1997, Levitt et al. 1999, Lomi & Larsen 2001) are we able to even consider the whole design space as such. For instance, to represent and reason about organizational processes, one can conduct computational experiments with levels of rigor and control comparable to laboratory experimentation. This can support greater internal validity and reliability than is obtainable often through fieldwork, and computational experiments can be conducted many orders of magnitude more quickly than physical experiments can. As another instance, computational experiments can be conducted to examine myriad different organizational designs—*including cases that have yet to be implemented in physical organizations* (Nissen 2005). This can support broad generalizability of results—even to classes of organizations that have yet to be invented, much less instantiated and experimented upon. As a third instance, mission-environmental contexts are not manipulated easily in the field, and laboratory experiments are limited generally to micro-level organizational phenomena, with problems in terms of external validity and generalizability. Computational experimentation can ameliorate such methodological difficulties.

In the balance of this article, we present theoretical background and hypotheses, and then describe our computational model, present the results, and summarize important conclusions for organization theory and C2 practice.

THEORETICAL BACKGROUND & HYPOTHESES

In this section, we summarize briefly: Mintzberg's (1979, 1980) classic, archetypal organization forms; the Edge organization; and the seven testable research hypotheses developed by Nissen (2005). For more detailed discussion, we encourage the interested reader to consult the references cited below.

To begin, Mintzberg (1980) suggests a typology of five, archetypal organizational configurations: Simple Structure, Machine Bureaucracy, Professional Bureaucracy, Divisionalized Form, and Adhocracy. The different configurations vary according to the structuring and predominance of their organizational parts, coordination mechanisms, design parameters, and contingency factors. In Mintzberg's own words (p. 322):

> In Simple Structure, the key part is the strategic apex, which coordinates by direct supervision; the structure is minimally elaborated and highly centralized; it is associated with simple, dynamic environments and strong leaders, and tends to be found in smaller, younger organizations or those facing severe crises. The

Machine Bureaucracy coordinates primarily by the imposition of work standards from the technostructure; jobs are highly specialized and formalized, units functional and very large (at the operating level), power centralized vertically at the strategic apex with limited horizontal decentralization to the technostructure; this structure tends to be found in simple, stable environments, and is often associated with older, larger organizations, sometimes externally controlled, and mass production technical systems. The Professional Bureaucracy relies on the standardization of skills in its operating core for coordination; jobs are highly specialized but minimally formalized, training is extensive and grouping is on a concurrent functional and market basis, with large sized operating units, and decentralization is extensive in both the vertical and horizontal dimensions; this structure is typically found in complex but stable environments, with technical systems that are simple and non-regulating. In the Divisionalized Form, a good deal of power is delegated to market-based units in the middle line (limited vertical decentralization), whose efforts are coordinated by the standardization of outputs, through the extensive use of performance control systems; such structures are typically found in very large, mature organizations, above all operating in diversified markets. Adhocracy coordinates primarily by mutual adjustment among all of its parts, calling especially for the collaboration of its support staff; jobs are specialized, involving extensive training but little formalization, units are small and combine functional and market bases in matrix structures, liaison devices are used extensively, and the structure is decentralized selectively in both the vertical and horizontal dimensions; these structures are found in complex, dynamic environments, and are often associated with highly sophisticated and automated technical systems.

These five, archetypal organization forms from theory are broadly applicable, mutually distinct, and empirically confirmed. Hence they are broadly representative of current organizational conceptualizations and contemporary organizational practice, and many of the emerging organizational forms (e.g., strategic alliances, networked firms, Edge organizations) can be analyzed recombinantly through consideration of their separate parts, mechanisms, parameters and factors.

Indeed, we show (see Nissen 2005) how the Edge organization shares similarities with the Adhocracy (e.g., coordination by mutual adjustment, small unit size, many liaison links throughout, selective decentralization), Professional Bureaucracy (e.g., low vertical specialization, high training and indoctrination, market and functional grouping), and Simple Structure (e.g., low horizontal specialization, low formalization), but it also demonstrates several key differences, and does not correspond cleanly with any single archetype. Key to Edge characterization is decentralization, empowerment, shared awareness and freely flowing knowledge required to push power for informed decision making and competent action to the "edges" of organizations (Alberts and Hayes 2003), where they interact directly with their environments and other players in the corresponding organizational field (Scott 2001). In contrast with the forms noted above, with which the Edge organization shares several similarities, the Edge shares almost no similarities with the Machine Bureaucracy (cf. high training and indoctrination). Indeed, as observed through our prior research with the Hierarchy, the Machine Bureaucracy form provides a contrast with the Edge, yet it maps cleanly to the Hierarchy. We refer to the Machine Bureaucracy and Hierarchy forms interchangeably.

Finally, we revisit and recapitulate the key hypotheses developed through our prior research, which are rooted in current Edge "theory" (see esp. Alberts & Hayes 2003, but in addition: Garstka and Alberts 2004, Maxwell 2004, and Nissen 2004). This sets the stage for computational experimentation. The key Edge hypotheses are restated below for reference (see Nissen 2005 for derivation and discussion).

Hypothesis 0. Edge organizations can outperform Hierarchy organizations in demanding mission environmental contexts. This represents the fundamental, null hypothesis.

Hypothesis 1. "Power to the Edge is the correct response to the increased uncertainty, volatility, and complexity associated with [21st century] military operations" [p. 6].

Hypothesis 2. "The correct C2 approach depends on [five] factors": 1) shift from static/trench to mobile/maneuver warfare; 2) shift from cyclic to continuous communications; 3) volume and quality of information; 4) professional competence; and 5) creativity and initiative [p. 19].

Hypothesis 3. "Given a robustly networked force, any one of the six effective command and control philosophies proven useful in the Industrial Era is possible" [p. 32].

Hypothesis 4. People who work together, over time, and learn to operate in a "post and smart-pull" environment, will outperform similarly organized and capable people who do not.

Hypothesis 5. "The more uncertain and dynamic an adversary and/or the environment are, the more valuable agility becomes" [p. 124].

Hypothesis 6. "An organization's power can be increased without significant resource expenditures" [p. 172].

In addition, we draw two further hypotheses, based on the organizational ecologist perspective (e.g., see Nelson and Winter 1982).

Hypothesis 7: Of all the organization forms, the Machine Bureaucracy will have experienced the greatest relative decline in performance over the past century.

Hypothesis 8: Of all the organization forms, the Edge organization will have displayed the greatest relative increase in performance over the past century.

These latter two hypotheses are also supported by Senge's (1994) observation that the 21st Century requires more nimble, more adaptable organizations to match the ever-growing rates of technological change and complexity that characterize our modern era.

COMPUTATIONAL MODELING BACKGROUND

In this section we discuss computational organization theory briefly, and draw heavily from Nissen and Levitt (2004) to provide an overview of our computational modeling approach. We then describe the computational model developed to test our hypotheses.

Computational Organization Theory Research

Computational organization theory (COT) is an emerging, multidisciplinary field that integrates aspects of artificial intelligence, organization studies and system dynamics/simulation (e.g., see Carley and Prietula 1994). Nearly all research in this developing field involves computational tools, which are employed to support computational experimentation and theorem proving through executable models developed to emulate the behaviors of physical organizations (e.g., see Burton et al. 2002, Carley and Lin 1997, Levitt et al. 1999).

As the field has matured, several distinct classes of models have evolved for particular purposes, including: descriptive models, quasi-realistic models, normative models, and man-machine interaction models for training (Cohen and Cyert 1965, Burton and Obel 1995). More recent models have been used for purposes such as developing theory, testing theory and competing hypotheses, fine-tuning laboratory experiments and field studies, reconstructing historical events, extrapolating and analyzing past trends, exploring basic principles, and reasoning about organizational and social phenomena (Carley and Hill 2001: 87).

Our COT methods and tools build upon the planned accumulation of collaborative research over almost two decades to develop rich, theory-based models of organizational processes (Levitt 2004). Using an agent-based representation (Cohen 1992, Kunz et al. 1999), 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 shown how the qualitative and quantitative behaviors of our computational models correspond closely with a diversity of enterprise processes in practice.

This research stream continues today with the goal of developing new micro-organization theory, and 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, virtual prototypes. Clearly this represents a significant challenge. 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 analysis of such physical systems yields easily differential equations and precise numerical computing. Of course, people, organizations and enterprise processes differ from bridges, airplanes and semiconductors, 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, verbal, atheoretic descriptions of C2 organizational behavior. For instance, the domain of organization theory is imbued with a rich, time-tested collection of micro-theories that lend themselves to computational 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 on such theory, 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 be used to emulate organizational dynamics.

Even though the representation has qualitative elements (e.g., lacking the precision offered by numerical models), through commitment to computational modeling, it becomes semi-formal (e.g., most 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.

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 or longitudinally. Thus, when modeling aggregations of people, such as work groups, departments and firms, one can augment the kind of symbolic model from above with certain aspects of numerical representation. 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 irregular attention of a worker to any particular activity or event (e.g., new work task or communication) 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 hardly new (Law and Kelton 1991). But this approach enables us to *integrate* the kinds of dynamic, qualitative behaviors emulated by symbolic models with quantitative metrics generated through discrete-event simulation. It is through such integration of qualitative and quantitative models—bolstered by reliance on sound theory and devotion to empirical validation—that our approach diverges most from extant research methods, and offers new insight into organizational dynamics.

Computational Modeling Environment

The computational modeling environment consists of the elements described in Table 1, and has been developed directly from Galbraith’s information processing view of organizations. This view of organizations, described in detail by Jin and Levitt (1996), has two key implications. 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 constrains their behaviors. Figure 1 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, levels 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.

Table 1 Model Elements and Descriptions

Model Element	Element Description
Tasks	Abstract representations of any work that consumes time, is required for project completion and can generate exceptions.
Actors	A person or a group of persons who perform work and process information.
Exceptions	Simulated situations where an actor needs additional information, requires a decision from a supervisor, or discovers an error that needs correcting.
Milestones	Points in a project where major business objectives are accomplished, but such markers neither represent tasks nor entail effort.
Successor links	Define an order in which tasks and milestones occur in a model, but they do not constrain these events to occur in a strict sequence. Tasks can also occur in parallel. Three types of successor links include: finish-start, start-start and finish-finish.
Rework links	Similar to successor links because they connect one task (called the *driver* task) with another (called the *dependent* task). However, rework links also indicate that the dependent task depends on the success of the driver task, and that the project's success is also in some way dependent on this. If the driver fails, some rework time is added to all dependent tasks linked to the driver task by rework links. The volume of rework is then associated with the project error probability settings.
Task assignments	Show which actors are responsible for completing direct and indirect work resulting from a task.
Supervision links	Show which actors supervise which subordinates. The supervision structure (also called the *exception-handling hierarchy*) represents a hierarchy of positions, defining who a subordinate would go to for information or to report an exception.

As suggested by the figure also, 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 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.

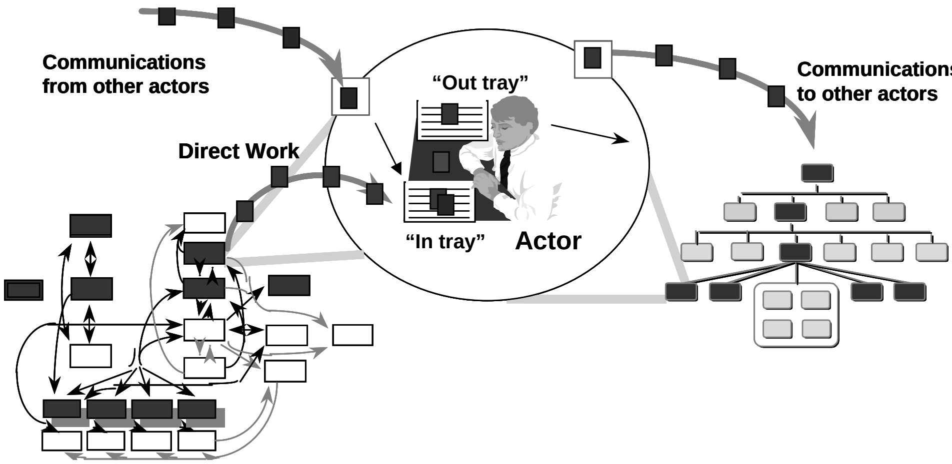

Figure 1 Information Processing View of Knowledge Work

The second implication is computational: *work volume* is modeled in terms of both *direct work* (e.g., planning, design, manufacturing) and *indirect work* (e.g., decision wait time, rework, coordination work). Measuring indirect work enables the quantitative assessment of (virtual) process performance (e.g., through schedule growth, cost growth, quality).

Computational Model Validation

The computational modeling environment has been validated extensively, over a period spanning almost two decades, by a team of more than 30 researchers (Levitt 2004). This validation process has involved three primary streams of effort: 1) internal validation against micro-social science research findings and against observed micro-behaviors in real-world organizations, 2) external validation against the predictions of macro-theory and against the observed macro-experience of real-world organizations, and 3) model cross-docking experiments against the predictions of other computational models with the same input data sets (Levitt et al. 2005). Ours is one of the few, implemented, computational organization modeling environments that has been subjected to such a thorough, multi-method trajectory of validation.

COMPUTATIONAL EXPERIMENTATION & HYPOTHESIS TESTING

In this section we formulate a computational model of the different organization forms. Then we develop a three-pronged set of experimental manipulations to test our hypotheses, and to examine the comparative performance of the different organizational forms under Industrial Era and 21st Century conditions. We discuss our contributions to theory and practice in turn.

Model Set-Up: Organization Forms

Table 2 shows how our COT modeling environment is used to formulate models of archetypal and Edge organizational forms, and how select model variables are used to operationalize the various organization design parameters. The three structural factors (i.e., organization, communication, work) derive directly from our prior computational experiments (Nissen 2005); the Mintzberg design parameters derive directly from Mintzberg (1980); and the model parameters derive directly from our computational models. These latter parameters are manipulated deliberately to represent each of the diverse organizational archetypes. Notice that each organizational archetype consists of a unique combination of parameter settings in our computational models.

Parameter settings for the Edge and Machine Bureaucracy (i.e., equivalent to the Hierarchy in our prior article) replicate those reported by Nissen (2005), hence we concentrate here on extensions to the additional archetypal forms. For example, the Simple Structure is characterized by high centralization of decision making, low formalization of behavior, a two-level hierarchy, few liaison devices (which are represented by a combination of relatively few communication links and a low setting (0.1) for the information exchange), a relatively small number of meetings (i.e. 2 hours per month), a low likelihood that actors will actually attend those meetings (which is represented by a low value on the matrix strength variable), and low levels of interdependence and concurrency between tasks.

Notice how the Simple Structure exhibits both similarities and differences with respect to the Edge and Machine Bureaucracy forms. Our computational model enables specification of each, contrasting and unique, archetypal organization form in considerable detail. Parameter settings for the Professional Bureaucracy, Divisionalized Form and Adhocracy follow accordingly. To preserve continuity for the non-modeler, the discussion here remains at a relatively high level. See Nissen (2005) for detailed definitions of the modeling concepts, terms and variables, for reference.

Table 2 Model Set-Up: Organization Forms

Structural Factor	Mintzberg Design Parameter	Model Parameter	Edge	Machine Bureacracy	Simple Structure	Prof. Bureacracy	Divisionalized Form	Adhocracy
Organization Structure	Decentralization	Centralization	Low	High	High	Low	Medium	Low
	Formalization of behavior	Formalization	Low	High	Low	Low	High	Low
	Vertical specialization	Hierarchy Set-Up	1-level	3-level	2-level	2-level	4-level	1-level
	"	Holding Company (PM)	0 FTE	0 FTE	0 FTE	0 FTE	2 FTE	0 FTE
	"	Command Position (PM)	0 FTE	3 FTE	5,000 FTE	7,000 FTE	4 FTE	0 FTE
	"	Coordination Position (SL)	0 FTE	200 FTE	0 FTE	0 FTE	500 FTE	0 FTE
	"	Operations Position (ST)	40,000 FTE	40,000 FTE	35,000 FTE	33,000 FTE	40,000 FTE	40,000 FTE
	Size	# of Total FTEs	40,000	40,203	40,000	40,000	40,006	40,000
	Unit Size	# of FTEs per Unit	100 - 1800	10,000	17,500	3700	9,875	100 - 1800
	N/A	# of Units	16	4	2	10	4	16
	Training	Skill Level[1]	Med.	Med.	Low	Med	Med.	Low
	Indoctrination	App. Experience[1]	Med.	Low	Low	High	Med.	Low
Communication Structure	Liaison Devices	Communication Links	Many	None	Few	Some	Few	Many
	"	Information Exchange[1]	0.9	0.1	0.1	0.3	0.1	0.9
	Planning & Control Systems	Meetings	No Meetings	2 hrs/day	2 hrs/month	0.5 hr./day	2 hrs/week	0.5 hr./day
	"	Matrix Strength	High	Low	Low	Med.	Low	High
Work Structure	N/A[2]	Number of Operational Tasks	16	4	3	10	4	16
	"	Degree of Concurrency	Massive Concurrency	Sequential, 2 Phase	Sequential	Concurrent	Sequential, 4 Phase	Massive Concurrency
	"	Interdependence	High	Low	Low	Med	Low	High
	"	Rework Links	Many	Few	Few	Some	Few	Many
	"	Rework Strength	0.1	0.3	0.2	0.2	0.3	0.2
	Environment - Complxity	FEP/PEP	0.2	0.1	0.1	0.2	0.1	0.2

[1] This is the baseline value for the Industrial Age case; the values are adjusted for the 21st Century case as specified in Table 4.
[2] Mintzberg does not explicitly address "work structure" in his paper.

Model Set-Up: Industrial Era and 21st Century Conditions

We model organizational contexts of the Industrial Era and the 21st Century via the three dimensions specified by Nissen (2005): mission and environmental context, network architecture, and professional competency. These dimensions capture our first six research hypotheses, and hence provide a principal basis for experimentation. Using our computational modeling tools, each manipulation can be conducted independently to isolate separate effects, or conducted collectively to emulate aggregate effects. The experimental manipulations are listed in Table 3, which summarize how each of the three experimental manipulations is specified across the two alternate scenarios. As noted at the bottom of in the table, we include a fourth, aggregate manipulation also. This aggregate manipulation includes all of the effects described in the other three manipulations: mission and environmental context, network architecture, and professional competency.

The first manipulation is labeled “Mission & Environmental Context,” and derives principally from Hypotheses 1 and 5 above. This manipulation is intended to capture differences between mission-environmental contexts of the Industrial Era and the 21st Century. Following Carroll and Burton (2000) in part, we depict this context as one of “medium complexity” for the Industrial Era scenario. Clearly *complexity* is relative. Even a “medium” complexity military operation would be considered “very complex” with respect to most organizations in the world. But within our experimental design, we use the level *medium* here principally for contrast with the alternate, 21st Century scenario. We specify medium complexity via two model parameters: *requirement complexity* and *solution complexity*. The same holds for *uncertainty*, which we specify here as "medium" in like manner. Additionally, the Industrial Era scenario depicts a set of relatively routine and analyzable problems (Perrow 1967) to be solved. In the 21st Century scenario, however, tasks are envisioned to be much more challenging. Hence we use higher levels for error parameters (i.e., *FEP, PEP*).

Table 3 Model Set-Up: Industrial Era and 21st Century Conditions

Manipulation	Model Parameter	Industrial Era Value	21st Century Value
Mission & Environmental Context (P1, 5)	Soln. Complexity	Med.	High
	Requirement Complexity	Med.	High
	Uncertainty	Med.	High
	FEP	Baseline in Table 3	Baseline + 0.1
	PEP	Baseline in Table 3	Baseline + 0.1
Network Architecture (P2, 3)	Noise	0.3[a]	0.01
	Info. Exchange Prob.	Baseline in Table 3	Baseline + 0.3[b]
Professional Competency (P2, 4)	App. Experience	Baseline in Table 3	Baseline in Table 3
	Skill Level	Baseline in Table 3	Baseline + one level
	Team Experience	Med	High
Aggregate (P1 - 6)	All of the above	All of the above	All of the above

[a] 0.3 is the Baseline setting for this parameter.
[b] Except in the case of the Edge organization, for which the info exchange settings within the VDT model can only be increased by one level to 1.0 in the 21st Century case.

The second manipulation is labeled "Network Architecture," and derives principally from Hypotheses 2 and 3. This manipulation is intended to capture information infrastructure differences between the centralized, vertical configurations in use today and the fully networked, global topologies being developed for tomorrow. Following Alberts and Hayes (2003), Garstka and Alberts (2004), and Maxwell (2004), as well as Carroll and Burton (2000) and Nogueira (2000), we characterize the current scenario as one of a "stove piped" architecture, in which networks, processes and cultural norms support principally vertical communication within functional "silos" or "chimneys." This current network architecture is characterized also in terms of "low bandwidth." Again as above, *bandwidth* is relative. But many military combatants in the air, at sea and on the ground have much poorer bandwidth than most land-based organizations do. Following Carroll and Burton (2000) in part, we specify this situation using *noise,* and include a relatively high level (0.3) in the Industrial Era Scenario. We use the parameter *information exchange probability* also, and specify the relatively low, Baseline level in the Industrial Era Scenario. The levels summarized in Table 3 for the 21st Century scenario reflect consistently a more robust and capable network architecture, which forms the predominate focus of most C2 leaders today, as they prepare for the 21st Century environment.

The third manipulation is labeled "Professional Competency," and derives principally from Hypotheses 2 and 4. This manipulation is intended to capture differences in organization and knowledge flows between the efficiency-oriented approaches practiced widely in the Industrial Era and the agility-focused ones informed by emerging Knowledge-Flow Theory (e.g., see Nissen 2006) for the 21st Century. Professional competency pertains to the level of knowledge that people, groups and organizations possess with respect to their organizations, missions and environments. In the Industrial Era scenario, people, teams and organizations are able to develop extreme degrees of proficiency with the specific, limited set of missions and environments that they plan, generally well in advance, to encounter. Education and training are extensive, and the Military in particular has accumulated and documented vast amounts of doctrine to formalize organizational learning along these lines. This suggests a relatively higher level for the parameter *application experience*. However, push, broadcast style information dissemination complicates the information-processing tasks associated with searching for important knowledge. This suggests a relatively lower level for *application experience*. On balance, we do not manipulate this parameter here, and leave it instead at "Low" as specified by Nissen (2005). Further, people change jobs frequently (e.g., every 2 – 3 years in the Military) in the Industrial Era. This makes it difficult for individuals to develop high skills specific to any particular job. We specify this effect through the relatively low, Baseline level for the parameter *skill level*. This frequent job rotation makes it difficult also for teams to develop long-term, cohesive bonds—which affect trust—and the kind of deep familiarity and understanding that comes only through tacit learning over extended periods of time. We specify this effect through medium level *team experience*.

The levels summarized in Table 3 for the 21st Century scenario reflect a relative increase in *team experience* and *skill level* with respect to those specified for its Industrial Era counterpart. In particular, because the organization as a whole stresses *agility* over efficacy or efficiency (Alberts & Hayes 2003, p. 180), it must prepare for a much wider variety of diverse missions and environments than its counterparts do. This offsets in part the kind of cumulative learning noted above and renders the organization in a situation requiring rapid learning on the margin for each, distinct mission. Departing somewhat from Nissen (2005), in which this effect is specified by adjusting the *application experience* level, we make no such adjustment here; our modeling environment lacks the range currently to manipulate this parameter as specified. We plan to readdress this application-experience effect in the next phase of computational experimentation. Conversely, agility calls for relatively small, experienced, cohesive units that can self-organize into larger compositions of units, and that can self-synchronize their operations dynamically. Our interpretation of this is that less personnel rotation across units will become the norm (e.g., as it is in many knowledge organizations such as universities). We specify this effect by raising *skill level* and *team experience*.

In design terms, this provides the basis for a *full factorial, 6 x 4 x 2 experiment* (i.e., 6 archetypes, 4 manipulations, 2 scenarios), and our detailed specification of the models and manipulations should enable systematic experimentation and reliable replication by researchers. In this present article, we begin by examining the two, contrasting organizational forms specified through our prior research: Edge and Hierarchy/Machine Bureaucracy. Extending this prior research—which manipulated only Mission-Environmental Context—here we examine these contrasting organizational forms across all four experimental manipulations. The other four organizational forms—Simple Structure, Professional Bureaucracy, Divisionalized Form, Adhocracy will be addressed in the next phase of experimentation. Hence this present article reports the results of a 2 x 4 x 2 factorial experiment.

Model Set-Up: Dependent Variables

Table 4 details the dependent variables—*time, cost, direct work, rework, coordination work, decision wait time, and project risk*—that we use to assess the multidimensional performance of the different organization forms.

Table 4 Dependent Variables and Description of Model Parameters

Dependent Variable	**Parameter Description**
Time	*Time* (days) is the predicted time to perform a project, in working days, which includes both direct and indirect (i.e. coordination, rework and decision latency) work.
Cost	*Cost* (dollars) is the predicted cost of labor to perform a project, in dollars, which includes both direct and indirect (i.e. coordination, rework and decision latency) work.
Direct Work	*Direct work* measures the amount of time, in person-days, that all actors in a project spend completing direct functional or technical activities – excluding rework, coordination work, and decision wait time – related to the completion the project.
Rework	*Rework* measures the amount of time, in person-days, that all actors in a project spend redoing tasks in the project that have generated exceptions.
Coordination Work	*Coordination work* measures the amount of time, in person-days, that all actors in a project spend attending to meetings and processing information requests from other positions.
Decision Wait Time	*Decision wait time* measures the amount of time, in person-days, that all actors in a project spend waiting for information and responses about how to handle exceptions.
Project risk (PRI)	*Project risk index* (PRI) measures the risk to quality arising from project exceptions. PRI represents the likelihood that all of the planned work components will not be integrated well by project completion, or that the integration will have residual defects based on incomplete rework and exception handling. Numerically, PRI is calculated as the fraction of effort needed to process ignored and quick-fixed project exceptions normalized by the total effort to rework all predicted project exceptions.

RESULTS

In this section, we describe the experimental results produced using the computational models and (6 x 4 x 2) experimental design outlined above. Specifically, here we evaluate emulated organizational performance for Edge and Hierarchy/Machine Bureaucracy organizations, across four experimental manipulations, under both Industrial Era and 21st Century conditions. Results are summarized in Table 5 in terms of the seven-variable, multidimensional array of performance measures summarized above. For each of the organizational forms shown in Table 5, the first column includes the seven measures that summarize and report performance under the Industrial Era conditions. The data in this column can be considered as a baseline for comparison with the 21st Century Conditions. For instance, in the case of the Industrial Era Edge scenario, simulated time and cost are 223 days and \$894M, respectively. Corresponding 21st Century values are 234 days and \$970M, representing respective increases of 5% and 9%.

Table 5 Organizational Performance

		Edge			Machine Bureacracy		
		Industrial Era	21st Century	% Change	Industrial Era	21st Century	% Change
Mission & Environ-mental Context	Time (days)	223	234	5%	229	313	37%
	Cost (\$M)	894	970	9%	1165	1621	39%
	Direct Work (k-days)	819	819	0%	830	830	0%
	Rework (k-days)	113	166	47%	135	429	218%
	Coordination (k-days)	186	227	22%	15	39	160%
	Decision Wait (k-days)	0	0	0%	62	189	205%
	PRI	0.77	0.77	0%	0.37	0.36	-3%
Network Architecture	Time (days)	223	223	0%	229	229	0%
	Cost (\$M)	894	893	0%	1165	1159	-1%
	Direct Work (k-days)	819	819	0%	830	830	0%
	Rework (k-days)	113	113	0%	135	135	0%
	Coordination (k-days)	186	184	-1%	15	11	-27%
	Decision Wait (k-days)	0	0	0%	62	60	-3%
	PRI	0.77	0.77	0%	0.37	0.36	-3%
Professional Competency	Time (days)	223	149	-33%	229	172	-25%
	Cost (\$M)	894	611	-32%	1165	871	-25%
	Direct Work (k-days)	819	819	0%	830	830	0%
	Rework (k-days)	113	81	-28%	135	100	-26%
	Coordination (k-days)	186	163	-12%	15	11	-27%
	Decision Wait (k-days)	0	0	0%	62	44	-29%
	PRI	0.77	0.77	0%	0.37	0.37	0%
All Combined	Time (days)	223	159	-29%	229	224	-2%
	Cost (\$M)	894	685	-23%	1165	1152	-1%
	Direct Work (k-days)	819	819	0%	830	830	0%
	Rework (k-days)	113	145	28%	135	315	133%
	Coordination (k-days)	186	214	15%	15	26	73%
	Decision Wait (k-days)	0	0	0%	62	143	131%
	PRI	0.77	0.77	0%	0.37	0.36	-3%

In the following subsections, we first make some comparisons across the two organizational forms, providing empirical data for comparison across theoretically distinct forms. We then discuss the relative change in performance of each form observed across the Industrial and 21st Century Eras. In turn we make comparisons across the four experimental manipulations, examining each experimental condition affects the behavior and performance of these, contrasting organizational archetypes, across the two eras. We close by summarizing the empirical results in terms of our research hypotheses.

Comparisons across Organizational Forms

The first set of observations pertains to performance of the two, contrasting organizational forms. For this we concentrate on the first manipulation row in the table (i.e., the Mission-Environmental Context) and the Industrial Era case. This represents the Baseline set of conditions for both the Edge and Hierarchy/Machine Bureaucracy organizational forms; that is, we control for the mission-environmental context, setting it at levels appropriate for the familiar Industrial Era, and vary the organizational form. This provides us with a relatively clean view of how organizational form affects performance in this context, and it enables us to compare these empirical results with theoretical predictions. These results match those reported in Nissen (2005)—albeit varying insignificantly in a few places due to rounding.

First, notice that the time required for mission performance is comparable: 223 days for the Edge and 229 for the Hierarchy/Machine Bureaucracy. However, the Edge mission cost ($894M) is roughly 25% less than that of the Hierarchy. This is due in large part to the additional overhead associated with the Machine Bureaucracy organization. Direct work represents the accomplishment of planned mission tasks, and is comparable across the two organizations. The Edge level (819K person-days) is a bit lower than that of the Hierarchy because the latter organization includes explicit Command and Coordination work (see Table 2). This corresponds in part to the additional overhead noted above. Rework measures the amount of mission work that is redone. The values reported in the table indicate that the Edge organization (113K person-days) engages in somewhat less rework than the Hierarchy (135K) does. In contrast, the Edge engages in an order of magnitude greater coordination work (186K person-days) than the Hierarchy (15K) does. This reflects directly the flat organization and highly networked, peer-to-peer communication structures associated with the Edge. In further contrast, the Edge organization incurs no decision wait time, whereas the Hierarchy reveals a sizeable amount (62K person-days). Unlike the Hierarchy, in which actors wait for supervisors to make decisions and to provide information, Edge actors make the best decisions that they can, and use the best information that they have, when called to perform their mission tasks. This accounts in part for the slightly faster mission-execution time. Finally, PRI is a mission-risk index, which quantifies the magnitude of work that would be required to correct all exceptions that were not reworked completely. The Edge (0.77) exhibits double the risk associated with mission performance by the Machine Bureaucracy (0.37).

In summary, looking across this multidimensional characterization of comparative organizational performance, neither organizational form is clearly dominant in the Industrial Era mission-environmental context. The Edge form is slightly faster and considerably less expensive than the Machine Bureaucracy is, plus it engages in less rework than the Hierarchy does, and incurs no decision wait time. Alternatively, the Edge exhibits an order of magnitude greater coordination cost and double the mission risk associated with the Hierarchy. Which one is "better" depends upon stakeholder performance preferences.

Comparisons across Eras

The second set of observations pertains to performance of the organizations across the Industrial and 21st Century Eras. For this we continue to concentrate on the first manipulation row in the table, but here we look across the two eras. Looking first at the Edge organization, notice that performance is worse across nearly every dimension. For instance, time (234 vs. 223), cost ($970M vs. $894M), rework (166 vs. 113), and coordination work (227 vs. 186) are all higher in the 21st Century Era than in the Industrial Era. Alternatively, direct work, decision wait, and risk are all unchanged for the Edge organization across eras. As predicted theoretically, the 21st Century mission-environmental context is more challenging and demanding than the Industrial Era is.

The same applies generally to the Machine Bureaucracy, but notice that performance differences across the two eras are more extreme here than reflected for the Edge organization. For instance, whereas mission time and cost extend only slightly (5%, 9%, respectively) for the Edge form, the increases for the Hierarchy are much larger (37%, 39%). Performance degradation for the Hierarchy across eras is even more extreme in terms of rework (218%), coordination (160%) and decision wait time (205%). The Machine Bureaucracy organization clearly struggles to perform in the 21st Century mission-environmental context, and hence makes the Edge form appear to be far more robust to mission-environmental change. This provides empirical support for the Edge form exhibiting greater agility than the Hierarchy does.

Comparisons across Experimental Manipulations

The third set of observations pertains to performance of the organizations across the four experimental manipulations. For this we look down the columns of the table, and we concentrate on the 21st Century Era, since this represents more of the present and future than the past. Looking first at the Edge organization, we compare its 21st Century performance reported above in the Mission & Environmental Context row with that summarized in the Network Architecture row of the table. Notice that organizational performance improves across most dimensions through this network manipulation. Indeed, all of the Edge performance values for the Network Architecture manipulation in the 21st Century Era are very close to their baseline values *in the Industrial Era*. This provides a striking contrast to results from above, in which the organization performs consistently worse in the 21st Century Era than in the Industrial Era. In essence, the network-architecture effects serve to cancel out impacts of moving to the more challenging and demanding 21st Century Era. For instance, whereas Edge performance in the 21st Century Era would degrade (e.g., to 234 days in terms of time, $970M in terms of cost) without the improved network architecture, with such architecture effects, the Edge organization becomes highly robust to the associated challenges and demands (e.g., 223 days, $893M). Although the network architecture manipulation does not improve Edge performance, *it enables the organization to sustain its performance level* even in the face of a more challenging and demanding environment. This provides empirical support for the network architecture effects enabling greater agility than the current, vertical architecture does.

These effects are even more pronounced for the Machine Bureaucracy than for the Edge organization. As above, the improved network architecture insulates the Hierarchy organization from the challenges and demands of the 21st Century environment, but recall from above how this latter organizational form struggles with the 21st Century. For instance, whereas Machine Bureaucracy performance in the 21st Century Era would degrade (e.g., to 313 days in terms of time, $1621M in terms of cost) without the improved network architecture, with such architecture effects, the Hierarchy organization becomes highly robust to the associated challenges and demands (e.g., 229 days, $1159M). Also as above, although the network architecture manipulation does not improve Machine Bureaucracy performance, it enables the organization to sustain its performance level even in the face of a more challenging and demanding environment. This provides empirical support for the network architecture effects enabling greater agility than the current, vertical architecture does, *particularly for an inherently less agile organizational form*. Here we find an insightful substitution effect: network-architecture improvements to the Hierarchy/Machine Bureaucracy can produce similar results in terms of agility as those associated with adopting the Edge organizational form. Hence a change in organizational form can be substituted to some degree for a change in network architecture, and vice versa. This represents a noteworthy, empirical result, both in terms of organization theory and C2 practice.

Looking again at the Edge organization, here we compare its 21st Century performance reported above in the Mission & Environmental Context row with that summarized for the Professional Competency manipulation. Notice that organizational performance improves dramatically across multiple dimensions through this manipulation. For instance, 21st Century Era Edge performance for the Professional Competency manipulation improves by one third to one half in terms of time (36%), cost (37%) and rework (51%). This quantifies the huge importance of organization and knowledge flows in terms of performance. Notice also that 21st Century Era Edge performance for the Professional Competency manipulation is *better than baseline Edge performance in the Industrial Era*. Even stronger than the insulating effect described above in terms of the Network Architecture manipulation—through which performance does not degrade in the more challenging and demanding 21st Century Era—improving professional competency makes the Edge organization even better in the 21st Century Era than in the Industrial Era. This provides empirical support for the professional competency effects enabling much, much greater agility—and much better organizational performance—than the current, efficiency-oriented approach to organization and knowledge flows does.

Also as above in the Network Architecture manipulation, these effects are even more pronounced for the Machine Bureaucracy than for the Edge organization. The improved professional competency enables even more dramatic performance improvements (e.g., 45% in terms of time, 46% in terms of cost, 77% in terms of rework, 72% in terms of coordination, 77% in terms of decision wait time) for the Hierarchy organization than for the Edge. Also as above, the professional competency manipulation enables the organization to improve its performance level even in the face of a more challenging and demanding environment. This provides empirical support for the professional competency effects enabling greater agility than the current, efficiency-oriented approach does, *particularly for an inherently less agile organizational form*. Here we find an insightful *hyper*-substitution effect: professional competency improvements to the Hierarchy/Machine Bureaucracy can produce even more dramatic results in terms of agility as those associated with adopting the Edge organizational form. Hence a change in professional competency can be substituted to a large degree for a change in organizational form. Unlike the substitution effects noted above for the network architecture manipulation, however, the converse does not hold for professional competency: changing organizational form does not compensate for a reversion to an efficiency-oriented organization and knowledge-flow approach. This represents another noteworthy, empirical result, both in terms of organization theory and C2 practice.

Finally, we look at the fourth, aggregate manipulation, which combines all the effects of all three manipulations discussed above. Because the professional competency manipulation exerts the greatest effects on organizational performance—for the Edge and Hierarchy/Machine Bureaucracy alike—this aggregate manipulation reflects the values of its professional competency counterpart closely. However, the results exhibit some interaction effects between the three manipulations, in which combining all three manipulations together actually *degrades* performance a bit when compared with only the professional competency effects, for instance. This signals that the organizational scholar needs to conduct additional research to understand such interaction effects better, and that the C2 practitioner needs to be judicious about combining effects. Nonetheless, when all manipulations are combined, both the Edge organization and its Hierarchy counterpart perform considerably better in the 21st Century Era than in the Industrial Era, and both become much more agile and robust to the challenges and demands of the 21st Century Era. Hence one can argue that C2 leaders and policy makers should pursue the kinds of manipulations in practice that we examine through our computational experimentation here.

Support for Research Hypotheses

The final set of observations pertains to support for the research hypotheses developed by Nissen (2005) and summarized above. We repeat these hypotheses here for reference, and address each in turn.

Hypothesis 0. Edge organizations can outperform Hierarchy organizations in demanding mission environmental contexts. This, null hypothesis demands an omnibus assessment of Edge and Hierarchy/Machine Bureaucracy organizational performance across eras. As noted above, the Edge organization outperforms the Hierarchy in the 21st Century Era, and its agility enables it to be more robust to demanding mission-environmental changes. This provides good support for the hypothesis.

Hypothesis 1. "Power to the Edge is the correct response to the increased uncertainty, volatility, and complexity associated with [21st century] military operations" [p. 6]. As noted above, our Mission & Environmental Context manipulation addresses this hypothesis in part, and results above in terms of comparisons across eras provides considerable support for this hypothesis. The Edge organization exhibits considerably greater agility, and hence is more robust to the challenges and demands of the 21st Century Era than the Hierarchy is.

Hypothesis 2. "The correct C2 approach depends on [five] factors": 1) shift from static/trench to mobile/maneuver warfare; 2) shift from cyclic to continuous communications; 3) volume and quality of information; 4) professional competence; and 5) creativity and initiative [p. 19]. As noted above, our Network Architecture manipulation addresses this hypothesis in part, and the Professional Competency manipulation addresses it too. If we look to the Aggregate manipulation above, we see that improving the network architecture and enhancing professional competency improves organizational performance considerably, for the Edge and Hierarchy alike. Hence this hypothesis is supported for multiple (i.e., at least two) organizational forms.

Hypothesis 3. "Given a robustly networked force, any one of the six effective command and control philosophies proven useful in the Industrial Era is possible" [p. 32]. As noted above, our Network Architecture manipulation addresses this hypothesis in part, as we find evidence that improving network architecture increases organizational agility, and makes the organization more robust to challenges and demands of the 21st Century Era. However, our computational models do not represent each of six different C2 philosophies explicitly; hence our support for this hypothesis is limited.

Hypothesis 4. People who work together, over time, and learn to operate in a "post and smart-pull" environment, will outperform similarly organized and capable people who do not. As noted above, our Professional Competency manipulation addresses this hypothesis in large part, but the Network Architecture manipulation plays some role too (e.g., post and smart-pull environment). If we focus on professional competency effects, which include people working together over time, we find substantial support for this hypothesis.

Hypothesis 5. "The more uncertain and dynamic an adversary and/or the environment are, the more valuable agility becomes" [p. 124]. As noted above also, our Mission & Environmental Context manipulation addresses this hypothesis in part, and results above in terms of comparisons across eras provide considerable support for this hypothesis. The Edge organization exhibits considerably greater agility, and hence is more robust to the uncertainties and dynamics of the 21st Century Era than the Hierarchy is.

Hypothesis 6. "An organization's power can be increased without significant resource expenditures" [p. 172]. This hypothesis is difficulty to assess via our computational results, for we do not represent resource expenditures explicitly, nor do we have variables to measure *power*. Indeed, the kinds of network architecture effects represented in our model demand huge resource investments in global communications infrastructure. Such investments provide some evidence against this hypothesis. Alternatively, the kinds of professional competency effects represented in our model do not demand large resource investments, as simply changing organizational policy to reduce job and personnel turnover can bring about considerable improvements in knowledge flows—and in turn organizational performance.

In addition, we draw two further hypotheses, based on the organizational ecologist perspective (e.g., see Nelson and Winter 1982).

Hypothesis 7: Of all the organization forms, the Machine Bureaucracy will have experienced the greatest relative decline in performance over the past century. This hypothesis is designed to examine a multitude of diverse organizational forms, not just the two examined here, so assessing the level of support for it will have to wait until we have examined all six of the forms discussed above through our campaign of computational experimentation. In terms of just the Edge and Hierarchy/Machine Bureaucracy forms, however, our results provide some support for this hypothesis.

Hypothesis 8: Of all the organization forms, the Edge organization will have displayed the greatest relative increase in performance over the past century. The rationale and explanation presented to address Hypothesis 7 above applies to Hypothesis 8 also.

CONCLUSION

The *Edge* represents a fresh approach to organizational design. It appears to be particularly appropriate in the context of modern military warfare, but also raises issues regarding comparative performance of alternate organizational designs. Building upon prior C2 research, we seek to understand the comparative performance of the Edge and *all* organizational forms, across 21st Century and *all* mission-environmental conditions, and hence characterize the entire *organization design space* systematically. Leveraging recent advances in computational organization theory, we extend our campaign of experimentation to specify six, diverse, archetypal organizational forms from theory, and to evaluate their comparative performance empirically.

Results confirm the contingency-theoretic maxim that no single organizational form is "best" for all circumstances. However, they also highlight the kinds of contingent circumstances for which the Edge and other kinds of organizations perform relatively better than one another, and they elucidate seven specific performance measures that provide multidimensional insight into different aspects of organizational performance. Indeed, we find that the Edge outperforms the Hierarchy/Machine Bureaucracy in terms of some measures, but is outperformed in terms of others. Alternatively, as predicted, our empirical results reveal that the Edge form exhibits considerable *agility*, capable of resisting performance degradation—and with some improvements such as in professional competency to achieve performance enhancement—even when encountering the challenging and demanding mission-environmental context associated with the 21st Century Era.

This research makes a contribution by grounding the Edge organization firmly in well-established organization theory, providing theoretical characterization of the Edge for the first time, and enabling organization scholars and C2 practitioners to engage in mutually informed discussion. This research also makes a contribution by providing empirical support both for and against claims regarding this novel organizational form, elaborating dynamic behaviors and performance impacts of the Edge. Of particular theoretical and practical interest are the substitution and hyper-substitution effects demonstrated across experimental manipulations. Toward the former, we find that organization form and network architecture improvements are substitutable for one another in terms of making the organization robust to mission-environmental changes. This offers theoretical insight into substitution effects, and it provides practical guidance for the C2 leader and policy maker interested in organizational design and change. Toward the latter, we find that professional competency improvements are hyper-substitutable in terms of organizational form and network architecture in this regard, enhancing performance even through mission-environmental changes. This offers theoretical insight and practical guidance also.

In terms of practical guidance, the C2 leader and policy maker should pursue improvements in network architecture to the extent that resources permit, for this improves organizational agility, but he or she should also pursue organizational change toward the Edge form, particularly where the challenges and demands of the current mission-environmental context diverge substantially from those faced during the Industrial Era. Likewise, the C2 leader and practitioner should pursue improvements in professional competency also, with an added bonus of being able to effect such improvements without large resource investments. Indeed, results suggest that organizational change as simple as reducing job and personnel turnover may produce stunning performance gains. However, the leader and policy maker should be judicious about pursuing all of the organizational changes examined in this study at the same time. The various experimental manipulations reveal interactions that are not immediately clear, but which combine to impact organizational performance negatively. More research into such interactions is warranted.

In terms of continued research, we have established solid and well-articulated computational models of the Edge and Hierarchy/Machine Bureaucracy organizations, which other researchers can use to continue this campaign of experimentation. Indeed, we propose that all C2 researchers compare the structure and behavior of their computational models to these, using our models as standards for analysis. This can provide the C2 Research Community with known and understood baselines for comparison. Additionally, we have conducted multiple experiments on these organizations, across four experimental manipulations, and across two mission-environmental contexts and historical eras. This provides a foundation on which other researchers can build to test other manipulations of theoretical and practical interest. Further, we have specified four additional, classic, archetypal organizational forms from the literature, which need to be tested along side of the forms examined in this present study. This represents the primary focus of our next set of computational experiments, as we continue the cumulative accretion of new knowledge through research. If we are successful, and elaborate the entire organizational design space via computational experimentation, we will produce the first, comprehensive map of contingent organizational performance, which will likely be heralded as a seminal research contribution.

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Appendix I – Model Parameter Definitions

In this appendix, we both paraphrase and quote from [SV online help] to include definitions of the model elements and parameters that are discussed above and applicable to the computational experimentation reported in this study.

Activity - See Task.

Actor - See Position.

Application experience - A measure of how familiar the position or person is with similar projects.

Behavior file - A file that specifies the simulator's default behavior, such as how much rework to add to tasks with exceptions.

Centralization - A measure of how centralized the decision - making is in a project. For example, high centralization indicates that most decisions are made and exceptions handled by top managerial positions such as the Project Manager. Low centralization means decisions are made by individual responsible positions.

Communication - The passing of information between positions about tasks.

Communications link - A dashed green link that links two tasks, indicating that the position responsible for the first task must communicate with the other position during or at the completion of the first task.

Coordination - A combination of the information exchange generated by communication and meetings.

Coordination Volume - The predicted time during a project or program that all positions spend at meetings and processing information requests from other positions.

Critical path - The set of tasks in a project that determine the total project duration. Lengthening any of the tasks on the critical path lengthens the project duration.

Decision wait time - The time a position waits for a response from the supervisor about how to handle an exception, plus any time the position waits for exception resolution before making the decision by default. See also Wait Volume.

Exception - A situation detected by the simulator where part of a task requires additional information or a decision, or generates an error that may need correcting.

Exception handling - Involves positions reporting exceptions to supervisors and supervisors making decisions on how to deal with the exceptions.

Failure dependency link - See Rework link.

Formalization - A measure of the formality of communication in an organization. For example, high formalization indicates that most communication occurs in formal meetings.

FRI (Functional Risk Index) - A measure of the likelihood that components produced by a project have defects. Also called CQI, or Component Quality Index.

Full - time equivalent (FTE) - A measure of position or person availability to perform a task. For example, a position with an FTE value of 3 has the equivalent of 3 full - time employees to perform tasks.

Functional exception - An error that causes rework in a task but does not affect any dependent tasks.

Links - A set of color - coded arrows that represent the relationships between shapes.

Matrix Strength - A measure of the level of supervision in a project or program, and a reflection of the structure of the organization. Low matrix strength means that positions are located in skillbased functional departments and supervised directly by functional managers. High matrix strength means positions are co-located with other skill specialists in dedicated project teams and have project supervision from a Project Manager.

Meeting - A gathering of positions to communicate about the project and project tasks.

Meeting Participant link - A dashed grey line that links a position to a meeting, indicating that the position must attend the meeting.

Milestone - A point in a project or program where a major business objective is completed.

Model - A visual representation of a program and its projects.

Noise - The probability that a position is distracted from assigned tasks.

Organization - A group of departments that staff a program or project.

Organization Assignment link - A solid pink line that links an organization to a project within a program.

PM - Project Manager, the position that assumes overall responsibility for a project.

Position - An abstract group representing one or more FTEs (full - time equivalents) that performs work and processes information. In a staffed project, positions represent a person or a group of persons.

PRI (Project Risk Index) - A measure of the likelihood that components produced by a project will not be integrated at the end of the project, or that the integration will have defects. PRI is thus a measure of the success of system integration.

Primary Assignment link - A solid blue line that links a position to a primary task, which is a task that takes priority over any secondary assignments.

Program - A set of related projects that share dependencies and together achieve the client's business objectives. A program also includes the associated responsible organizations, milestones, and relationships between projects.

Project - A project represents work an organization must perform to achieve a major business milestone. The work is represented by tasks, milestones, the positions that perform tasks, meetings, and the dependencies between all these elements. While a model may contain numerous projects, it need only contain one. Each project in a model supports the goal of the program to which the project belongs.

Project exceptions - Errors that might cause rework in a driver task and all its dependent tasks.

Project Exception Rate - The probability that a subtask will fail and generate rework for failure dependent tasks. This probability is generally in the range 0.01 (low) to 0.10 (significant, but common). If the Project Exception Rate is greater than about 0.20, so much rework can be generated that the project may never finish.

Project Successor link - A solid black line that links a project to another project or to a project milestone.

Rework - Redoing all or part of a task. Compare with direct work.

Rework Cost - The predicted cost of rework, or rework volume weighted by average cost per FTE of positions that do rework.

Rework link - A dashed red line that links a task to a dependent task that will need rework if the driver task fails.

Rework Volume - The predicted time needed for all positions on a project to do the required rework.

Scenario - See Case.

Secondary Assignment link - A dashed blue line that links a position to a secondary task, which is a task that can be worked whenever the position is not working on a primary task.

Simulator - Software that simulates the work done by positions as they perform individual project tasks, including both planned direct work and coordination and rework.

Simulation charts - Charts that summarize and provide details of the simulated performance of the program and the individual modeled projects.

Successor link - A solid black line that links milestones and tasks.

Supervision link - A solid black line that links a supervisory position to its supervised position.

Task - Any work that consumes time, can generate communications or exceptions, and is required for project completion.

VFP (Verification Failure Probability) - The probability that an exception will be generated for a task. The VFP is calculated during simulation based on a number of factors, including noise, communication rates, and team experience.

Wait Volume - A measure of the cumulative time spent by positions waiting for decisions to be made in a project.

Work volume - The predicted time that all positions on a project spend doing direct work.