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Using Extreme Collaboration?
A Model Based Analysis**

By

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ABSTRACT

This paper sets out our observations, modeling results, and conclusions regarding a novel organizational form applied variously as “extreme collaboration” (XC) or “radical collocation.” XC teams are cross-functional, co-located groups enabled with high-performance computer modeling and simulation tools, large interactive graphic displays, a mature shared generic project model that the design team instantiates for the project, and specialized charter, training, support and culture. Our primary data source is the Jet Propulsion Laboratory’s Team-X, which has consistently reduced task durations over many hundreds of projects from original values of 3-9 months down to a few days. Based on our observations, interviews, and surveys of the JPL team, we employ several computational models including the Virtual Design Team (VDT) to illuminate the practice’s basic mechanisms. Key aspects include very short information request-response latency (less than a minute to answer to a question, vs. several days in a traditional team) and a bounded and dedicated knowledge network that provides all the required skills and experience. Our models suggest steps by which designers can re-organize a limited range of projects to reproduce XC and reduce their durations by an order of magnitude. We do not evaluate the impact of this method on the team’s total work volume, cost, or quality. Nevertheless, we conclude that tightening collaboration in ways that are inspired by XC is a strategically powerful tool that is appropriate for most projects.

1. INTRODUCTION

Extreme Collaboration (XC) is a novel organizational form that has garnered increasing attention in recent days. XC teams are cross-functional, co-located groups enabled with high-performance computer modeling and simulation tools, large interactive graphic displays, a mature shared generic project model that the design team instantiates for the project, and specialized charter, training, support and

culture. Some collaborative engineering teams consistently enjoy considerable benefits from the practice, including project schedule reductions of one or two orders of magnitude.

XC is sufficiently new that few (if any) individuals claim an intuition on the system’s behavior and means of success. There is little generally available documentation on the behavior of XC projects [notably Mark 2002, Teasley et al 2000]. In addition, the literature does not comprehensively explain the system’s fundamental mechanisms.

Either to gain competitive advantage or to compete with teams that already employ XC, many organizational designers are tempted to emulate the novel practice with their own teams. Because the method differs from tradition in many ways, it is appropriate for organizational designers to respect the difficulty of reproducing the successful systems’ complex and interdependent organizations, processes, and technical infrastructure. *This paper’s primary focus is the practical organizational designer’s question of how and when XC works.*

Our methodology includes on-site observation, interviews, and surveys. However, our primary contributions result from carefully applying formal models to test the predictions of fundamental (traditional and modern) theories. *A secondary goal of our paper is to illustrate the value of computational organizational modeling in evaluating a domain where intuition breaks down.* By developing each discussion with a computational model, we conserves the systems’ complexities while simultaneously offering a roadmap for many directions of further study. Our models, based on the fundamental theories of traditional organization, suggest new, intuitive theories of XC.

These theoretical results suggest methods by which an important range of applications can adopt XC in its entirety. Of equal importance, they articulate reasons why most organizations may find this move prohibitively challenging in the short term. *Our third and final purpose is to identify a metric that can help teams significantly improve their effectiveness in traditional collaboration.*



Figure 1: The JPL extreme collaboration facility has a number of co-located cross-functional designers, each with a unique specialty, and each having a modeling and simulation workstation. The projection screens can display any workstation's data. A working environment that supports efficient networking is essential, but not sufficient for extreme collaboration to be successful. Photograph courtesy of NASA/JPL/Caltech.

2. EXTREME COLLABORATION

In hundreds of projects over eight years, the Team-X organization at the Jet Propulsion Laboratory (JPL) has developed and applied XC during their “design sessions”. Figure 1 shows Team-X in a room they have outfitted for XC. Like most Team-X projects, the example project we studied aimed to develop a NASA mission proposal document that conveys an analysis of those designs that Team-X believes can feasibly meet a customer's scientific goals.

The team aimed to complete the design using fewer than five hundred full-time-equivalent hours over a four-week period. In the first, “pre-session” week, certain select engineers pinned down the scientific requirements and mission design with a customer representative. During the second week, the team met for three intensive “design sessions” of XC, each lasting three hours. In the two weeks following the design sessions, the team completed its documentation in a more traditional, distributed fashion.

In practical terms, the design sessions of XC entail the co-location of ten or twenty “station” representatives, each from a different engineering function. These design sessions resemble traditional meetings in that a designated facilitator communicates the agenda and monitors the session's progress. However, in XC the participants continuously form and dissolve “sidebar” conversations to share information or solve emergent problems. Ordinarily, many such conversations are evident through the physical orientation and movement of engineers in the room. Even though the engineers may represent different organizational divisions, there are no managers present in the design session. Instead, the sole facilitator helps sidebars to form, and draws attention to important developments.

The Team-X facilitator monitors the collective design socially and through an information technology infrastructure that is characteristic of the XC method. Three large screens cover one wall and typically monitor top-level

design conformance measures, the mission trajectory, and the designed vehicle's physical configuration. Each domain representative runs a networked spreadsheet model that communicates the design choices currently being considered. The one table without dedicated monitors is typically used by a facilitator, by customer representatives using laptops, and by a speakerphone that connects to remote participants.

We visited JPL's Team-X and ethnographically observed a sample project's three design sessions. In several hours of on-site interviews, we collected quantitative and qualitative details about the participating organization, process, and culture. Finally, after examining this information back at Stanford, we followed up with an online survey covering the amount of time each participant spent in direct work, communication, and rework. While these observations, interviews, and survey provide the foundation of our research, we interpret the data primarily through a set of computational organizational models.

3. ORGANIZATIONAL MODELING

Both in planning and execution, it is sometimes appropriate to introduce changes to a project based solely on intuition. At other times, it may be more effective to test interventions first in a computational model. This can allow a practitioner rapidly and economically to gauge the interactions between a complex product, organization, and process

Tracking systems such as Microsoft Project are the most frequently consulted project models, but they are not the most sophisticated. When testing interventions in the Virtual Design Team (VDT) simulator, for example, planners can compare project participants' predicted backlog, coordination effectiveness, schedule risk, and other results between many alternative cases [Kunz et al 1998, ACM; Jin et al 1995, Levitt 1996, Levitt et al, Management Science]. In this way, modelers can plan joint adaptations to organizations, processes, and culture that will meet a project's goals. In time, our team believes tools like VDT

will enable us to engineer projects with a comparable methodology and confidence as is demonstrated on today's automobiles.

In recent years, the computational modeling of organizations has enjoyed a popular resurgence among researchers seeking to better understand new and established theories [March, and Burton, in Lomi and Larsen '01]. By grounding a computational model explicitly in a theoretical framework, researchers can explore complex ramifications of a theory (or set of theories) that extend qualitatively beyond the reach of human intuition. In addition, we have used models to quantitatively predict the effects of theoretical and practical changes in a baseline model. Following the tradition of mathematical proof, when a model of theory produces a recognizable pattern of results, we interpret this and make a new claim. In a perfect world, if the new hypothesis is shown to be false, the model's theoretical premises are disproved (a "proof by contradiction"). At this time, however, model based theory generation is new to domains as complex as project design. In this paper, we apply the technique in its most common modern form- as an engineering method that relies in part on intuition and external observation to validate its claims.

4. ORGANIZATIONAL THEORY

Although it does not tell the whole story, much of mainstream theoretical research on organizations does apply to XC. Thompson [1967] recommends assigning interdependent tasks to teams that are in close organizational proximity. According to this theory, concurrent engineering warrants a flat hierarchy that lowers costs and reduces coordination delays among the many interdependent domains.

As a second example, Galbraith [1977] predicts that when a large number of dependency issues arise, organizations may form temporary, interdisciplinary task forces. We may view the whole of Team-X as one such task force at JPL, while the incessantly forming and dissolving "sidebar" conversations during design sessions serve a parallel function at the temporal and organizational micro-level.

Unfortunately, neither those traditional theories that validly apply to XC, nor the limited literature that is dedicated to the practice, conclusively and concisely explain the effectiveness of XC. Conclusively isolating the set of exact reasons for the effectiveness of XC will require substantial further research.

Fortunately, within limits, an organizational designer may proceed much as engineers do, reaping benefits from the paradigm without regard to the controversy over its most elementary basis. We submit that an organizational designer may productively view XC simply as a purification of the collaborative process- as an absence of unfortunate, complicating factors. In this view, it offers a standard to compare other projects with, and not vice versa.

5. COORDINATION LATENCY

Total schedule duration is typically calculated using the critical path method. Perhaps the most common question that is used to determine priorities during project execution is: "Is the task in question on the critical path?" If it is, a given task will receive priority because any delay extends the total schedule duration. Highly optimized schedules, like those of collaborative engineering, often include many parallel tasks that will fall onto the critical path if any substantial delay arises.

Whenever a task lies on the critical path, its requests for information are also on the critical path. The amount of time that elapses between a request for information or action and the satisfaction of that request is termed "coordination latency". Even the best traditional engineering collaboration teams routinely require many hours or even days to service information requests. If each day's labor includes even one request with a substantial latency, the schedules will grow significantly- even though total work volume remains unchanged.

Because XC sessions condense a project timeline by an order of magnitude, the significance of minor delays increases dramatically. A single hour's delay, routine and inconsequential under traditional conditions, can eliminate over one tenth of the Team-X XC period, and waste over a dozen top engineers' time. To be effective, therefore, an XC team must minimize or eliminate all sources of delay- no matter how insignificant they might be under traditional engineering conditions.

6. RESULTS

We use latency as the theoretical key to understanding the necessary and sufficient conditions for effective XC. However, the conceptual simplicity of latency reduction obscures the complexity and difficulty of its achievement. Just as in battling costs, we find that components of latency come in a multitude of forms, some of which may never be entirely eliminated. Achieving a sufficiently low latency to support XC requires the minimization of every physical, social, and technological coordination barrier.

Table 1 outlines ten of the key latency sources that our study has identified. Organizational designers who seek to improve their coordination effectiveness through latency reduction should realistically assess each of these critical factors. In order for XC to be successful, each of the indicated critical factors must satisfy the corresponding success condition. Aligning a given critical factor will involve an organization-specific technique and difficulty, as the table suggests. We believe that adjusting the critical factors toward success conditions can dramatically improve project schedules, even without engaging in full-blown XC. However, dramatically tightening coordination (through any mechanism) without first assessing and addressing each of the critical factors is likely to produce the indicated failure modes.

Critical Factor	Success Condition	Controllability	Failure Modes	References
Structure Dependence	Natural resource allocation- see below	Low- Re-engineer project, organization and process	Unnecessary bottlenecks, idle resources, waiting	IVA
Serial Tasks	Tasks are parallel and highly interdependent	Medium- Restructure tasks, automate / support decisions, stagger sessions	Sessions suspended or postponed	CPM
Rich Media	Precise, high bandwidth communications (shared databases and displays)	High- Buy/build technologies	Magnified communication errors and overhead	ICEMaker
Knowledge Network	Required information must be immediately available.	High- Dedicate / hire experts	Delay for access to external resources	Blanche
Flat Hierarchy	No organizational barriers or management overhead	Medium- Empower workers	Decision making slows to a crawl	Thompson
Authoritativeness	Actors must command the respect of co-developers	Medium- Staff the confident and competent	Infighting, over-conservatism, defensiveness	
Goal Congruence	Participants aspire only to the collective achievement.	Low- Team building, Incentives, indemnification	Inefficient products, infighting, corruption	OrgCon
Equivocality	Procedures and goals are well understood	Low- Reduce range of projects	Inaccurate plans, extended debates	B+O
Group Communications	Actors must be able to converse in groups of three or more	Medium- Co-locate, buy/build tech	Sub-optimal joint choices, inefficient/ confused processes, failures to commit	Galbraith, Graph Theory

Table 1: This table outlines ten obstacles that organizational designers must hurdle in order to effectively employ extreme collaboration. Each factor introduces coordination latency through a distinctive means, and requires unique adaptations.

This paper is too short to fully explain each of the latency sources. We introduce many of them, however, in the following assessments of three crucial elements of extreme collaboration project management.

7. MANAGEMENT AND STRUCTURE

The hierarchy of authoritative management plays a central role in traditional organizational theory. Because XC depends less on this mechanism, understanding the new organizational form requires us to explore new theories. This section explains how the need for management direction interacts with the processes of XC.

Some of the earliest literature on organizations shows that the activities of multiple managers create delays through the divergence of priorities and processes. Thompson [1967] and Galbraith [1977] indicate that trying to avoid these problems with a multi-layer hierarchy would impose routing delays. Because none of these phenomena is acceptable at the speed of a full-blown extreme collaboration, we argue based on theory that XC requires a relatively flat management hierarchy.

At the same time, a single manager is only able to supervise eighteen engineers with a light hand. Our observations at JPL’s Team-X conform to this analysis, where a single facilitator is supported by a display of collective results, and routinely leaves participants free to embark upon processes of their own choosing. Again, we argue based on theory and observation that the feasibility of extreme collaboration for a given project depends on its ability to operate efficiently with minimal managerial intervention.

Interaction Value Analysis (IVA) uses mathematical queuing theory to demonstrate that imposing structure-through management, for example- only improves significantly upon long-term, naturally emergent organizational behavior under precise circumstances [Nasrallah et al 2003]. They show that some projects are highly unlikely ever to develop efficient (globally optimal) operations without sustained management intervention. Others are likely, in time, to naturally achieve a perfectly efficient equilibrium (in which Pareto optimality equals global optimality).

Alternate Factor	Target	Factor Definition
Diversity	High	The number of independent skill types possessed by parties in the network
Interdependence	Low	The degree to which parties with distinct skills need to collaborate in order for their individual tasks to be of value to the organization
Differentiation	Low	The contrast in skill levels between the most skilled and the least skilled parties for a given skill type
Urgency	Low	The rate at which pending work becomes useless if not completed
Load	Medium-Low	The demand for work relative to resources

Table 2: Reproduced from Nasrallah, Levitt, and Glynn [2003]. The mathematical Interaction Value Analysis model indicates that management structure adds little long-term value to a project when *any* of the factors listed achieves the value in the second column. As an example, JPL’s Team-X does not require rigid organizational structure because its diversity is high- each participant represents a unique discipline. We argue that XC cannot accommodate projects that require a substantial amount of imposed management structure.

Setting realistic expectations and budgeting for XC’s learning curve can provide enough time for IVA’s long-term results to apply. However, the criteria that IVA identifies may involve additional adjustments that are specific to an application. According to IVA, an extreme collaboration project should satisfy one of the criteria that Nasrallah et al identify, and that we reproduce in Table 2. If the project can be shaped to meet *just one* of the criteria, it will develop efficient operations in the long term. If the project can meet none of the criteria, substantial inefficiencies will result from the removal of management structure, and the management style exemplified at Team-X will prove insufficient. Our analysis suggests that under these latter conditions, the project is not amenable to extreme collaboration.

8. MANAGEMENT DECISION MAKING

The mere knowledge that management will make few of an organization’s decisions does not enable us to plan all that is necessary for a shift to extreme collaboration. Our study uses Virtual Design Team (VDT) simulations to investigate the detailed matter of *how* XC organization differs from traditional organization.

Academics and professionals have calibrated the VDT model with experience from a wide range of project studies, and have used it to make some strikingly accurate predictions. The system predicts project performance, however, based on the assumption that workers route substantial decisions *only* through the management hierarchy. We may thus interpret the simulator’s findings as representative of the predictions that an expert in traditional project planning might offer.

As technology accelerates, it becomes less common for supervisors to possess the specialized knowledge that is required to assist subordinates in technical work. The manager’s centrality is reduced, in that problems are frequently directed elsewhere, through a network of technically knowledgeable experts. Over its long development, Team-X has adapted to distribute its total exception-handling load effectively among the specialist participants. Therefore, we assume that their reported work volumes fairly represent actual project demands, including knowledge flow.

By comparing the VDT simulation results with those reported by Team-X, we measured the differences between operations under the authority hierarchy and knowledge network paradigms. Technically, we modeled the XC project with engineers assigned to individual tasks, with the same direct work volumes predicted by Team-X participants. We then calibrated the simulator and retrospectively predicted approximately the same total coordination volume reported among all Team-X participants.

This experiment produced two significant results. The first is based on a simulator prediction that engineers waste approximately ten percent of their time waiting for management decisions. True, even in extreme collaboration, management plays an important leadership role. However, at JPL we observed virtually no project delays that were accountable to a management bottleneck. This outcome dramatically illustrates the inadequacy of traditional authority hierarchy theory. In fact, we suggest that the result *quantifies* in approximate terms our allegation that planners – including human ones – who depend on traditional intuition to design a decentralized, collaborative engineering structure (like XC) are likely to overestimate the importance of management direction. The ten percent

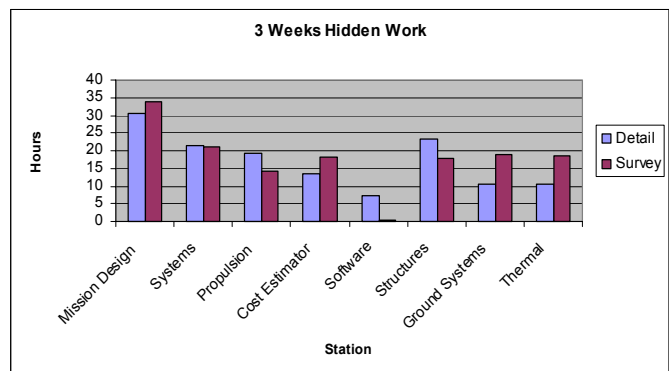


Figure 2: This chart contrasts the “hidden work” reported in a survey of Team X with the “Detail” hidden work predicted for several stations by the VDT simulator. Hidden work consists of coordination and rework that knowledge workers produce, but that less sophisticated planners fail to account for. The differences between these values preliminarily quantify the inconsistency between traditional theories and those required to account for extreme collaboration.

figure also suggests an amount of acceleration that similar projects might experience simply from going from a bottlenecked management hierarchy to a more efficient knowledge network.

Our second result is that although VDT can be retrospectively calibrated to show the same total coordination volume reported by Team-X participants, the simulated *distribution* of hidden work *among individual tasks* did not match perfectly (Figure 4). We believe this results from the simulator’s inability to model the routing of decisions through the knowledge network of participants. Based on this result, we alert organizational designers to the danger of underestimating the workload that technical experts will incur as they coordinate heavily in decentralized knowledge-based projects such as XC.

9. MANAGEMENT AND KNOWLEDGE

Practices such as XC are both explicitly designed and naturally evolved to effectively manage the knowledge network itself. More specifically, every member of Team-X uses a spreadsheet that his or her organization has established explicitly for the task. XC requires the engineer and spreadsheet to encapsulate much of the data and procedural knowledge that is required during design sessions. Further, while most organizations occasionally leverage outside resources’ technical capabilities, XC requires that the team of engineers collectively possesses all of the technical expertise that may be called upon during the

design session. In terms of theory, the XC team uses a closed and instantly available knowledge network.

Team-X’s adaptation contrasts starkly with the alternative. If an XC session were to require knowledge that lies outside the ken of its participants, the team has to access outside resources, and this will introduce substantial latency. Because of the high task interdependence, one such instance could render worthless a sizable fraction of the available design session time.

Another substantial coordination problem emerges when a large number of dependencies stretch across the knowledge network. In mathematical terms, “hierarchy” describes a directed, acyclic graph structure, also known as a “tree”. The illuminating word here is *acyclic* (lacking cycles). Under a simple model of decision making and information exchange, a hierarchy may be guaranteed to effectively distribute authority and reliably gain closure- albeit at a sometimes suboptimal solution. However, where cycles arise among *dyadic* (two-person) relations, termination at any solution may not be guaranteed. Failing to diagnose this phenomenon may be the basis for substantial delays in collaborative engineering where response latencies have non-trivial durations.

Team-X solves this problem in XC “sidebars” by enabling *all* members of a decision-making cycle to virtually pool information, preferences and alternatives. Mathematically, we view this process as virtually collapsing a subgraph that contains cycles a special “sidebar node”.

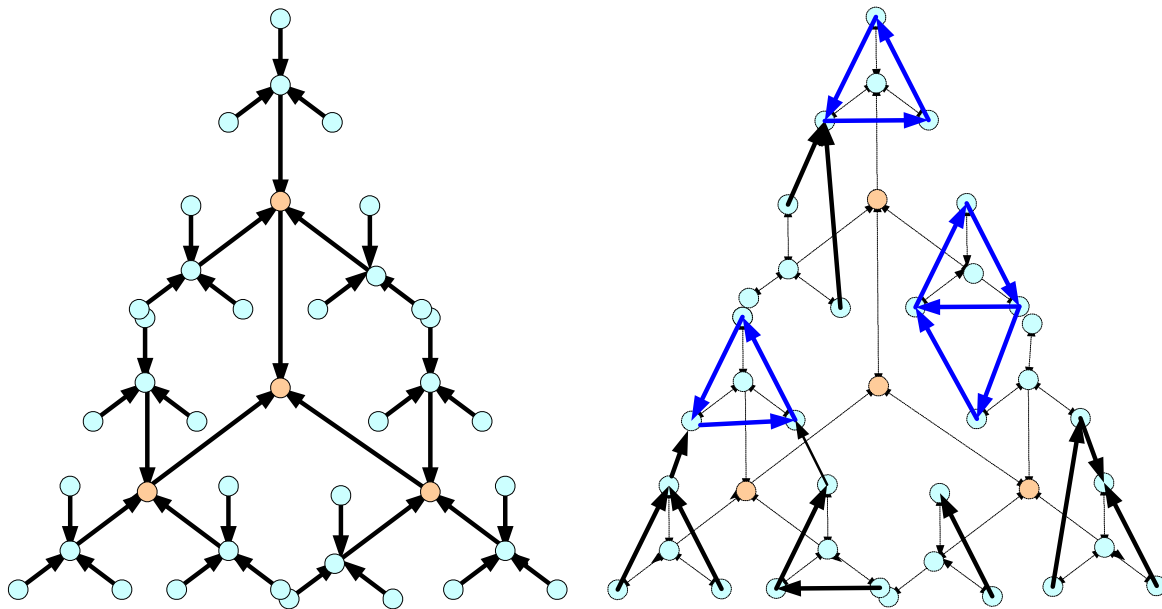


Figure 3: The graph at left shows a typical hierarchy of traditional information flow- a flow that is opposite that of decisions. Laying the traditional ‘org chart’ in this alternative format facilitates the cognitive leap from a tree to a network (at right). On the right is a typical information flow mandated by the content of knowledge work and the expertise of organizational actors. Routine interdependence produces cycles that motivate organizational adaptations such as group communications, extreme collaboration, and elimination of managerial bottlenecks.

One implication of this theory is that XC requires a culture that promotes egalitarian and respectful collaboration and technical conflict resolution. In addition, this analysis indicates that XC requires multiple, simultaneous group communications. Team-X provides this through physical collocation, while Mission Control produces the same value with interlocking voice loops.

10. DISCUSSION

XC is analogous to the operation of high-performance automobiles in that many elements of the total system are designed for specialized behavior. Bumps in the road, hardly noticeable at twenty miles per hour, can be disastrous at two hundred. Therefore, well before a race, the track must be cleaned and smoothed, and this is the function of Team-X's week long "pre-session" study of the project at hand. Similarly, just as every engine component is specialized and inspected, every station's home organization painstakingly prepares its product model and participating representative. Finally, once the race is on, there is no time for ambivalence. An XC team, like a driver, must be prepared to make decisions quickly and conclusively. While the appearance and performance that result from these adaptations is radically different on the surface, the fundamental forces and operations in play remain the same. Even at high speed (low latency), we are still looking at a car, and we can understand it by extending the fundamentals.

The complexities of extreme collaboration merit a healthy respect. In technical terms, extreme collaboration is a chaotic system that may behave quite differently under only slightly differing conditions. We advise organizational designers to adopt the practice gradually and warily until the effectiveness of XC becomes more thoroughly understood.

With this caution in mind, we have also sought to convey our optimism that the intuitive theories that explain XC apply quite broadly. Of particular interest to practitioners, this implies that we may learn much about XC simply by carefully applying established theories to the new domain. Theorists may find equally provocative the inverse conjecture that new theories uncovered by observations of XC might illuminate broad fields that have suffered from a lack of profoundly distinct data points.

Clearly, much remains to be said about the design of extreme collaboration. Each of the latency sources in Figure 1, for example, merits an exposition of considerable depth. Nevertheless, we believe our example analyses to conclusively impart several important points.

In particular, we hope to have drawn attention to and shed light upon two fundamental elements of modern organizational behavior. The first, coordination latency, indicates that all organizations are located on a quantifiable continuum of collaborative efficiency. We suggest that every organization can benefit from an audit of individual latency sources.

The second major theoretical concept, knowledge based exception handling, alerts practitioners to the steady

increase in dependence on experts in the technical labor force. Organizational designers cannot afford to continue discounting this phenomenon or addressing it with short-term solutions. Today's knowledge and expertise bottlenecks may have similar impacts to yesterday's management bottlenecks, but they also herald an entirely new set of dynamics and opportunities.

The recent expansions of particularly compatible social science theories and analytic techniques are creating an exciting time for computational organizational modelers [March, and Burton, in Lomi and Larsen 2001]. Properly applied, the methodology can facilitate practical organizational design just as effectively as it strengthens scholarly results [Kunz et al 1998]. Our work illustrates the power of computational organizational models to both extend and lend specificity to qualitative theory, ethnography, and survey research.

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