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Hypothesis Testing of Edge Organizations: Modeling the C2 Organization Design Space

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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 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*. Additionally, through organizational modeling and analysis, we articulate an organization design space for the first time. 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

Recent advances in computational organization theory (e.g., see Burton et al. 2002, Carley and Lin 1997, Levitt et al. 1999, Lomi & Larsen 2001) and computational social science (see NAACSOS 2007) offer promising potential to test the performance of different organizational forms in a variety of mission-environmental contexts. 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. 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 2005b). Moreover, mission-environmental contexts are not manipulated easily in the field, and laboratory experiments are limited generally to micro-level organizational phenomena.

The present paper represents part four in our campaign of experimentation, which began with a paper presented at the 2004 CCRTS conference (Nissen and Buettner 2004). In that paper, the relative advantages and disadvantages of computational experimentation were presented, and this, computational research method was described in terms of a complementary, empirical approach. The 2005 ICCRTS paper followed (Nissen 2005a), in which more than 25, diverse organizational forms were compared and analyzed, and the *Edge* organization form was shown to be theoretically distinct and uniquely differentiated from other organization forms described by prior investigators. This 2005 paper also offered a theoretical discussion and set of hypotheses about the performance of *Edge* and *Hierarchy* organization forms under different mission-environmental conditions, and provided insight into relative characteristics and behaviors of *Hierarchy* and *Edge* organizations. Then in our 2006 ICCRTS paper (Orr and Nissen 2006), we expanded the study to specify and model four other, classic, theoretically grounded organization forms: *Simple Structure*, *Professional Bureaucracy*, *Divisionalized Form*, and *Adhocracy* (Mintzberg 1979, 1980). We also employed computational experimentation to compare and contrast empirically the relative performance of *Hierarchy* and *Edge* organizational forms, using a multidimensional set of performance measures, under the mission-environmental conditions at two different points in history: the *Industrial Era*, and the *21st Century*.

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 are clearly not exhaustive, by including a diversity of classic organizational archetypes from theory, and examining them across both current and contrasting 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. Hence this research is empirical in nature, and targets theoretical development as well as practical application. This represents the focus of the present paper: we employ computational experimentation to examine the relative, multidimensional performance of all six,

theoretically distinct organizational forms, across four experimental manipulations, in both the Industrial Era and the 21st Century scenarios. The following section presents theoretical background and hypotheses, after which we describe our computational model, present the results, and draw final conclusions.

BACKGROUND

Drawing heavily from Orr and Nissen (2006), we begin by summarizing briefly Mintzberg's (1979, 1980) classic, archetypal organization forms, the Edge organization, and the seven hypotheses developed in the first part of this research effort (Nissen 2005a). We then outline background information pertaining to computational modeling.

Organizational Archetypes and Edge Hypotheses

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. These five, archetypal organization forms are broadly applicable, mutually distinct, and derived from both theory and practice. Hence they are representative of many contemporary organizations observable in practice today, and many of the emerging organizational forms (e.g., strategic alliances, networked firms, Edge organizations) can be analyzed as hybrids through consideration of their separate parts, mechanisms, parameters and factors.

Indeed, we show (see Nissen 2005a, Orr and Nissen 2006) 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 it does not correspond cleanly with any single archetype (e.g., it is characterized as an hybrid *Professional Adhocracy*—a combination of archetypes). 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, the Edge organization shares almost no similarities with the Machine Bureaucracy (cf. high training and indoctrination), the latter to which we refer interchangeably as “Hierarchy.”

Finally, we revisit and recapitulate the key hypotheses developed through our prior research, which are rooted in current Edge “theory”. This sets the stage for computational experimentation. The key Edge hypotheses are restated below for reference (see Nissen 2005a for derivation and discussion).

Hypothesis 0. Edge organizations can outperform Hierarchy organizations in demanding mission environmental contexts.

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].

Computational Modeling

In this section we discuss computational organization theory and computational social science briefly, and we draw directly 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 and Social Science Research. Computational Organization Theory (COT) and Computational Social Science (CSS) are emerging, multidisciplinary fields that integrate 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 phenomenon (Carley and Hill 2001: 87).

Our COT/CSS research builds 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 the 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. Such virtual prototypes also enable us to take great strides beyond relying upon the kinds of informal and ambiguous, verbal, natural-language descriptions that comprise the bulk of organization theory today. For instance, in addition to providing textual description, 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 micro-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, when modeling aggregations of people, such as work groups, departments, or 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 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 in Jin and Levitt (1996), has three key implications.

Table 1 Model Elements and Descriptions (adapted from Orr and Nissen 2006)

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. VDT offers three types of successor links: finish-start, start-start and finish-finish.
Rework links	Similar to successor links because they connect one task (called the <i>driver</i> task) with another (called the <i>dependent</i> 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. In VDT, the supervision structure (also called the <i>exception-handling hierarchy</i>) represents a hierarchy of positions, defining who a subordinate would go to for information or to report an exception.

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.

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.

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).

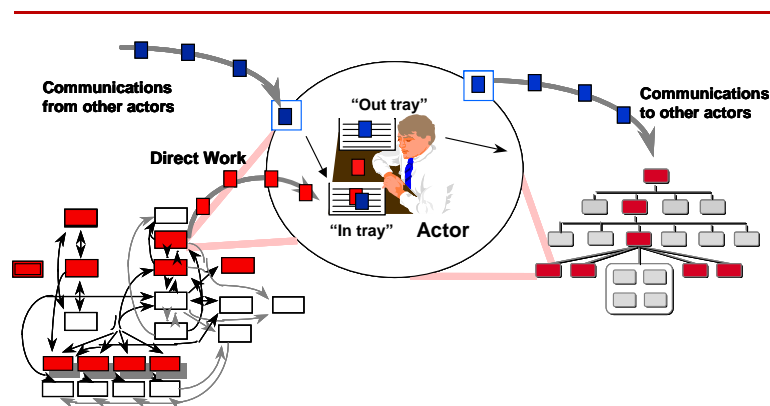


Figure 1 Information Processing View of Knowledge Work

The third implication is validational: 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). As such, ours is one of the few, implemented, computational organization modeling environments that has been subjected to such a thorough, multi-method trajectory of validation.

RESEARCH DESIGN

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.

Model Formulation – Organization Forms

Table 2 shows how this modeling environment is used to formulate models of the 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 2005a, Orr and Nissen 2006); the Mintzberg design parameters derive directly from Mintzberg (1980); and the model parameters derive directly from our computational models. These latter parameters are specified precisely to represent each of the diverse organizational archetypes noted above. Notice that each organizational archetype consists of a unique combination of parameter settings in our computational models.

Table 2 Model Formulation – Organization Forms

Structural Factor	Mintzberg Design Parameter	Model Parameter	Edge	Machine Bureaucracy	Simple Structure	Prof. Bureaucracy	Divisional 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
	"	Operating Core Role	ST	ST	ST	ST	ST	ST
	"	Holding Company (PM)	0	0	0	0	3	0
	"	Command Position (PM)	0	3	3	3	3	0
	"	Coordination Position (SL)	0	200	0	0	225	0
	"	Operations Position (ST)	13,000	13,000	13,000	13,000	13,000	13,000
	Size	# of Total FTEs	13,000	13,203	13,003	13,003	13,231	13,000
	Unit Size	# of FTEs per Unit	813	1650	2601	765	778	813
	N/A	# of Units	16	8	5	17	17	16
	Training	Skill Level	Med	Med	Med	Med	Med	Med
	Communication Structure	Indoctrination	App. Experience ^{1,2}	Med	High	Med	High	High
"		Team experience	Med	Low	Low	Med	Low	Low
Communication Structure	Liaison Devices	Communication Links	Many	Few	Some	Many	Few	Many
	"	Information Exchange ¹	0.9	0.1	0.1	0.3	0.1	0.9
Work Structure	Planning & Control Systems	Meetings	No Meetings	2 hrs/day (staff) ⁴	2 hrs/week (10% ops) ⁵	2 hrs/month (10% ops) ⁵	2 hrs/day (staff) ⁴ , 2 hrs/week (top mgmt)	No Meetings
	"	Matrix Strength	High	Low	Low	Med.	Low	High
	"	App. Experience ³	Add 1 level	Subt 1 level	Same level	Same level	Subt 1 level	Same level
	N/A ⁶	Number of Operational Tasks	16	4	4	16	4	16
	"	Degree of Concurrency	Massive Concurrency	Sequential, 2 Phase	Sequential, 2 Phase	Massive Concurrency	Sequential, 2 Phase	Massive Concurrency
	"	Interdependence	High	Low	Low	High	Low	High
	"	Rework Links	Many	Some	Some	Many	Some	Many
Work Structure	"	Rework Strength	0.1	0.3	0.3	0.1	0.3	0.1
	Environment - Complexity	FEP/PEP	0.2	0.1	0.1	0.2	0.1	0.2

¹ This parameter has two aspects: indoctrination and planning & control systems.

² The indoctrination aspect of this parameter reflects the organization's familiarity with its environment.

³ The planning & control systems aspect of this parameter reflects the organization's information processing environment; adjustment wrt indoctrination value.

⁴ These meetings are between the Commander and Staff members.

⁵ These meetings are between the Leader(s) and 10% of Operational Core members.

⁶ Mintzberg does not explicitly address "work structure" in his paper.

Parameter settings for the Edge and Machine Bureaucracy (i.e., equivalent to the Hierarchy in our prior article) replicate those reported in Nissen (2005a) very closely, hence we concentrate here on extensions to the additional archetypal forms. Parameter settings for the Simple Structure, Professional Bureaucracy, Divisionalized Form, and Adhocracy are comparable overall with those developed by Orr and Nissen (2006), but they reflect some, relatively minor adjustments that enhance the level of consistency across forms. The interested reader can consult this prior work for discussion of and rationale for the parameter settings, and we include Appendix A to this article to summarize them for easy reference. We summarize the model formulations here in Table 2. Even close examination of the table indicates how these model formulations mirror theory very closely. Hence we present a theoretically grounded model formulation of six, distinct, organizational forms with relevance to C2.

Model Manipulations – 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 the research hypotheses from above, and hence provide a principal basis for experimentation. Using our computational modeling tools, each manipulation can be conducted independently to isolate separate effects, or can be 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. In design terms, this represents a *full factorial, 6 x 4 x 2 experiment* (i.e., 6 archetypes, 4 manipulations, 2 scenarios). As above, the interested reader can consult our prior work for details, and we include Appendix B to this article to summarize them for easy reference.

Table 3 Model Manipulations – 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 2	Baseline + 0.1
	PEP	Baseline in Table 2	Baseline + 0.1
	App. Experience	Baseline in Table 2	Baseline - one level ^d
Network Architecture (P2, 3)	Noise	0.3 ^b	0.01
	Info. Exchange Prob.	Baseline in Table 2	Baseline + 0.3 ^b
	Communication links	Baseline	Baseline for Edge; more for Hierarchy ^e
	Organization settings ^c	Baseline for Hierarchy; opposite for Edge	Baseline for Edge; opposite for Hierarchy
Professional Competency (P2, 4)	App. Experience	Baseline in Table 2	Baseline in Table 2
	Skill Level	Baseline in Table 2	Baseline + one level
	Team Experience	Baseline in Table 2	Baseline + one level
Aggregate (P1 - 6)	All of the above	All of the above	All of the above

Model Measurement – Dependent Variables

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

Table 4 Model Measurement – Dependent Variables

Dependent Variable	Parameter Description
Time	<i>Time</i> (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	<i>Cost</i> (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	<i>Direct work</i> 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	<i>Rework</i> 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	<i>Coordination work</i> 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	<i>Decision wait time</i> 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.
Maximum Backlog	<i>Maximum Backlog</i> measures the number of days' work that an organizational actor has backlogged; that is, it measures the degree to which an actor is behind schedule. A backlog of one day would represent an actor that is fully busy but not behind.
Product 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 defe

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 Machine Bureaucracy, Edge, Simple Structure, Professional Bureaucracy, Divisionalized Form and Adhocracy organizations, subject to the four experimental manipulations, under both Industrial Era and 21st Century conditions. In the following subsections, we first provide some empirical data for comparison across theoretically distinct forms. We then make comparisons down the four experimental manipulations, examining how the different experimental conditions affect the behavior and performance of these organizational archetypes. We summarize the empirical results in terms of our research hypotheses subsequently. We then discuss the organization design space as a whole.

Table 5 Organizational Performance under Industrial Era & 21st Century Conditions

		Machine Bureaucracy			Edge			Simple Structure			Professional Bureaucracy			Divisionalized Form			Adhocracy		
		Industrial Era	21st Century	% Change	Industrial Era	21st Century	% Change	Industrial Era	21st Century	% Change	Industrial Era	21st Century	% Change	Industrial Era	21st Century	% Change	Industrial Era	21st Century	% Change
Mission & Environmental Context	Time (days)	161	313	94%	150	220	47%	168	375	123%	154	342	122%	157	308	96%	346	446	29%
	Cost (\$M)	822	1625	98%	655	972	48%	837	1940	132%	603	1537	155%	795	1568	97%	1340	1816	36%
	Direct Work (k-days)	830	830	0%	819	819	0%	824	824	0%	819	819	0%	829	829	0%	819	819	0%
	Rework (k-days)	113	429	280%	131	168	28%	145	645	345%	157	520	231%	94	391	316%	190	194	2%
	Coordination (k-days)	13	40	208%	185	227	23%	31	103	232%	48	371	673%	15	49	227%	234	245	5%
	Decision Wait (k-days)	70	193	176%	0	0	0%	47	225	379%	55	212	285%	57	168	195%	0	0	0%
	Max Backlog (days)	18	28	56%	11	16	45%	9	28	211%	13	32	146%	19	30	58%	15	20	33%
	PRJ	0.39	0.36	-8%	0.77	0.78	1%	0.31	0.30	-3%	0.35	0.57	63%	0.47	0.45	-4%	0.77	0.77	0%
Network Architecture	Time (days)	161	209	30%	150	138	-8%	168	284	69%	154	176	14%	157	331	111%	346	298	-14%
	Cost (\$M)	822	811	-1%	655	609	-7%	837	1471	76%	603	839	39%	795	813	2%	1340	1260	-6%
	Direct Work (k-days)	830	830	0%	819	819	0%	824	824	0%	819	819	0%	829	829	0%	819	819	0%
	Rework (k-days)	113	103	-9%	131	81	-38%	145	596	311%	157	254	62%	94	120	28%	190	141	-26%
	Coordination (k-days)	13	29	123%	185	162	-12%	31	228	635%	48	241	402%	15	35	133%	234	204	-13%
	Decision Wait (k-days)	70	50	-29%	0	0	0%	47	194	313%	55	92	67%	57	32	-44%	0	0	0%
	Max Backlog (days)	18	24	33%	11	12	9%	9	17	89%	13	16	23%	19	44	132%	15	16	7%
	PRJ	0.39	0.47	21%	0.77	0.77	0%	0.31	0.36	16%	0.35	0.57	63%	0.47	0.63	34%	0.77	0.78	1%
Professional Competency	Time (days)	161	102	-37%	150	103	-31%	168	107	-36%	154	109	-29%	157	101	-36%	346	230	-34%
	Cost (\$M)	822	516	-37%	655	463	-29%	837	528	-37%	603	438	-27%	795	510	-36%	1340	986	-26%
	Direct Work (k-days)	830	830	0%	819	819	0%	824	824	0%	819	819	0%	829	829	0%	819	819	0%
	Rework (k-days)	113	78	-31%	131	55	-58%	145	95	-34%	157	100	-36%	94	64	-32%	190	119	-37%
	Coordination (k-days)	13	9	-31%	185	141	-24%	31	20	-35%	48	68	42%	15	11	-27%	234	191	-18%
	Decision Wait (k-days)	70	31	-56%	0	0	0%	47	27	-43%	55	20	-64%	57	31	-46%	0	0	0%
	Max Backlog (days)	18	10	-44%	11	10	-9%	9	6	-33%	13	8	-38%	19	12	-37%	15	15	0%
	PRJ	0.39	0.34	-13%	0.77	0.77	0%	0.31	0.31	0%	0.35	0.57	63%	0.47	0.48	2%	0.77	0.78	1%
All Combined	Time (days)	161	288	79%	150	148	-1%	168	430	156%	154	238	55%	157	463	195%	346	315	-9%
	Cost (\$M)	822	1133	38%	655	684	4%	837	2202	163%	603	1135	88%	795	1133	43%	1340	1335	0%
	Direct Work (k-days)	830	830	0%	819	819	0%	824	824	0%	819	819	0%	829	829	0%	819	819	0%
	Rework (k-days)	113	291	158%	131	144	10%	145	1000	590%	157	457	191%	94	282	200%	190	183	-4%
	Coordination (k-days)	13	47	262%	185	214	16%	31	357	#####	48	381	694%	15	81	440%	234	237	1%
	Decision Wait (k-days)	70	123	76%	0	0	0%	47	370	687%	55	187	240%	57	93	63%	0	0	0%
	Max Backlog (days)	18	36	100%	11	14	27%	9	28	211%	13	23	77%	19	64	237%	15	17	13%
	PRJ	0.39	0.46	18%	0.77	0.78	1%	0.31	0.36	16%	0.35	0.57	63%	0.47	0.63	34%	0.77	0.77	0%

Comparisons across Organizational Forms

For each of the organizational forms shown in Table 5, the first column includes the eight 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 each of the 21st Century manipulations. For instance, in the case of the Industrial Era Machine Bureaucracy scenario—which represents the overall baseline for comparison, since this is the predominant C2 organizational form today—simulated time and cost are 161 days and \$822M, respectively.

The first set of observations pertains to performance of the various organizational forms in the Industrial Era case; 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. Results in the table match those reported by Nissen (2005) and Orr and Nissen (2006)—varying somewhat due to minor model refinement. We begin by recapitulating the contrast between the Machine Bureaucracy and Edge forms, and then expand the discussion to address the full slate of archetypes, first in the Industrial Era mission-environmental context and then in its 21st Century counterpart.

Industrial Era. First, notice that the time required for mission performance is comparable for the Machine Bureaucracy and Edge forms (161 vs. 150 days) in the Industrial Era. However, the Edge mission cost (\$655M) is roughly 20% less than that of the Machine Bureaucracy. 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 Machine Bureaucracy, 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 due to

errors and exceptions. The values reported in the table indicate that the Edge organization (131K person-days) engages in somewhat more rework than the Machine Bureaucracy (113K) does. In contrast, the Edge engages in an order of magnitude greater coordination work (185K person-days) than the Machine Bureaucracy (13K) 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 Machine Bureaucracy reveals a sizeable amount (70K person-days). Unlike the Machine Bureaucracy, 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 and lower cost. Maximum backlog for the Edge organization (11 days) is less than that for the Machine Bureaucracy (18 days), indicating that the Commander in the Machine Bureaucracy gets several weeks behind at the peak. 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 (0.39).

Looking now across the other organizational forms, notice that time in this Industrial Era mission-environmental context is roughly comparable across all forms except for the Adhocracy. Specifically, the Simple Structure (168), Professional Bureaucracy (154) and Divisionalized Form (157) are all within 10% of the Machine Bureaucracy (161) time, whereas the Adhocracy (346) is more than double. In terms of time, most organizational forms appear to fit the Industrial Era relatively well, but the Adhocracy clearly represents a poor choice in terms of form in this context. The Edge (150) remains the fastest organizational form, but it is followed closely by the Professional Bureaucracy (154) and Divisionalized Form (157). In terms of cost, we observe greater variation across the forms. The Professional Bureaucracy (\$603M) is roughly 10% less expensive than the Edge form (\$655M) is, followed by the Divisionalized Form (\$795M), Machine Bureaucracy (\$822M) and Simple Structure (\$837M), with the Adhocracy (\$1340M) performing most poorly among the six forms.

The other results summarized in the table highlight different dimensions of performance across the various organizations. For instance, notice that the Edge form has the lowest decision wait time. Indeed, the Edge value (0 person-days) reveals that *no time* is wasted waiting for decisions and information from supervisors. The Adhocracy shares this aspect of organizational behavior. In contrast, the Simple Structure (47), Professional Bureaucracy (55) and Divisionalized Form (57) all reflect considerable decision wait time, and the Machine Bureaucracy (70) shows the worst performance across the six organizational forms with respect to this dimension. For another instance, The Edge (0.77) and Adhocracy (0.77) both reflect very high risk in terms of PRI, whereas all of the other forms show considerably lower risk.

To summarize, looking across this multidimensional characterization of comparative organizational performance, none of the six organizational forms is clearly dominant in the Industrial Era mission-environmental context. The Edge form, for instance, is the fastest in terms of time, and is one of the least expensive forms, reflecting zero decision wait time, but it reflects the highest risk level of all forms. Which one is “better” depends upon stakeholder performance preferences.

21st Century. Look next at 21st Century performance across the organizational forms. The Edge (220 days) reflects the fastest organizational form, and unlike in the Industrial Era above, the other forms are considerably slower than the Edge is. Hence the Edge appears to be relatively robust to environmental change when compared to the other forms, at least in terms of the performance dimension *time*. The Edge reflects the best performance across forms in terms of cost (\$972M) as well, with all of the other forms above the \$1.5B level in this more demanding, 21st Century mission-environmental context. A key part of the Edge form’s robustness can be seen via the third column labeled “% change” for the six forms. Whereas Edge performance degrades by roughly 20 – 50% across the shift from Industrial Era to 21st Century conditions, most of the other organizational forms experience performance degradation of 100% or more, across multiple performance dimensions. Alternatively, Edge performance in terms of risk remains very high (0.78) when compared to the other organizational forms.

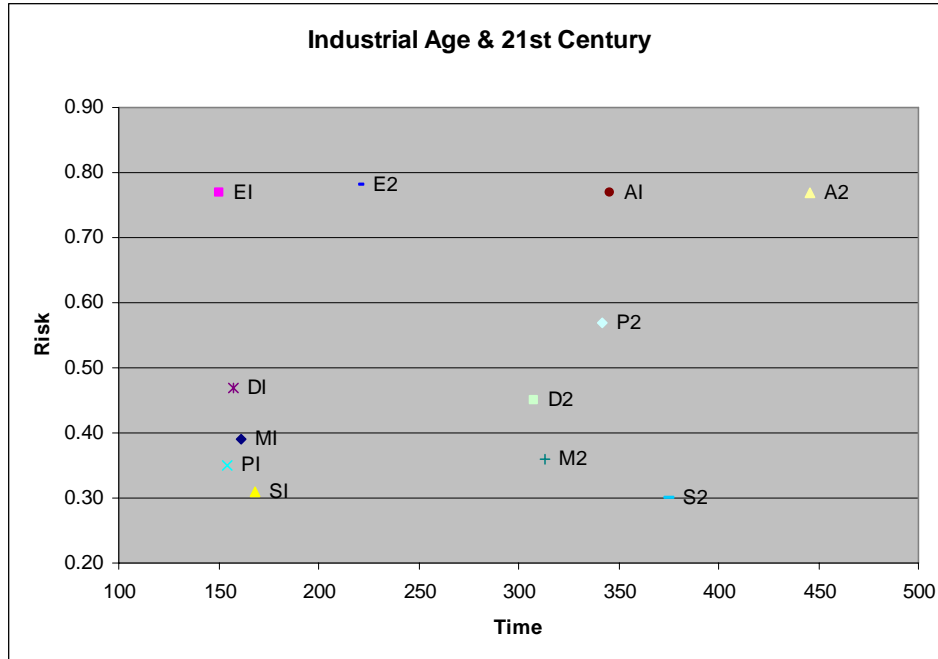


Figure 2 Time-Risk Performance Summary across Forms & Eras

This can be viewed clearly via the graph presented in Figure 2. This graph depicts comparative organizational performance in terms of the dimensions *time* (horizontal axis) and *risk* (vertical axis), for all six organizational forms, across the Industrial Era and 21st Century cases. The performance plot point for each organization is labeled for easy visual reference. For instance, the Machine Bureaucracy is labeled “MI” in the Industrial Era and “M2” in the 21st Century case; the Edge is labeled “EI” in the Industrial Era and “E2” in the 21st Century case; and so forth for the other forms (i.e., “SI” & “S2” for Simple Structure, “PI” & “P2” for Professional Bureaucracy, etc.). These plot points correspond directly to the performance results summarized in Table 5.

Notice how performance points for four forms (i.e., “MI,” “SI,” “PI,” “DI”) cluster in the lower-left corner of the graph: performance in the Industrial Era is quite comparable across these four organizational forms. In contrast, and as observable via the table, performance of the Edge and Adhocracy forms is much worse in terms of risk, and although the Edge reveals marginally better performance in terms of time than the other four forms do, the Adhocracy is by far the worst of all forms in the Industrial Era. As such, if a leader or policy maker were to select the “best” organizational form for the Industrial Era—with an interest in balancing performance in terms of time and risk—he or she would likely select one of the four forms in the lower-left corner. This result is consistent with observations from practice: most C2 organizations in the Industrial Era reflect one or more of the four forms clustered in that corner.

Alternatively, when comparing performance in the 21st Century across organizational forms, as summarized in the table, the graph reveals the dramatic performance degradation experience by all forms except for the Edge, and it shows how all four of the forms from above that balance time and risk well in the Industrial Era (i.e., labeled “MI,” “SI,” “PI,” “DI”) clearly struggle to perform in the 21st Century mission-environmental context. Nonetheless, whether the Edge (i.e., “E2”) is “better” in terms of *both* time and risk than these four forms is unclear: it depends upon how important one performance dimension is relative to the other.

Comparisons across Experimental Manipulations

Now we examine 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. We examine each of the manipulations in sequence, comparing each with results reported above.

Network Architecture. We begin by looking first at the Machine Bureaucracy—again, as the most common form today, and as a basis for comparison—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, when compared to 21st Century performance reported above, organizational performance of the Machine Bureaucracy improves across most dimensions through this network manipulation. For instance, time (209 vs. 313), cost (\$811M vs. \$1625M), decision wait time (50 vs. 193) and other measures reflect increased performance. Only the risk index increases (0.47 vs. 0.36) between these two manipulations. A similar result can be seen for the Edge organization, in which every performance measure reflects a lower value with the Network Architecture manipulation than when compared to 21st Century performance reported above.

Alternatively, when compared to Industrial Era performance reported above, organizational performance of the Machine Bureaucracy with this Network Architecture manipulation is *worse* in several respects than with the baseline. In particular, time (30%), coordination (123%), backlog (33%) and risk (21%) all reflect higher values in the Network Architecture case than in the baseline. A key part of this worsening of performance stems from the changes in organizational parameters. Whereas the enhanced network architecture enables the Machine Bureaucracy to exhibit somewhat less centralization and formalization, along with greater matrix strength (i.e., become somewhat less bureaucratic), it also precludes the organization from maintaining its strict controls and discipline. Hence “enhancing” the network architecture—and in turn enabling less bureaucratic organizational behaviors—represents a metaphorical two-edge sword: lateral communication and collaboration is enhanced, but bureaucratic safeguards are relaxed. Given the current, intensive focus placed on enhancing network architecture to support organizational C2, this result should be considered very carefully by leaders and policy makers.

In contrast, performance of the Edge organization with the Network Architecture manipulation in the 21st Century Era is better than in the Industrial Era. With the Edge structure, the network architecture enhancements complement the form’s inherent flexibility, and promote the kinds of lateral communication and collaboration that are central to Edge operations. Hence enhancing the network architecture serves to reinforce the Edge organizational form.

Results across the other organizational forms are similar but mixed. For instance, looking at the 21st Century column, performance of the Simple Structure, Professional Bureaucracy, Divisionalized Form and Adhocracy improves via the network-architecture manipulation over that reported above. Indeed, every organizational form reflects better 21st Century performance through enhanced network architecture. As with the Machine Bureaucracy above, the only exception pertains to risk, which increases somewhat for the Simple Structure and Divisionalized Form. Such monotonic performance improvement due to the network architecture manipulation suggests that the kinds of investments being made currently in the Global Information Grid and other network-centric infrastructure are well-advised, and offer potential to improve organizational performance in the demanding 21st Century environment. Of course, such investments come at considerable cost.

Professional Competency. Looking again at the Machine Bureaucracy, here we compare its 21st Century performance reported in the Mission & Environmental Context row above with that summarized for the Professional Competency row of the table. Notice that organizational performance improves dramatically across multiple dimensions through the professional competency manipulation. For instance, time (102 vs. 313), cost (\$516M vs. \$1625M), decision wait time (31 vs. 193) and other measures reflect increased performance, and unlike reported above for the network architecture manipulation, risk (0.34 vs. 0.36) does not rise via enhanced professional competency. This quantifies the huge importance of organization and knowledge flows in terms of performance.

A similar result can be seen for the Edge organization, in which every performance measure reflects a lower value with the network architecture manipulation than when compared to 21st Century performance reported above. Indeed, performance improves across all organizational forms when professional competency is enhanced dramatically. Hence regardless of which of these organizational forms is selected, increasing professional competency offers dramatic potential to improve performance. Moreover, notice that the magnitude of performance improvements via professional competency is

greater than that reflected via network architecture. To reinforce the comment above, given the relatively light emphasis placed upon enhancing the professional competency of C2 organizations today, this empirical result could call for decision makers and policy makers to reconsider their priorities also.

All Combined. Looking again at the Machine Bureaucracy, here we compare its 21st Century performance reported in the Mission & Environmental Context row above with that summarized for the All Combined row of the table. This fourth, aggregate manipulation combines the effects of all three manipulations discussed above. As one would expect, this aggregate manipulation reflects a combination of performance degradation observed in the 21st Century mission-environmental context with performance enhancement via the network architecture and professional competency manipulations. Hence, if an organization is thrust into the kind of more demanding mission-environmental context represented by our 21st Century case, then leaders and policy makers should seek to enhance performance through improved network architecture and increased professional competency.

So which organizational form is “best” in the 21st Century case? As suggested above, this depends upon which performance measures are of greatest importance to organizational stakeholders. Here with this all combined manipulation, for instance, the Edge demonstrates the greatest speed (148 days) and lowest cost (\$684M) of all forms, but it reflects considerable rework (144K person-days) and coordination (214K person-days), and this form retains the worst risk levels (0.78). In contrast, the Machine Bureaucracy, is slower (288 days) and more expensive (\$1133M) than the Edge is, and it incurs more rework (291K person-days) than the Edge does, but coordination (47K person-days) is less, and risk (0.46) is considerably less than that of the Edge form.

Nonetheless, one can say that some organizational forms dominate others in this 21st Century case. For instance, the Edge reflects faster speed (148 vs. 315) and lower cost (\$684M vs. \$1335M) than the Adhocracy does, and its rework (144 vs. 183) and coordination (214 vs. 237) are less than those of the Adhocracy, yet risk levels (0.78 vs. 0.77) are comparable. Hence one could say that the Edge form should be preferred strictly over the Adhocracy in the 21st Century case. The case for dominance is not as straightforward to establish in terms of the other organizational form, however. We need some mechanism for weighting and comparing performance across multiple dimensions. This remains for future research.

Editorial note: we plan to enhance this part of the results section in the final version of the paper

Support for Hypotheses

Despite expanding the scope of research in this present investigation to include six archetypal organizational forms, such expansion does not change the results reported by Orr and Nissen (2006) appreciably. Indeed, although the former study focused solely on a contrast between the Edge and Hierarchy/Machine Bureaucracy forms, the results of this current, expanded study remain consistent—albeit a bit weaker in terms of support across all organizational forms. We recapitulate and refine the results reported by Orr and Nissen (2006) here.

Hypothesis 0. Edge organizations can outperform Hierarchy organizations in demanding mission environmental contexts. This hypothesis demands an omnibus assessment of Edge and Hierarchy/Machine Bureaucracy organizational performance across eras. The Edge form outperforms the Machine Bureaucracy and other archetypal forms in the 21st Century Era (e.g., in terms of time and cost), but not across all performance measures (esp. risk). This provides partial 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]. Our Mission & Environmental Context manipulation addresses this hypothesis in part, and results above in terms of comparisons across eras provide partial 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 Machine Bureaucracy and several other forms are. However, the Edge form retains higher risk levels than those exhibited by most other organizations.

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]. 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, Machine Bureaucracy and other organizational forms alike. Hence this hypothesis is supported for multiple 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]. 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. 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]. Our Mission & Environmental Context manipulation addresses this hypothesis in part, and results above in terms of comparisons across eras provide some 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 Machine Bureaucracy and most other forms are. The adhocracy represents an exception, however, as it experiences very low percentage degradation in organizational performance in the 21st Century case.

Hypothesis 6. “An organization’s power can be increased without significant resource expenditures” [p. 172]. This hypothesis is difficult 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.

Editorial note: we plan to enhance this part of the results section in the final version of the paper

Organization Design Space

The discussion above provides empirical comparisons and contrasts between the six archetypal organizational forms examined, and it provides partial support for the seven research hypotheses articulated above. It appears that the Edge organization exhibits superior performance across some dimensions (e.g., *time*, *cost*, *decision wait time*)—particularly in the 21st Century case—but the Machine Bureaucracy exhibits superior performance across others (esp. *risk*), and the Adhocracy experiences lower percentage performance degradation in the 21st Century case. Indeed, each of the six organizational forms exhibits attributes that would make it perform better in some environments and contexts than in others.

The question is, how can one combine the best aspects of the Edge, Machine Bureaucracy, and others to compose a clearly superior organizational form? A related question follows, how can aspects of the other organizational forms contribute toward such superior form? In other words, how can we draw the best parts of alternate organizational forms, and combine them into a dominant hybrid? These are

questions of organizational design, and our computational models provide the basis for answering such questions. The key is to use the six, archetypal, computational models from above to represent an *organizational design space* via the dozens of parameters and settings used to specify each particular organizational form.

For instance, if we can identify the model parameters that enable the Edge organization to operate so quickly and inexpensively, and combine them with the parameters that enable the Machine Bureaucracy to reduce risk, and combine them with those enabling the Adhocracy to withstand environmental change, then we might be able to design a “new,” hybrid, organizational form that outperforms the Edge, Machine Bureaucracy and Adhocracy alike. Moreover, if we can identify the model parameters that enable the Simple Structure to keep risk below that of the Machine Bureaucracy, that enable the Professional Bureaucracy to operate so quickly in predictable environments such as the Industrial Era, and that enable the Divisionalized Form to keep rework down in predictable environments—that is, drawing the best from each organizational form—then we would establish the capability to *design* an organization that is tailored specifically to a particular environment. Further, if we can identify the model parameters that make each of the various organizational forms more or less effective in terms of responses to manipulations such as enhanced network architecture and increased professional competency, then we would establish the capability to *design* an organization that is tailored specifically to a particular manipulation. This represents the objective of articulating the organization design space: to facilitate organizational design specific to particular environments and managerial manipulations.

The first step is to understand how the various model parameters contribute to differentiate the six, archetypal organizational forms from one another. Referring back to the model specifications in Table 2, notice that most parameter settings are common across two or more different organizational forms. For instance, *centralization* is “low” for the Edge, Professional Bureaucracy and Adhocracy forms, and is “high” for the Machine Bureaucracy and Simple Structure. As another instance, *formalization* is “low” for the Edge, Professional Bureaucracy, Simple Structure and Adhocracy forms, and is “high” for the Machine Bureaucracy and Divisionalized Form. As a third instance, *hierarchy* is “1-level” for the Edge and Adhocracy, “2-level” for the Simple Structure and Professional Bureaucracy, and higher for the Machine Bureaucracy and Divisionalized Form. Clearly, looking across only these three parameter settings is sufficient to differentiate the six forms, but are all 25 of the parameters summarized in Table 2 necessary to differentiate these forms?

Table 6 Parametric Differentiation of Archetypes

	Centralization	Hierarchy Levels	Application Experience
Edge	Low	1	High
Adhocracy	Low	1	Low
Professional Bureaucracy	Low	2	High
Simple Structure	High	2	Med
Machine Bureaucracy	High	3	Med
Divisional Form	Med	4	Med

Through analysis of Table 2, we show that three parameters are sufficient to differentiate the six forms uniquely: *centralization*, *hierarchy* and *application experience*. This is summarized in Table 6. Notice how, on the basis of centralization, the Edge, Adhocracy and Professional Bureaucracy are alike,

and how these three forms are different than the other three. This centralization parameter setting divides the organizational forms into two groups. The levels of hierarchy parameter setting divides them further, and the application experience setting defines six unique organizational forms. Because each of these parameters is independent of the others, we establish here a minimal, orthogonal set of parameters required to differentiate the organization design space. Figure 3 delineates this space.

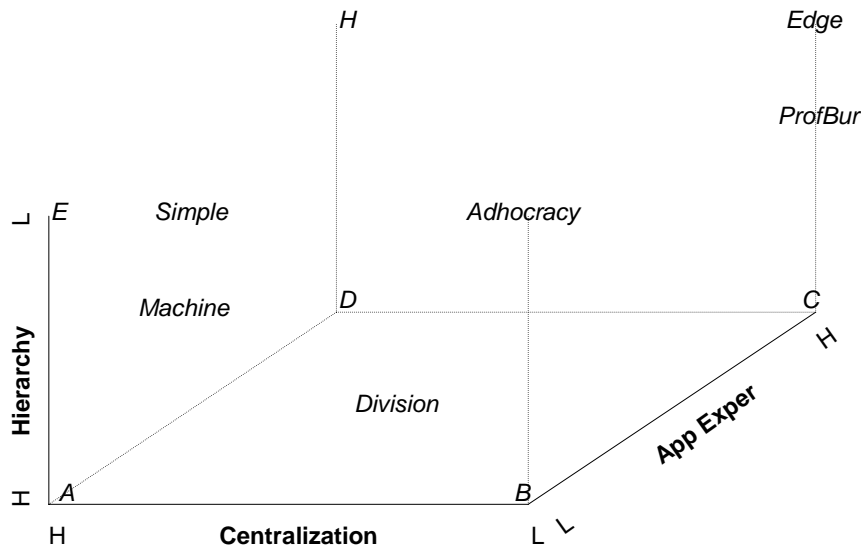


Figure 3 Minimal Orthogonal Organization Design Space

The figure displays a three-dimensional representation with each model parameter denoted on a separate axis. All three axes are denoted with high and low endpoints for ease of comparison across dimensions. Each of the six organizational forms is plotted according to the entries in this table. For instance, the Edge form is plotted at the low level of *centralization*, high level of *application experience*, and low (i.e., 1-level) end of *hierarchy*, in the right-rear-upper corner of the diagram. For some contrast, the Machine Bureaucracy is plotted at the high level of *centralization*, medium level of *application experience*, and relatively high (i.e., 3-level) end of *hierarchy*, in the left-middle-lower corner of the diagram. Following this same scheme: the Simple Structure plots “above” the Machine Bureaucracy; the Professional Bureaucracy plots “below” the Edge; and so forth as depicted in the figure.

Delineation of the six archetypal forms as such raises several noteworthy points. For one, as noted above, the six, theoretically unique, organizational forms can be differentiated via three parametric dimensions. This suggests that one can conceivably design organizations with as few as three design parameters. Such a finding would simplify the task of organizational design considerably. For another, the six organizational forms are clearly separate and distinct from one another in the figure, but some forms plot further apart than others do; that is, one can observe some relative clustering. For instance, the Edge, Professional Bureaucracy and Adhocracy all plot on the right side of the diagram, with the Edge and Adhocracy both plotting at the top, whereas the Simple Structure and Machine Bureaucracy plot on the left side of the diagram, and more toward the bottom. The Divisional Form plots in the center of the “floor” of the diagram. Notice the connection between this clustering in terms of *design* and that noted above in terms of *performance*. This provides a start to understanding the impact of various design parameters on resulting organizational performance.

For a third, only two of the eight “corners” of the diagram have an archetypal form plotted correspondingly: the Edge form plots at the right-rear-upper corner of the diagram; and the Adhocracy

plots at the right-front-upper corner. By plotting as such in one of the corners of this organization design space, this suggests that both the Edge and Adhocracy represent *extreme* organizational forms; that is, they reflect only maximum or minimum parameter settings across all three dimensions. The other corners—each representing an extreme organizational form within this design space also—do not have corresponding archetypes plotted. As an example, the corner labeled point “A” would reflect an organizational form with high centralization, low application experience, and very high (i.e., 4-level) hierarchy: none of the six archetypal forms corresponds to this point. This suggests that relatively pure, “ideal type” organizational forms beyond the six conceptualized by Mintzberg may be relevant in terms of organizational design. This same comment pertains to the corner points labeled “B,” “C,” “D,” “E,” and “H.” Understanding the relative structures, properties, behaviors and performance characteristics of organizational forms corresponding to these corner points represents an intriguing topic for future research.

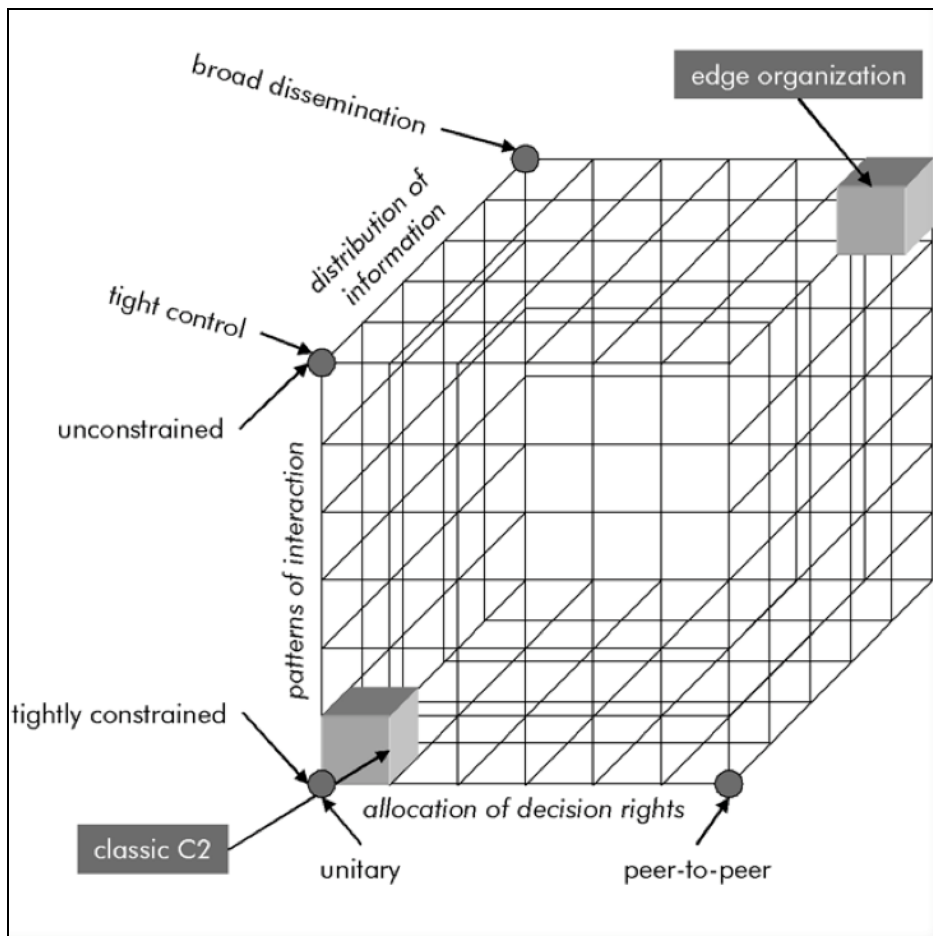


Figure 4: C2 Approach Space (adapted from Alberts and Hayes 2006)

Notice how this articulation of an organizational design space reveals both similarities and differences with respect to the “C2 approach space” that Alberts and Hayes (2006) outline for C2 organizations and processes. Specifically, their C2 approach space varies along three axes also: 1) patterns of interaction (from constrained to unconstrained), distribution of information (tight control to broad dissemination), and allocation of decision rights (from unitary to peer-to-peer). As shown in Figure 4, “Classic C2” (i.e., the Machine Bureaucracy) and the Edge, when viewed through this lens, are both at opposite and extreme corners of the approach space. Alternatively, whereas the Edge form plots in a similar position in our organization design space, the Machine Bureaucracy does not. This raises some question as to whether the Edge and Machine Bureaucracy forms represent “opposites” as depicted in

Figure 4, or whether they simply occupy different regions of design space. One would have to reconcile the model parameters and settings used to construct the organization design space above with the three axes used here in the C2 approach space; one would have to establish where each of the six, archetypal, organizational forms from above would plot in this latter approach space; and one would have to establish some correspondence between comparative organizational performance and the various regions of the C2 approach space in order to inform design. We reserve this for future research.

CONCLUSION

Editorial note: we plan to complete this section in the final version of the paper

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APPENDIX A – MODEL PARAMETER SETTINGS

<need to add this appendix to explain our rationale for the parameter settings>

For reference we include Table 2 from above here, and relabel it Table 6.

Table 7 Model Formulation – Organization Forms

Structural Factor	Mintzberg Design Parameter	Model Parameter	Edge	Machine Bureacracy	Simple Structure	Prof. Bureacracy	Divisional 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
	"	Operating Core Role	ST	ST	ST	ST	ST	ST
	"	Holding Company (PM)	0	0	0	0	3	0
	"	Command Position (PM)	0	3	3	3	3	0
	"	Coordination Position (SL)	0	200	0	0	225	0
	"	Operations Position (ST)	13,000	13,000	13,000	13,000	13,000	13,000
	Size	# of Total FTEs	13,000	13,203	13,003	13,003	13,231	13,000
	Unit Size	# of FTEs per Unit	813	1650	2601	765	778	813
N/A	# of Units	16	8	5	17	17	16	
Training	Skill Level	Med	Med	Med	Med	Med	Med	
Indoctrination	App. Experience ^{1,2}	Med	High	Med	High	High	Low	
	Team experience	Med	Low	Low	Med	Low	Low	
Communication Structure	Liaison Devices	Communication Links	Many	Few	Some	Many	Few	Many
	"	Information Exchange ¹	0.9	0.1	0.1	0.3	0.1	0.9
Work Structure	Planning & Control Systems	Meetings	No Meetings	2 hrs/day (staff) ⁴	2 hrs/week (10% ops) ⁵	2 hrs/month (10% ops) ⁵	2 hrs/day (staff) ⁴ , 2 hrs/week (top mgmt)	No Meetings
	"	Matrix Strength	High	Low	Low	Med.	Low	High
	"	App. Experience ³	Add 1 level	Subt 1 level	Same level	Same level	Subt 1 level	Same level
	N/A ⁶	Number of Operational Tasks	16	4	4	16	4	16
	"	Degree of Concurrency	Massive Concurrency	Sequential, 2 Phase	Sequential, 2 Phase	Massive Concurrency	Sequential, 2 Phase	Massive Concurrency
	"	Interdependence	High	Low	Low	High	Low	High
	"	Rework Links	Many	Some	Some	Many	Some	Many
Environment - Complexity	Rework Strength	0.1	0.3	0.3	0.1	0.3	0.1	
	FEP/PEP	0.2	0.1	0.1	0.2	0.1	0.2	

¹ This parameter has two aspects: indoctrination and planning & control systems.

² The indoctrination aspect of this parameter reflects the organization's familiarity with its environment.

³ The planning & control systems aspect of this parameter reflects the organization's information processing environment; adjustment wrt indoctrination value.

⁴ These meetings are between the Commander and Staff members.

⁵ These meetings are between the Leader(s) and 10% of Operational Core members.

⁶ Mintzberg does not explicitly address "work structure" in his paper.

APPENDIX B – MODEL PARAMETER MANIPULATIONS

<need to add this appendix to explain our rationale for the parameter manipulations>

For reference we include Table 3 from above here, and relabel it Table 7.

Table 8 Model Manipulations – 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 2	Baseline + 0.1
	PEP	Baseline in Table 2	Baseline + 0.1
	App. Experience	Baseline in Table 2	Baseline - one level ^d
Network Architecture (P2, 3)	Noise	0.3 ^a	0.01
	Info. Exchange Prob.	Baseline in Table 2	Baseline + 0.3 ^b
	Communication links	Baseline	Baseline for Edge; more for Hierarchy ^e
	Organization settings ^c	Baseline for Hierarchy; opposite for Edge	Baseline for Edge; opposite for Hierarchy
Professional Competency (P2, 4)	App. Experience	Baseline in Table 2	Baseline in Table 2
	Skill Level	Baseline in Table 2	Baseline + one level
	Team Experience	Baseline in Table 2	Baseline + one level
Aggregate (P1 - 6)	All of the above	All of the above	All of the above

APPENDIX C – 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 skill-based 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.

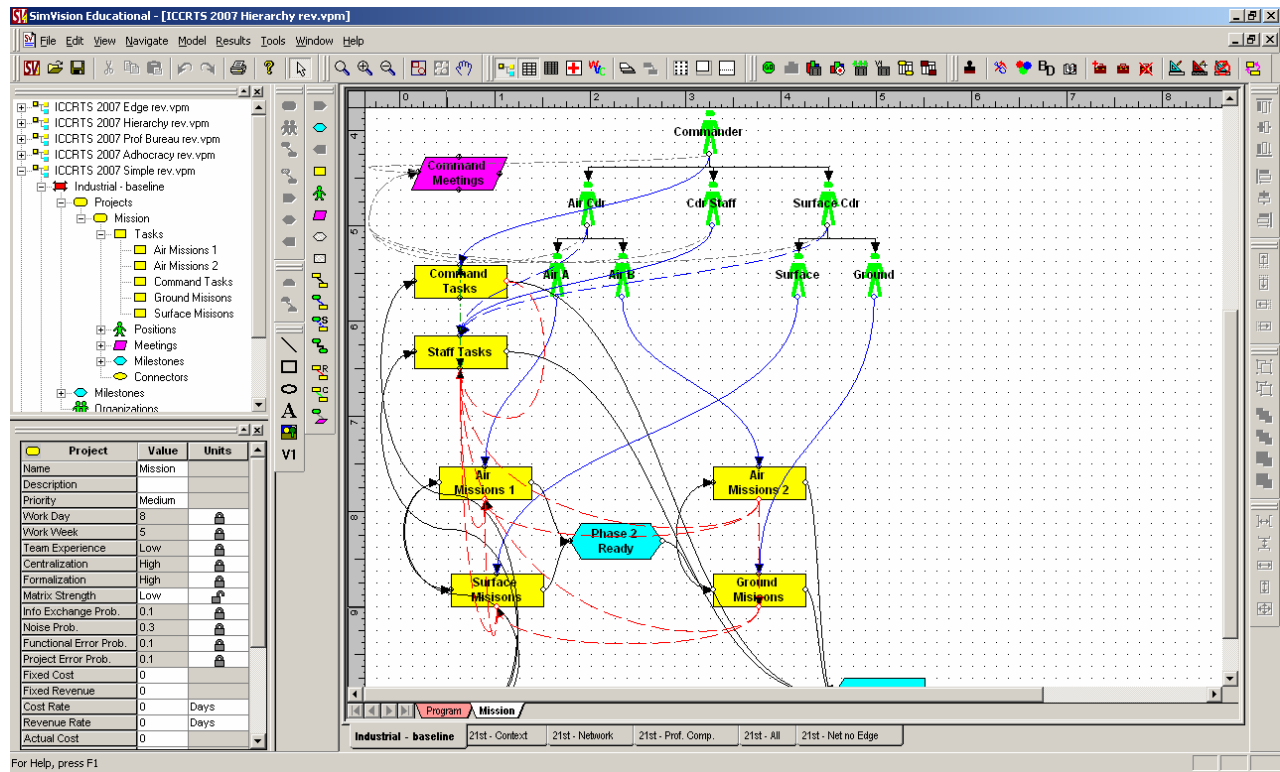


Figure 5 Machine Bureaucracy Model

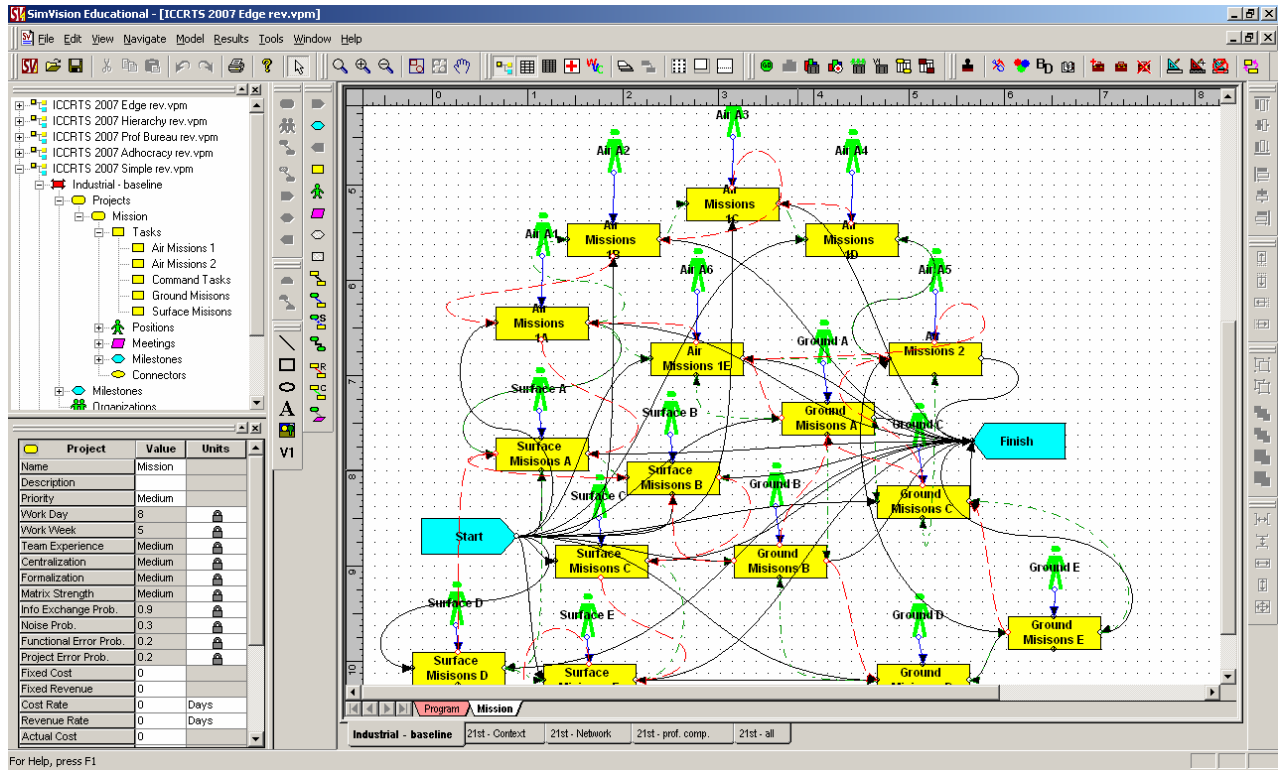


Figure 6 Edge Model

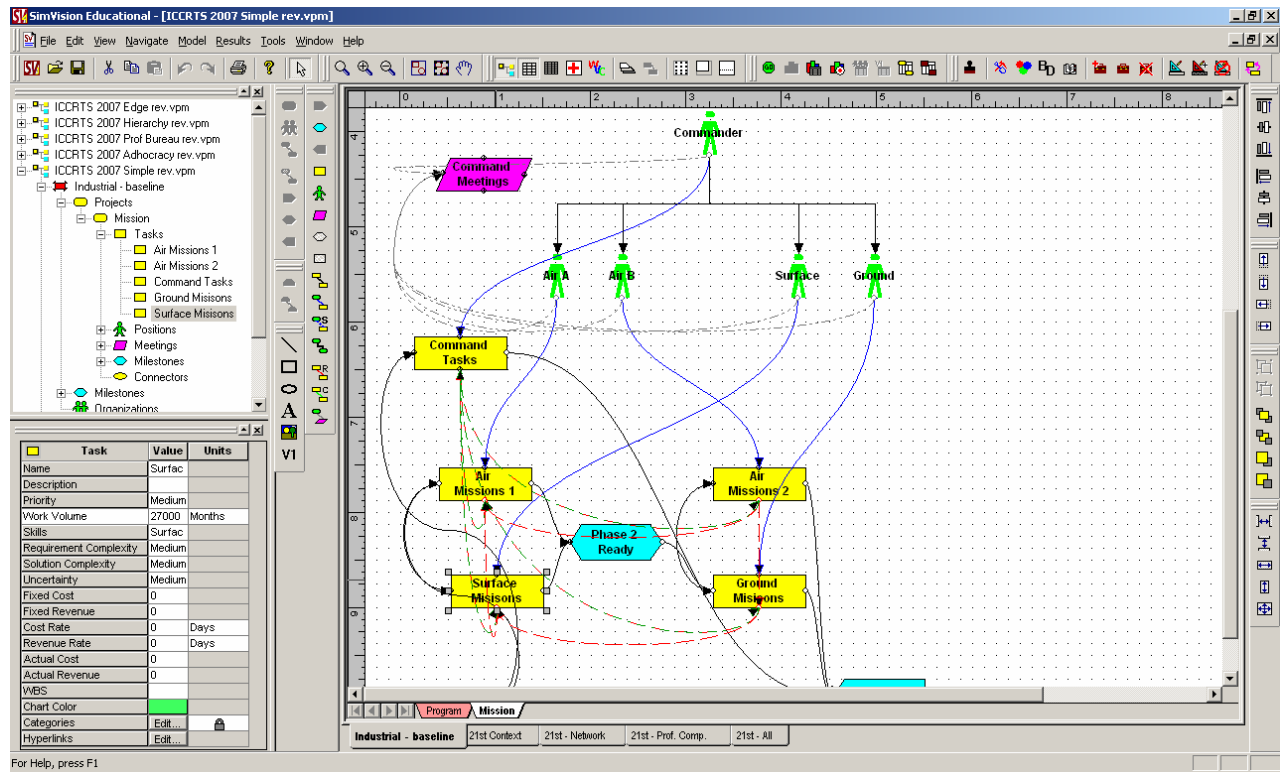


Figure 7 Simple Structure Model

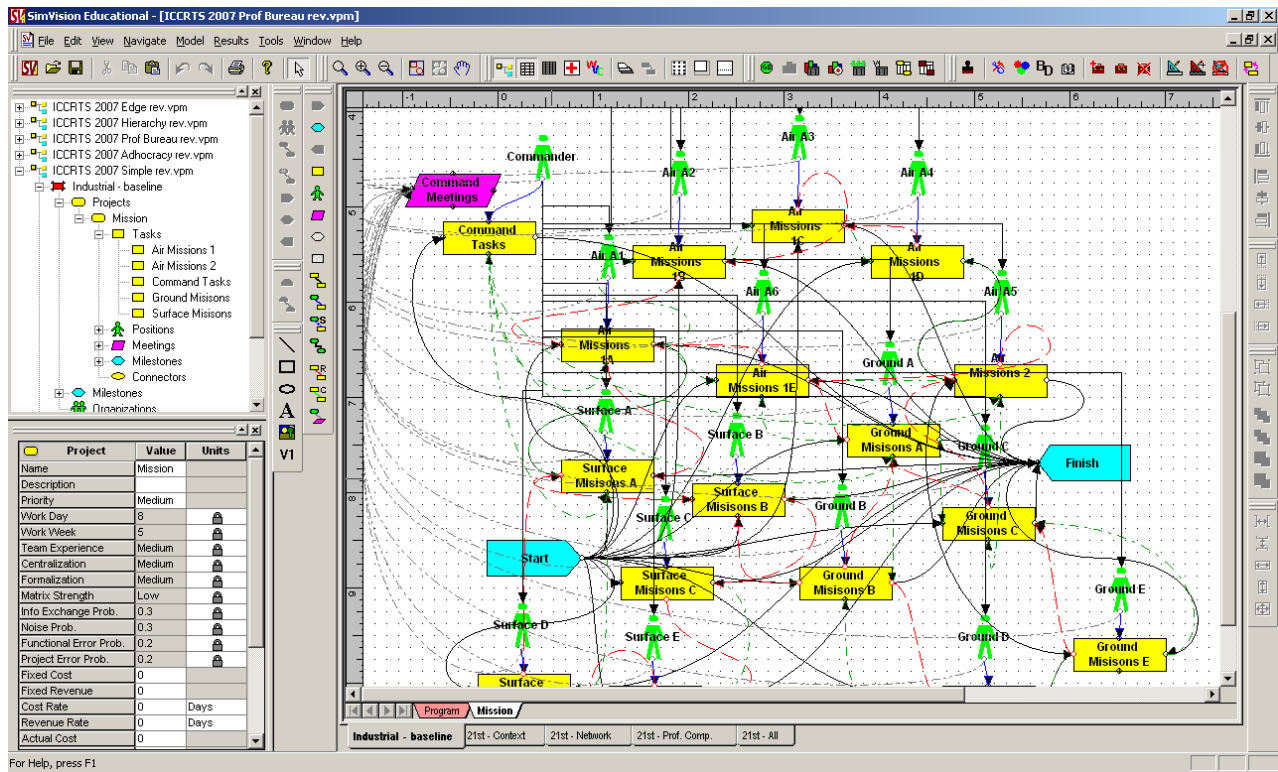


Figure 8 Professional Bureaucracy Model

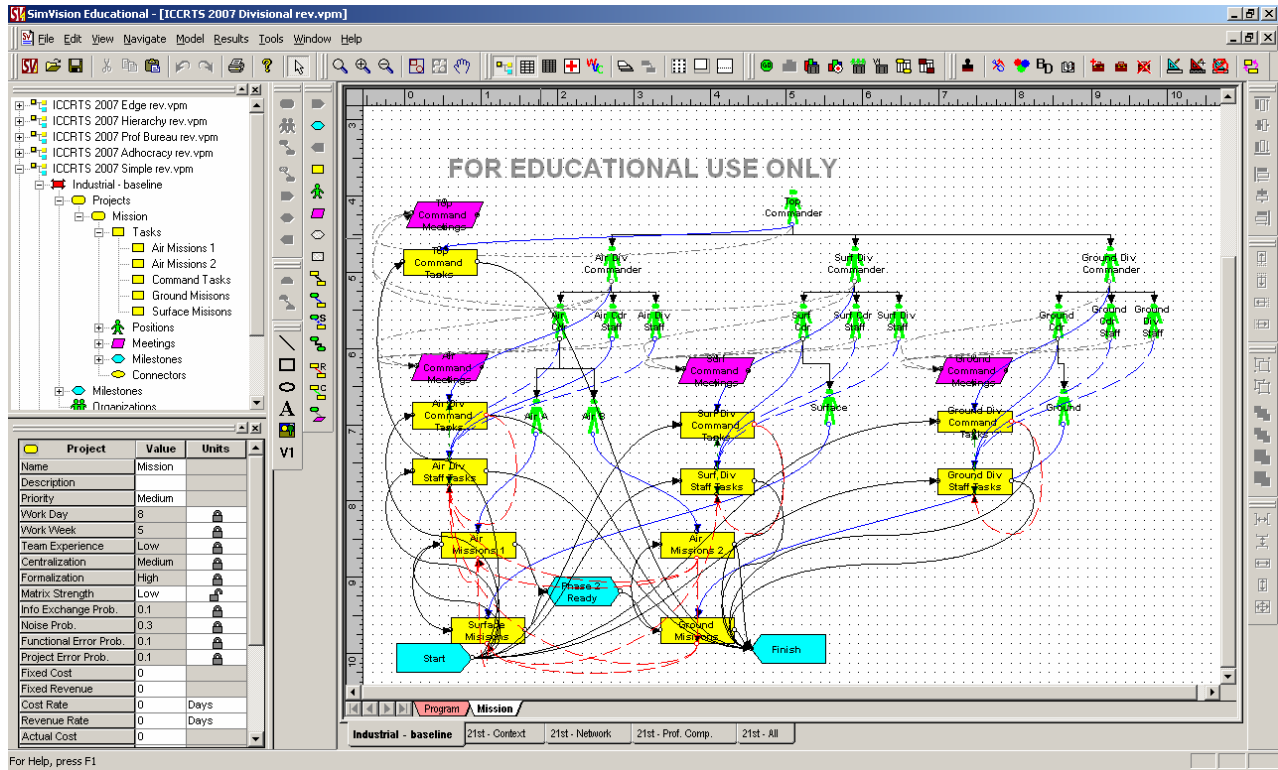


Figure 9 Divisionalized Model

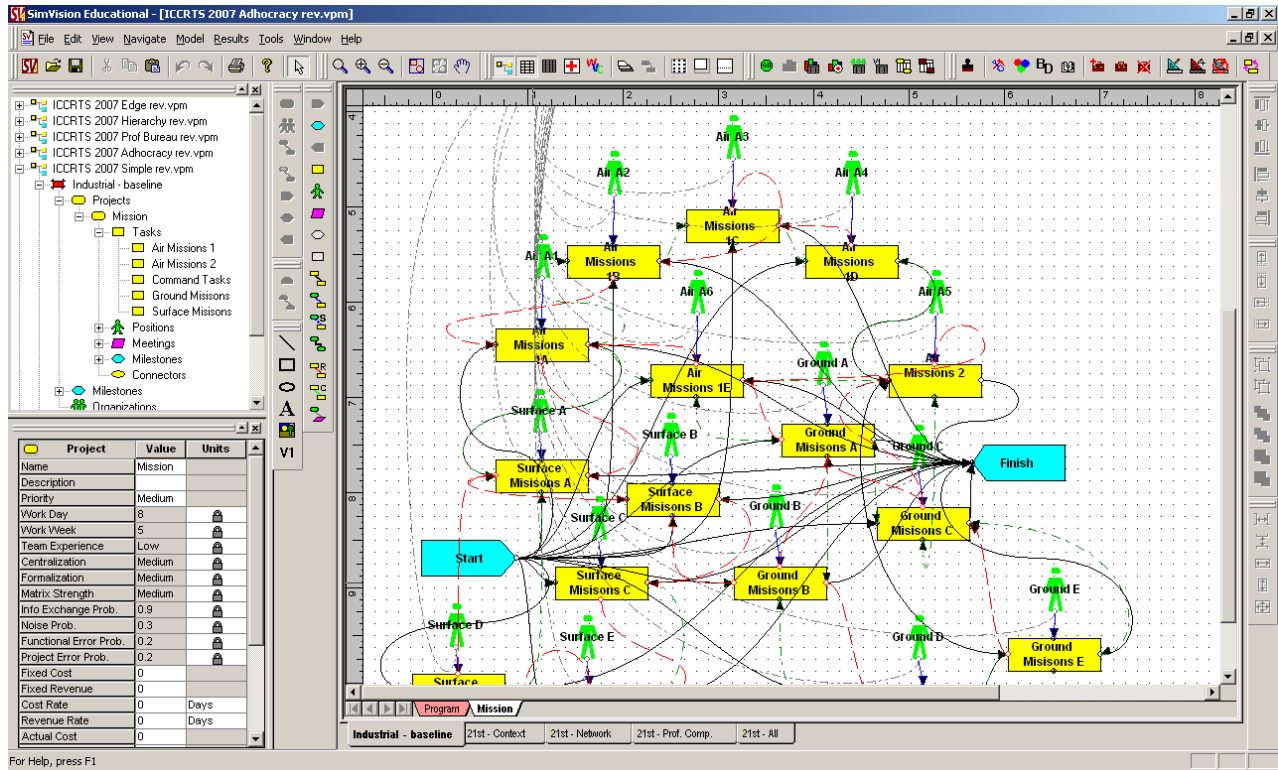


Figure 10 Adhocracy Model

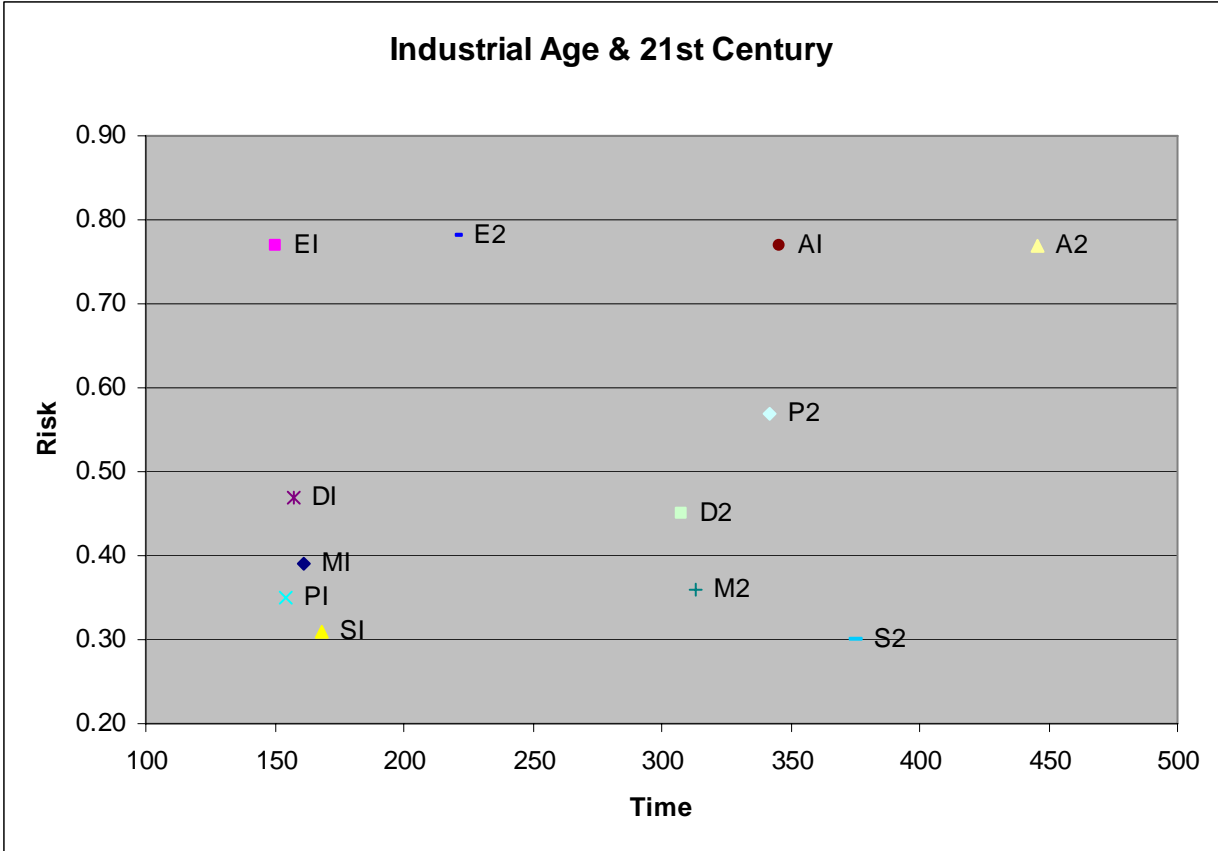


Figure 11 Industrial Age & 21st Century Performance Comparison - Time vs. Risk

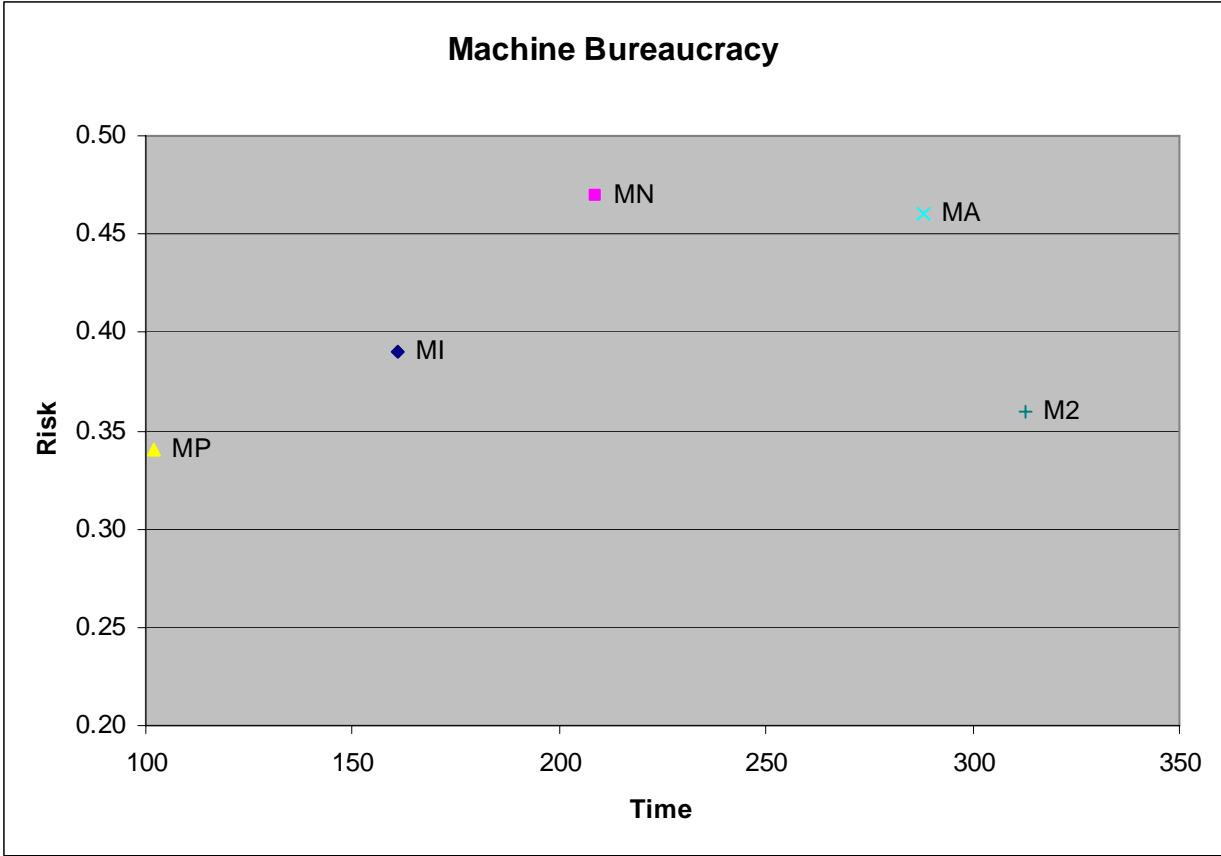


Figure 12 Machine Bureaucracy Manipulations - Time vs. Risk

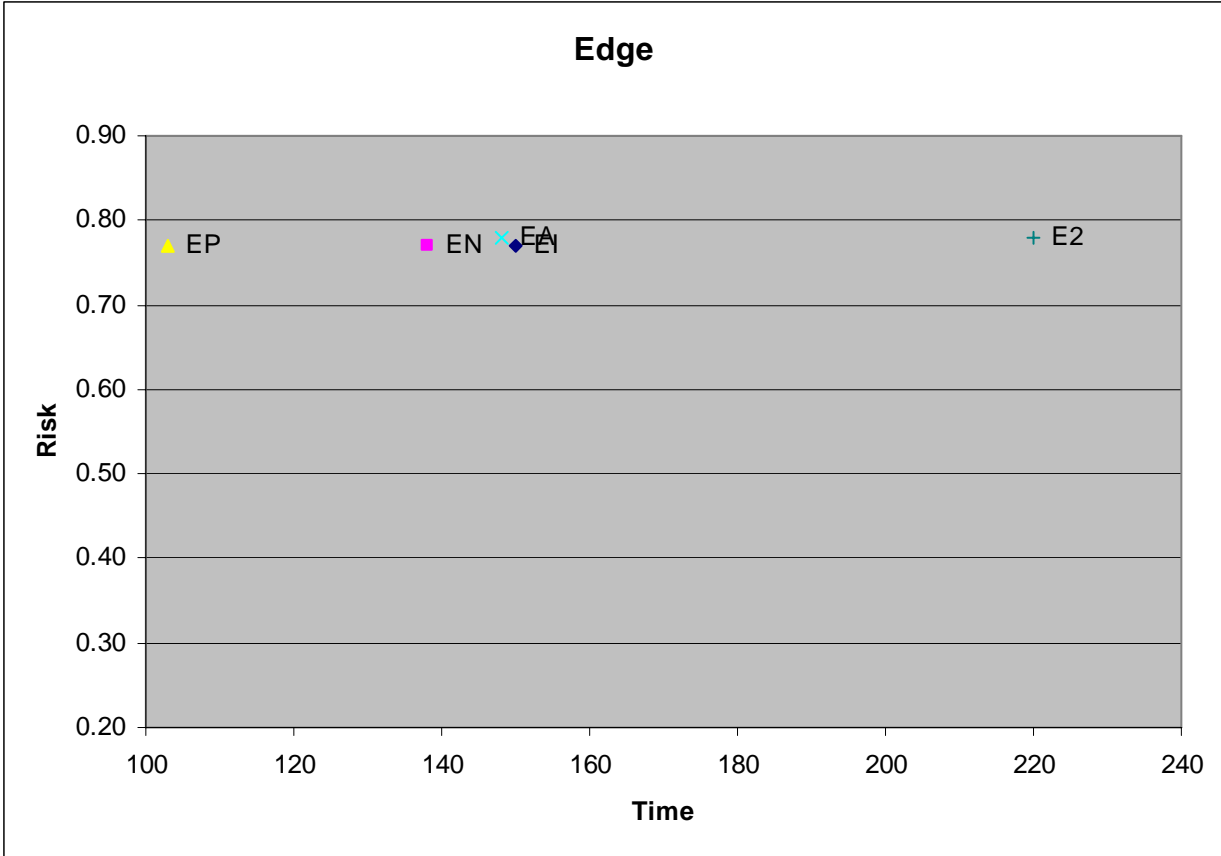


Figure 13 Edge Manipulations - Time vs. Risk

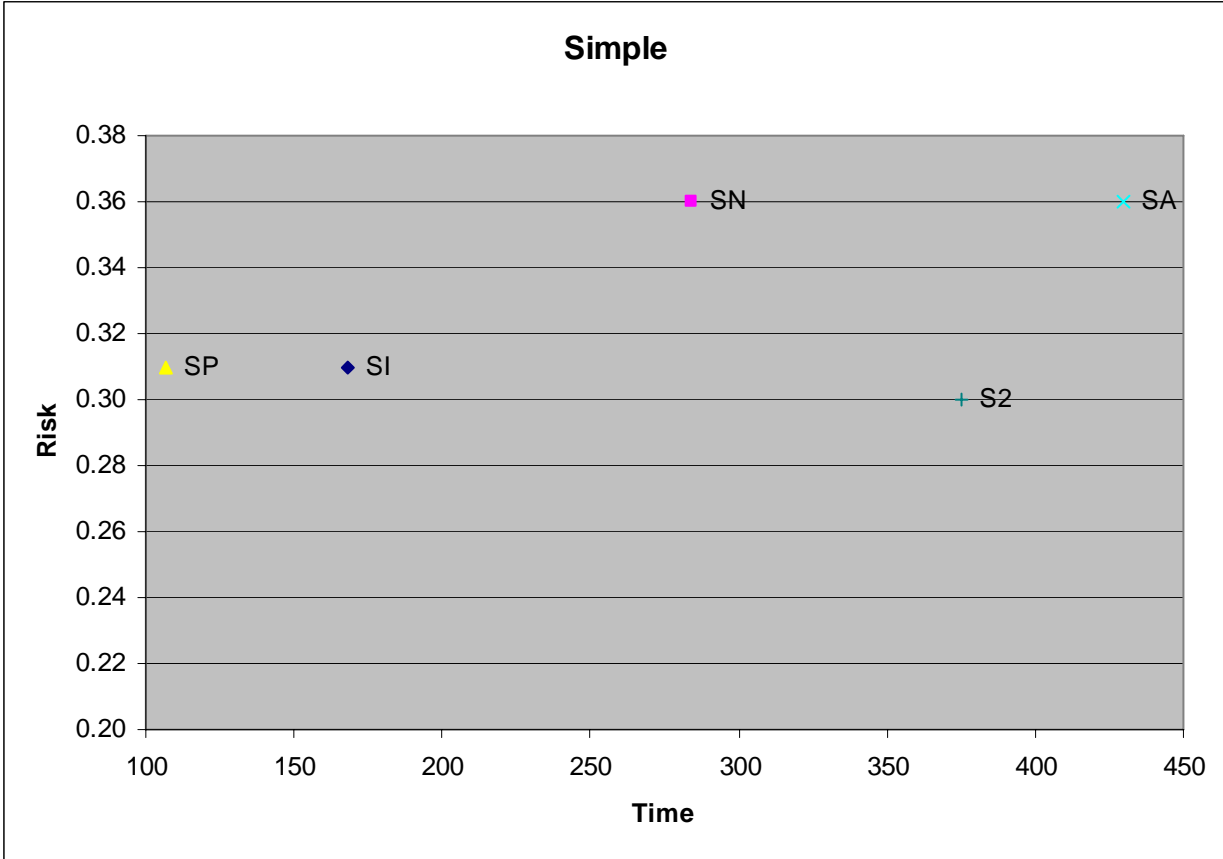


Figure 14 Simple Structure Manipulations - Time vs. Risk

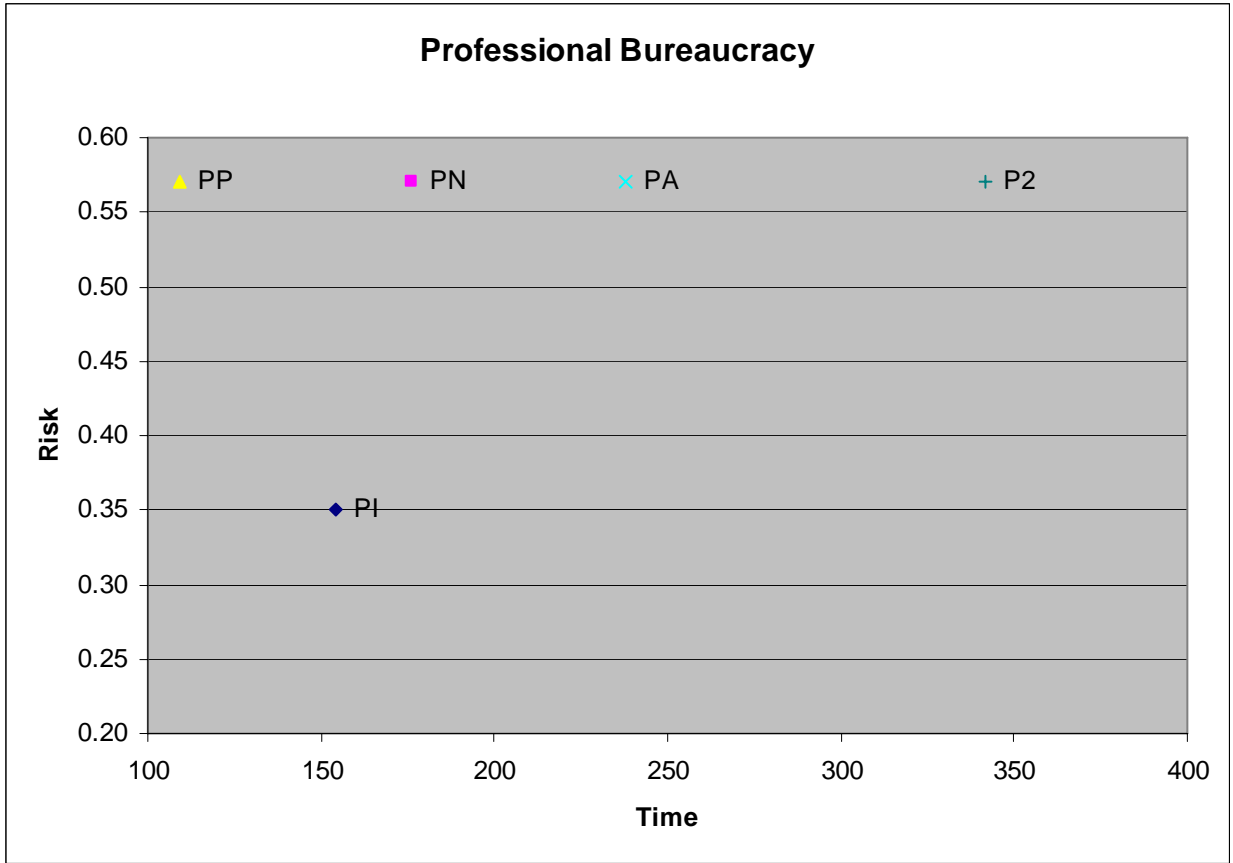


Figure 15 Professional Bureaucracy Manipulations - Time vs. Risk

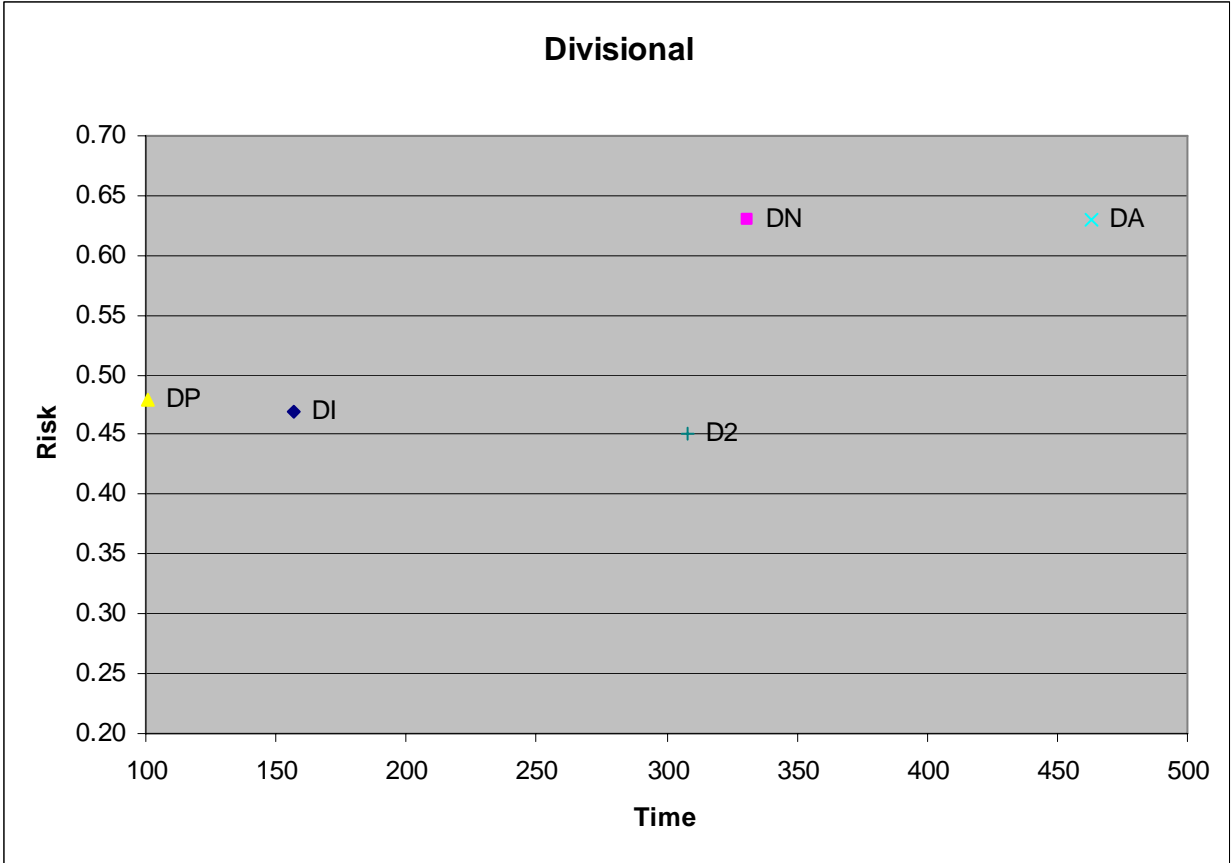


Figure 16 Divisional Manipulations - Time vs. Risk

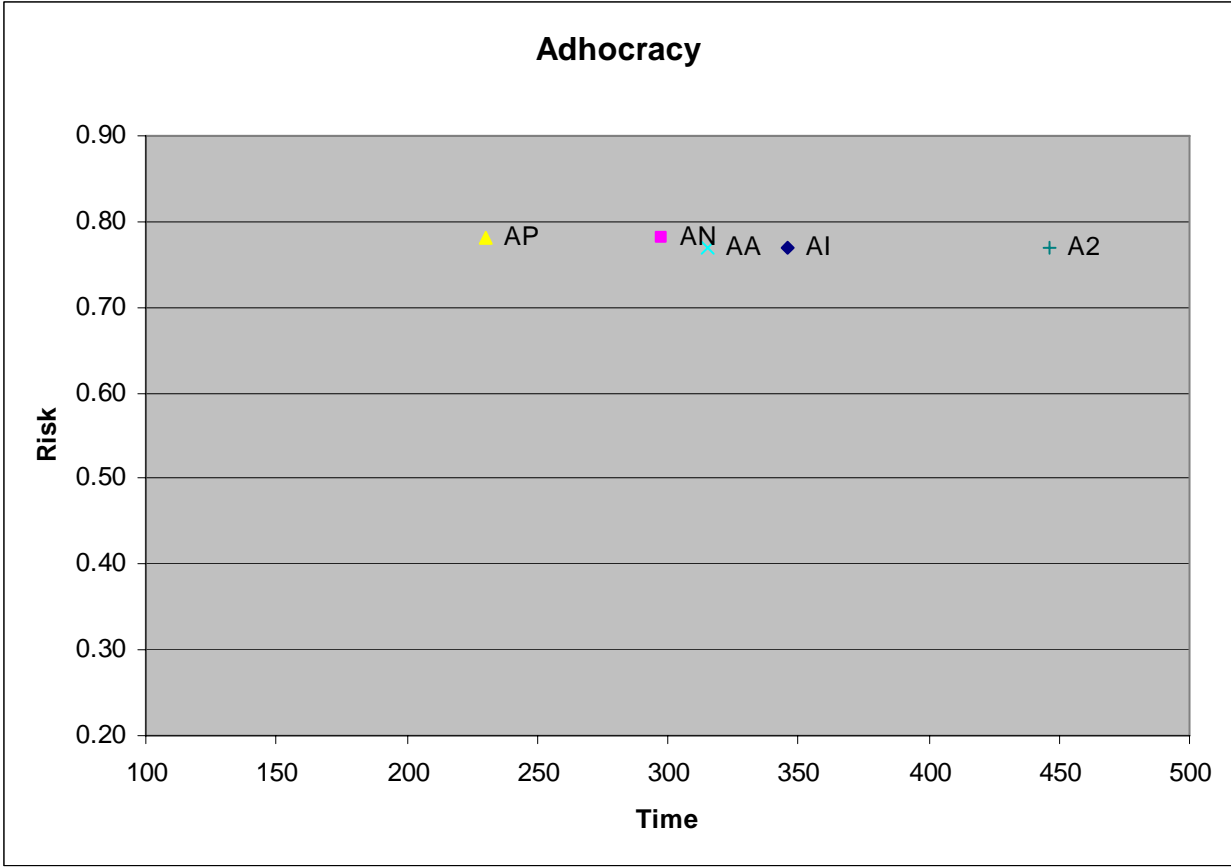


Figure 17 Adhocracy Manipulations - Time vs. Risk