

VDT-KS: Simulating the Impact of Flexible Knowledge Sharing Across the Internet¹

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Abstract

The information processing view of organizations, first conceived by March and Simon (1958), and introduced to managers by Jay Galbraith (1974), proposed that knowledge workers process information until they encounter “exceptions”—situations in which the information required to execute a non-routine task exceeds the information available to the person performing the task. They then refer exceptions upward in the hierarchy to find someone who can provide the needed information to resolve the exception. In this perspective on organizations, which underlies much of organizational contingency theory (Burton and Obel, 1998), the supervisory hierarchy is the primary resource available to workers for resolving their exceptions. The Virtual Design Team (VDT) computational modeling and simulation framework (Levitt et al, 1994; Kunz et al, 1998; Jin and Levitt, 1999) operationalized and extended Galbraith's framework to predict the both individual and organizational performance of project teams engaged in fast-paced knowledge work, assuming hierarchical exception handling. Modern organizations are attempting to leverage the Internet for more flexible knowledge sharing to resolve exceptions. VDT-Knowledge Sharing (VDT-KS) extends the VDT framework to model and simulate two kinds of more flexible knowledge sharing strategies: “*Connective Knowledge Management Solutions*” whereby organizations facilitate direct knowledge sharing between individuals by publishing knowledge directories and instituting incentives for experts to share their knowledge with others; and “*Communal Knowledge Management Solutions*” whereby organizations develop knowledge content repositories that can be accessed asynchronously, around the clock and around the world. This paper presents the VDT framework, and shows how VDT-KS extends VDT to model and simulate Communal and Connective knowledge sharing across the Internet.

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Knowledge Networks: Augmenting the Hierarchy

Classical organization theory dating back to Max Weber and Henri Fayol views the supervisory hierarchy not only as the primary means for resolving exceptions, but as the only legitimate means for sharing knowledge in an organization. In 20th-century organizations that were implemented in accordance with classical management guidelines, a worker who encountered an exception—any situation in which the worker lacked some required information or knowledge to proceed with a task—would ask his or her supervisor for advice to resolve it. If the first level supervisor did not possess the knowledge or authority to resolve this exception, he or she would pass the exception up to the next level, until it could be resolved. The information to resolve the exception would then be passed back down the hierarchy to the worker who initially generated the exception. Of course, even early 19th-century workers had informal access to peers from whom they could seek advice, but such access was practically limited to a relatively small group of peers within their local workgroups.

Galbraith (1974) helped to formalize the notion of matrix organizations in which multiple hierarchies overlap, so that many workers have two or more supervisors—for example, a project supervisor and a functional supervisor—to whom they can refer different kinds of exceptions. However, Galbraith still viewed these supervisory hierarchies as the primary knowledge management device for handling exceptions.

Galbraith's early work focused on both the information processing limitations (the “bounded rationality”) of workers and their supervisors, as well as the information communication limitations of earlier low bandwidth communication technologies such as memos and textual computer printouts. He asserted that bottlenecked supervisors and clogged information channels were the major limitations on the effectiveness of fast moving project teams, and proposed two kinds of generic strategies for addressing the information overload problem: reducing information processing demand, and increasing information processing capacity.

Strategies to Reduce Information Processing Demand

Galbraith's first strategy proposed that organizations attempt to reduce their information processing demand. He proposed that they (1) decentralize decision-making to autonomous subunits to reduce the need for referring exceptions to senior managers, and (2) increase “slack”—i.e., loosen technical performance requirements, budgets and schedules—to decrease the number of exceptions arising from violated technical, cost or schedule constraints. The former depends on the divisibility of tasks and the availability of competent, low-level leaders; the latter trades off lower product value and higher direct costs to reduce information processing costs.

For many modern organizations, neither of these solutions is viable. The components and subsystems that comprise custom products and solutions are highly interdependent with one another. Designing and manufacturing each of the components or subsystems of a custom system within autonomous, decentralized subunits would almost certainly lead to subsystem incompatibilities, with resulting product quality problems. At the same time, increased global competition and Internet-empowered customers are rapidly driving the last ounce of technical, cost and schedule slack out of every transaction in the global economy, so increasing slack is not an option that managers can employ to reduce information processing demand. Indeed, manufacturing theory and practice suggest strongly that reducing slack is a fundamental strategy in controlling and improving system performance (Galbraith and Lawler, 1993).

Information processing demand on organizations is thus likely to continue to increase rather than decrease for the foreseeable future.

Strategies to Increase Information Processing Capacity

Galbraith's second strategy proposes that organizations find ways to increase their information processing capacity. To increase organizational information processing capacity, he recommended

that organizations: (1) use enhanced communication technologies (hardware and software) to augment vertical communication; and (2) deploy matrix organizations with formalized multi-dimensional hierarchies and project-based teams to facilitate lateral communication.

The Internet has enabled and significantly accelerated both of these strategies for enhancing the information communication channel capacity of 21st century organizations. Thus, channel capacity is much less of a limitation for many firms that it was even five years ago. However, for many of today's fast-moving technologies, older, more experienced workers up the hierarchy are unlikely to have the needed technical skills and knowledge to resolve exceptions for younger, more newly hired workers. For example, a Java programmer's supervisor is likely to have been trained in an earlier programming language like C++; and his or her supervisor may have been trained in an even earlier programming language like Fortran or Cobol. The same dilemma exists for biotechnologists, microprocessor designers, and other knowledge economy professionals. Thus, the hierarchy frequently no longer possesses the requisite knowledge—even though it may have the raw information processing and communication capacity—to address complex technical exceptions encountered by many of today's most critical knowledge workers.

However, knowledge workers in 21st century networked organizations have access to a broad range of specialists outside of the various hierarchies in which they are embedded. Their networked peers may have relevant current knowledge, and they can often help to resolve exceptions that arise in their work. Moreover, Internet based video conferencing, desktop and application sharing, data mining and other communication and collaboration technologies are transforming the process of asking and resolving technical and managerial exceptions within and across organizations in ways that were undreamed of even ten years ago. Workers have a wide range of synchronous and asynchronous broadband tools available to them to access people and knowledge from around the world that they need to perform their complex tasks. As workers learn to exploit their new tools and emerging knowledge networks to resolve exceptions with increasing competence and confidence, the hierarchy is continuously receding in importance as an exception handling mechanism. Workers' informal knowledge networks are increasingly supplanting the hierarchies in which they are embedded as their primary mechanism for resolving exceptions.

For all of the reasons discussed above, there is strategic business importance and theoretical relevance in a firm's capability to leverage information technology and knowledge networks effectively to disseminate the knowledge of the best available experts within its own organization and its extended supply chain. To gain competitive advantage through better knowledge sharing, companies have spent millions of dollars and thousands of person years of scarce human resources to implement knowledge management IT solutions, with widely varying degrees of success. Orlikowsky (1992) has reported how two ostensibly similar, large management consulting firms implemented essentially the same knowledge management solution, with very different outcomes. The Lotus Notes™-based system was widely used and produced significant value in one firm, whereas it was little used in the second. Others have found a variety of more or less successful outcomes achieved by firms that implemented Internet based knowledge management solutions.

Absent validated theory and simulation tools that can reliably predict the individual and organizational performance of a given organization using alternative tools and approaches for knowledge sharing, managers must rely on costly, trial-and-error experiments to prototype and refine their Internet based knowledge sharing solutions. The balance of this paper reports on research to develop new kinds of computational models of organizations, information technologies and work processes that can help managers to model and simulate Internet-based knowledge sharing solutions in different organizational and work process contexts.

Computational Models of Information Processing

Since the 1950s, a small, but growing group of organizational researchers has built computational models of organizations that can be used to predict their behavior, and ultimately to support

managerial interventions aimed at optimizing organizational performance. The pioneering computational simulation models of Cyert and March (1963) showed that relatively simple models that embedded specified micro-behavior in computational agents could produce surprisingly accurate predictions of team and company level performance. Object-oriented programming languages and fast, low-cost processors have led to an explosion of such research in the last decade.

Computational organizational models are contributing both to organization theory, and to management practice. Cognitive and social psychology theories have traditionally been validated by synthetic experiments, frequently involving paid students subjects. It has been difficult to link theories at this level with organizational contingency theory or organizational ecology theory developed by sociologists, describing the behavior of organizations influenced by variables in their task environments. Computational models that bridge between these two levels can provide a semiformal theoretical bridge between well understood and validated theories of cognitive and social psychology, and organizational level predictions generated from more abstract contingency theory. Researchers can embed specific micro-theories in computational agents, and then exercise the simulations to generate predictions of organizational performance for groups of agents linked in different ways to simulate alternative organization structures.

Once validated against historical and contemporaneous empirical data, such computational models can generate predictions that managers will be able to rely on to intervene proactively in their organizations (Thomsen et al, 1999). Management consultants can use such tools to offer valuable new services as organizational designers.

The Virtual Design Team (VDT) Modeling and Simulation Framework

One organizational simulation framework that has gone through extensive development and validation, and is now in use in a number of Fortune 100 companies, is the Virtual Design Team system, developed at Stanford University over the last 12 years. In the remainder of this paper, we discuss the key concepts and limitations of VDT, and show how our research group at Stanford University is currently extending it to model Internet-based knowledge sharing⁵.

VDT Motivation

Executing interdependent tasks concurrently creates a huge volume of coordination and rework, compared to traditional sequential work processes. Fast track projects fail when the volume of indirect work plus direct work of participants overloads the project organization. Traditional project planning and scheduling tools based on the Critical Path Method ignore interdependencies between concurrent activities and do not model organization structure or communication processes and tools. The predictions of CPM-based tools are thus systematically optimistic for fast track projects. This simple theoretical argument is consistent with the widespread observation that projects are far more likely to finish late than early. The practical motivation for VDT was the desire to develop new theories, methodologies and tools that managers could easily use to predict the performance of organizations executing highly concurrent, fast track product development projects.

VDT Concepts

VDT is based on Jay Galbraith's (1974) information processing view of organizations. In this view, the details of tasks are abstracted away, and work is viewed simply as a volume of information to be processed by an organization consisting of individuals or subteams with specified information processing and communication capacity. Galbraith's theory provided the kinds of qualitative predictions and recommendations listed above. VDT research operationalized and quantified Galbraith's theory at the level of individual tasks and project participants.

⁵ For more detailed coverage of the concepts underlying VDT, and its application in a variety of settings, see (Jin & Levitt, 1999; Kunz et al, 2000; <http://www.vite.com/>).

VDT models direct work as a quantity of information to be processed, specified in person-hours or person-days. It operationalizes the notion of exceptions and their resolution as packets of information passing through communication tool channels into the in-boxes of organizational participants. Participants stochastically select one of several items to attend to from their in-boxes. We conducted ethnographic research in organizations to quantify the information processing volumes for typical exception handling and communication tasks, and we gathered data on organizational productivity rates and error rates to quantify the effect of participant skills and experience on information processing speed and error rates in task execution. VDT also quantifies the effect of a variety of organizational decision-making policies—e.g., the level of centralization of decision-making—on the routing of exceptions and the likelihood that they will be responded to. VDT thus generates specific predictions about activity and project schedule, cost and work process quality for a given organization assigned to specific project tasks.

Relatively simple, high-level VDT models contain 5 to 10 business milestones, each enabled by 5 to 10 activities, assigned to fewer than 20 organizational actors. These relatively sparse models describe complex product development efforts in sufficient detail to make extremely accurate predictions about schedule, cost and quality performance. The organization and work process models are graphical and intuitive, and we have found that developing such models real-time in a group setting can be extremely helpful in creating shared mental models of a work process and organization for all project participants. *Figure 1* shows a typical VDT model.

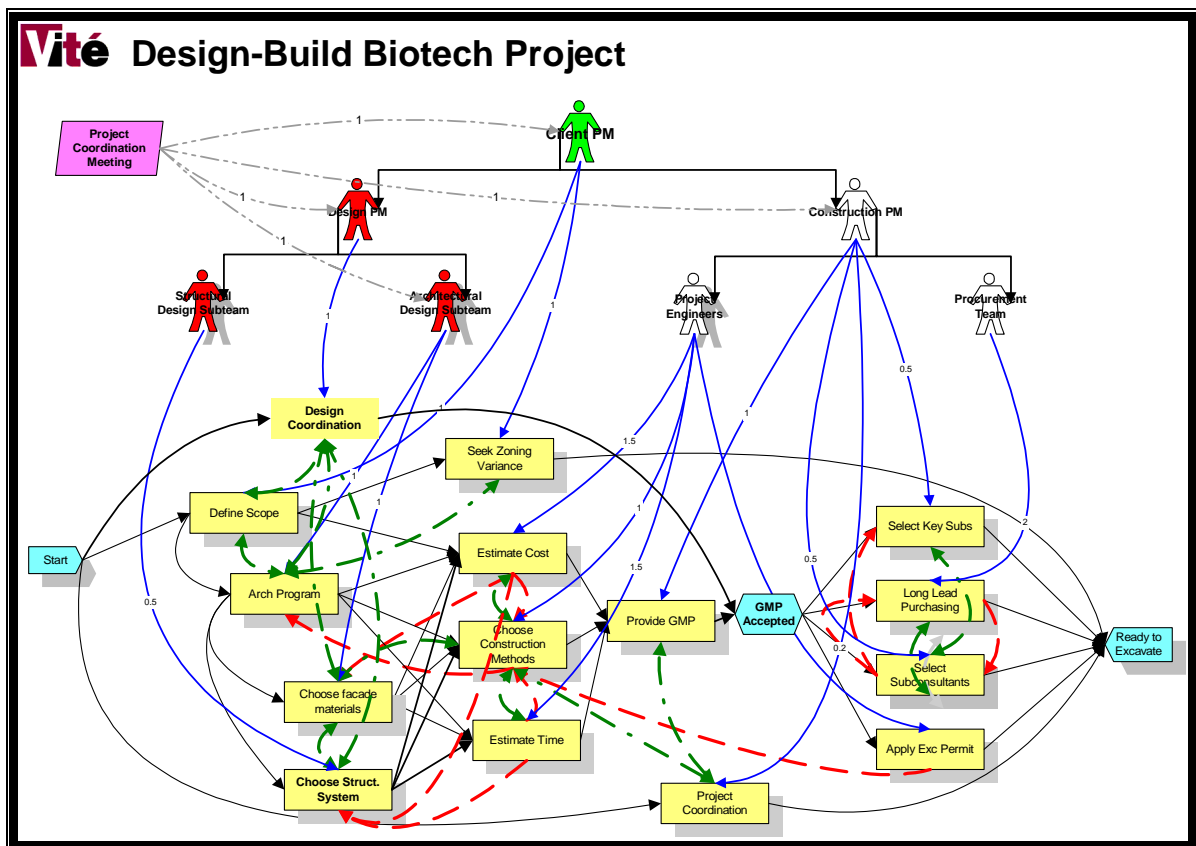


Figure 1. VDT/SimVision Model of a Project Work Process and Organization. This model shows the milestones (hexagon), tasks (rectangles), actors (human-like icons) and dependencies (connecting lines) for the pre-construction activities in developing a new Biotech facility. Note the relatively small number of milestones and tasks. By analyzing this model, the client determined that it would have to simplify the facility design to complete the project on schedule. (Graphics courtesy of Vité Corporation, www.vite.com)

VDT Validation

The original ethnographic research to quantify VDT parameters was conducted in organizations engaged in the design of oil refineries and power plants. Following the step-by-step validation trajectory outlined in Thomsen et al (1999), we subsequently validated VDT retrospectively, contemporaneously, and prospectively on more than 50 projects in construction, aerospace, consumer products, semiconductors, pharmaceuticals, and software development.

VDT Applications

After VDT had proven to be extremely accurate in predicting schedule and quality risks for the Lockheed Launch Vehicle prototype in 1995 (Kunz et al, 1998), Vité Corporation was formed to commercialize VDT under license from Stanford University. The current commercial release of the software, called SimVision™, is currently in use by dozens of companies, including Dell Computer, Procter & Gamble, AT&T Wireless, Seagate, Aviron and Hewlett-Packard. SimVision can model either a single project, a program consisting of a few projects, or an entire portfolio of programs and projects for an enterprise.

VDT Limitations

The VDT and SimVision model has proven extremely useful for designing and managing fast track development projects in a variety of industry settings. However it has significant limitations:

- VDT assumes that the work process and organization can be predefined and will be unchanged for the duration of the project. All tasks and organizational participants must be predefined; all tasks must be preassigned to given organizational participants. Any exceptions that arise will simply add information processing load to pre-specified participants; and any rework simply adds information processing volume to predefined activities. This abstraction is adequate for many kinds of routine, albeit fast-paced, product development work. However it falls short of accurately modeling “diagnose and repair” service or maintenance work. In service and maintenance work, diagnostic activities are used to define subsequent repair activities, and the work process must detect and resolve any side effects that arise in the course of executing diagnosis or repair activities. Health-care delivery, equipment maintenance, and other kinds of non-routine service work thus fall outside of the scope of the original VDT and SimVision frameworks.
- VDT assumes that the hierarchy is the only available knowledge network for resolving exceptions. SimVision extends VDT to model both project and functional hierarchies in a two-dimensional matrix organization structure. However even SimVision assumes that project and technical exceptions are resolved hierarchically, albeit within two distinct kinds of hierarchies. As we have discussed above, this idealization may be misleading for many high-tech enterprises where the requisite knowledge to resolve exceptions frequently lies outside of the hierarchy, or even outside of the firm. Moreover, a variety of technologies now exist to support more flexible knowledge sharing through direct peer-to-peer communications, mediated by communal knowledge repositories.

Next, we will describe a set of extensions to VDT that we are currently conceptualizing, implementing and testing to model peer-to-peer knowledge sharing within and across project teams.

The Virtual Design Team—Knowledge-Sharing (VDT-KS)

The knowledge management solutions that companies are attempting to develop fall into two broad categories. The first set of solutions attempts to capture, formalize and package expert knowledge in a form that can subsequently be accessed asynchronously by those who need it, without the need for them to consult the expert directly. The second wave of knowledge management solutions recognizes that it is very difficult to capture sufficient context around knowledge for it to be confidently reused by others. These solutions therefore attempt to help workers who encounter

exceptions to identify and link up with appropriately skilled and experienced human experts who can provide contextually embedded knowledge through direct communications. Janet Fulk and Peter Monge (2000) have termed these two approaches “Communal” vs. “Collective” knowledge sharing solutions, respectively.

We decided to develop representation and reasoning extensions to VDT to model each of these two kinds of knowledge management solutions as separate research efforts initially, and then attempt to combine them.

Modeling Communal Knowledge Management Solutions

Thomas Allen (1977) described how technical professionals attempt to resolve exceptions, but this research predates the ubiquitous nature of modern information technologies. Building on Allen’s work, we have identified and will operationalize and quantify the micro-behaviors associated with communal knowledge sharing in 21st century organizations. This communal knowledge sharing is viewed as being accomplished by interaction between the knowledge worker and a computer interface connected to a knowledge base (the Internet, intranets or databases). This interface and associated knowledge base define the Communal Knowledge Mechanisms (CKMs).

The micro behavior to be incorporated is relatively straightforward. When faced with an exception the knowledge worker must choose to ignore the exception, rework the activity, or pass the decision on to the next person in the hierarchy. The existing VDT software models this choice stochastically and each supervisor at a given level—i.e., each subteam leader or project manager—employs the same rules for deciding. As identified by Allen, most knowledge workers will tend to seek additional information before referring an exception upward to their supervisors. The new micro behavior will identify the mechanism by which a knowledge worker with an available CKM seeks additional information from that CKM before acting on the exception or referring it upward to a supervisor (original VDT) or laterally to a peer (described in the following section).

In Allen’s work, the micro behaviors that engineers (and other knowledge workers) exhibited in searching for information were strongly correlated with the knowledge worker’s perception of both the accessibility and credibility of the information source. This suggests that modern CKMs, which are generally perceived as accessible and often perceived as providing credible information, should play a significant role in supporting today’s knowledge workers. Hence accessibility and credibility are two important initial attributes of CKMs that we model.

We are developing additional attributes of CKMs based on the work of Nass & Reeves (1998) which suggest that advanced CKMs are likely to be treated as social entities by the knowledge worker, and interactions between a worker and a CKM should thus be modeled as being social in nature, in addition to being cognitive.

The existing VDT structure serves as both the theoretical and computational foundation for our work. Building on this foundation allows us to frame the attributes consistently with the previously validated theory and provides insight as to how to incorporate the attributes of CKM into the model. For example, VDT already incorporates “Skill Level” for actors using a scale of Low, Medium or High to indicate the relative knowledge level of the Actor for a given skill set. The incorporation of credibility for the CKM into VDT-KS is accomplished in a similar manner by rating the credibility of the information accessed via the CKM on the same Low-Medium-High scale for the same skill which now represents a knowledge domain instead of an Actor’s individual skill set. *Figure 2* illustrates one potential VDT-KS view of a project team with CKM included.

In the example project shown in *Figure 2*, workers from two collaborating companies can access multiple CKMs, each of which will have its own attributes. The impact of the CKM will vary based on the attributes of the Activity, the Actor and the CKM.

Focusing on exception handling during project work allows the impact of the CKM on performance to be separated from other benefits associated with information technologies such as improved

communications speed, administrative improvements and the impact of learning on individual performance. It also allows the impact to be studied independent of the cost associated with constructing and providing the CKM system.

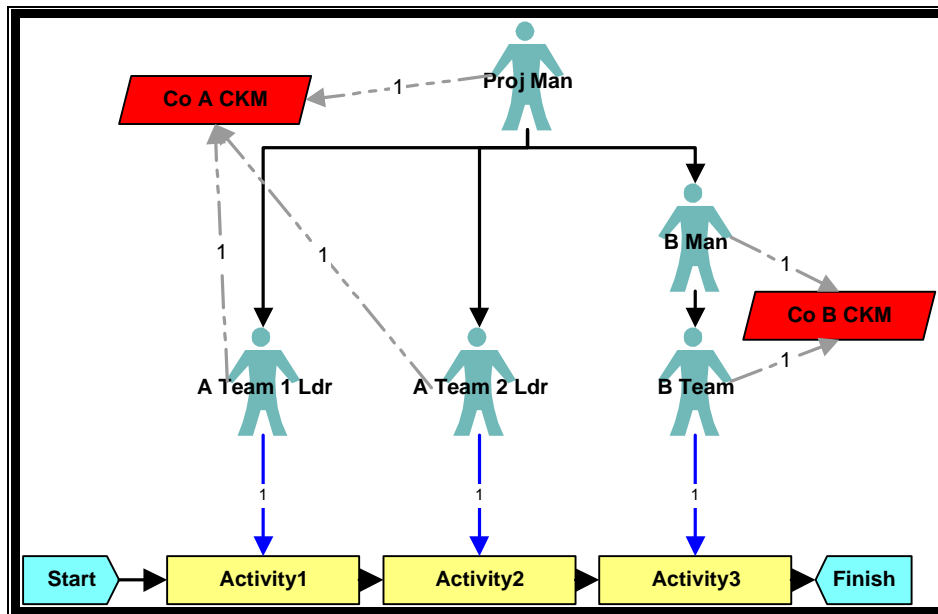


Figure 2. Including Communal Knowledge Mechanisms in VDT. This illustration depicts a VDT-KS representation of a project team consisting of two companies A and B, and two independent CKMs: one referenced (dashed line) by the **Proj Man**, **A Team 1 Ldr** and **A Team 2 Ldr** actors, the other referenced by the **B Man** and **B Team** actors. The actors also have reporting relationships (solid lines) and activity responsibilities (solid lines with “1”). Other configurations are possible, e.g., multiple CKMs within a single company or a CKM that is shared between employees of two or more companies collaborating on a project.

Modeling Connective Knowledge Management Solutions

Wegner(1987) describes transactive memory as a system for encoding, storing and retrieving information within a group. Our observations of technical project teams suggest that team members routinely employ elements of “transactive memory” for locating and coordinating expertise to handle certain types of exceptions that arise during project execution. Within a transactive memory system, group members engage in three key processes: (a) update their perceptions about the expertise of other members (i.e., who knows what), (b) allocate new information to other members believed to possess related expertise, and (c) retrieve information from other members most likely to possess relevant expertise. The various communications and transactions that occur between group members facilitate these encoding, storage and retrieval processes.

Our goal is to draw upon transactive memory as our framework for representing informal exception handling in cross-functional project teams. In the extended VDT model, we take the current state of a project team’s transactive memory as a new input to the model. When an actor encounters an exception, rather than automatically referring the exception up the hierarchy, the actor considers the expertise requirements of the current activity, searches its internal directory of who knows what, and invokes transactive retrieval as a mechanism for obtaining relevant expertise to handle the current exception.

As Figure 3 shows, these transactive memory micro-behaviors, when aggregated across all actors, result in an emergent network structure, which represents the operational (i.e., the “in-use”) exception-handling network. This exception-handling network differs from the default exception handling hierarchy contained in the current VDT model in that the properties of the operational

exception-handling network do not remain fixed over the duration of the project, but rather vary with attributes of the set of “active” tasks and the distribution of skills among actors.

We represent actors’ transactive memories as imposing certain constraints on actors’ actions to resolve exceptions using informal exception handling mechanisms. In the extended model, the emergent information-processing load associated with informal exception handling, coupled with certain network-based constraints on actor actions, work together to produce a dynamic load distribution across members of the project team. At the micro-level we describe this load distribution in terms of actor centrality within the operational exception-handling network, and at the macro-level in terms of network centralization and density. Using measures of individual and project performance contained in the current VDT model (i.e., actor backlog and communication risk, respectively) our goal is to examine the relationship between properties of the operational exception-handling network and individual and project-level performance.

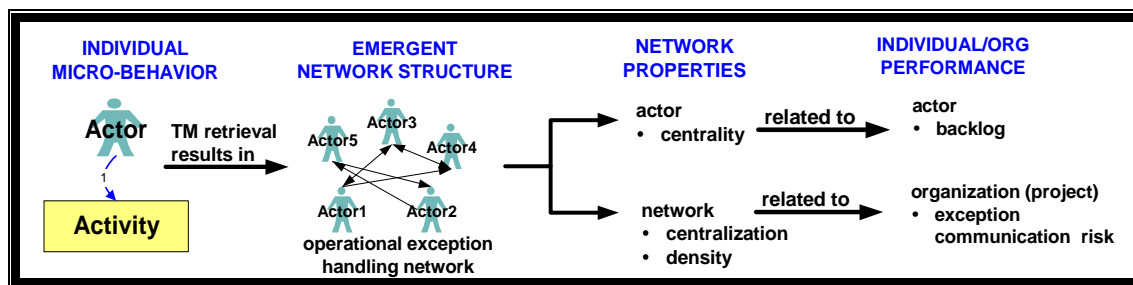


Figure 3. Connective Knowledge Network Extensions to VDT. In this extended version of VDT, individual actors have responsibility for activities, but they also have Transactive memory and actor communication technology so that they are not limited to using the actor reporting hierarchy for resolving exceptions. They can seek advice from anyone that they think might be able to help them, and to whom they are connected via one or more communication technologies (including face-to-face communication with collocated peers). The emergent exception-handling network has attributes that, in turn, affect individual question asking and answering behavior. The ongoing co evolution of individual knowledge and the knowledge network affects both individual and team performance metrics.

A Trajectory for Validating VDT-KS

We will first attempt to validate each of these sets of extensions separately, following the stepwise trajectory presented in Thomsen (1999). This includes steps to

- Check the internal validity of each of the new micro-behaviors using simple, toy problems;
- Perform a series of “intellective experiments” in which we use the simulator as a theorem prover to validate the macro predictions of each model against existing macro organization theory using idealized work processes, organizations and knowledge management solutions;
- Calibrate the parameters in the extensions by comparing model predictions to retrospective performance on real world projects; and
- Validate the calibrated model by comparing its predictions to contemporaneous and prospective real world project performance data.

Discussion

A small set of fundamental research questions has motivated the VDT program for over a decade, including:

1. *How can very simple micro theories of the behavior of organizational agents predict the observed behavior of organizations that classical organization theory does not explain effectively?*
2. *How can we validate the micro and macro predictions of theory?*

3. *How significant are the effects on project performance of actor-actor exception handling and coordination?*

Organization theory classically conceptualizes the organization as one entity, the project, or possibly two, the organization and the planned task. Our intuition has been that the details of the coordination work, exception handling and rework can, depending on the dynamic context of the project, dramatically affect the performance of actors doing direct work. We model project milestones, tasks and actors as computational agents that have attributes and behave in simple ways. The “micro theories” concern the behaviors of these modeled organizational agents. Our research method has implemented and validated this intuition in a number of clearly defined project domains.

Another fundamental research question concerns the method of research:

4. *How can discrete-event simulation of symbolic (non-numeric) models of organizational agents predict the dynamic information processing performance of both agents and aggregate projects?*

The agent micro-behaviors need somehow to aggregate to generate some measures of the classic project performance of duration, cost and quality. Our initial intuition was to simulate the performance of organizational agents using the computational method of discrete event simulation, a method widely used in factory simulation in the manufacturing industry. We can emphatically answer “YES” to the fundamental question of whether it is possible to use simulation of information processing and communication by agents to predict both individual and team performance. We continue to explore the methods of implementing simulation models and limits of the simulation-based predictions.

As we discussed in both the background on Knowledge Networks and the specific project summaries, the initial VDT model assumes that exception handling and actor coordination follow from the constraints of actor reporting, actor-task assignment and task coordination and rework dependencies. The fundamental research questions motivating our recent work include:

5. *How can very simple micro theories of the behavior of organizational agents predict the observable behavior of organizations that support peer-to-peer knowledge exchange among actors using voice, data and video networks?*
6. *In comparison with actor-actor coordination through the classic organization reporting hierarchy, how significant is the impact on project performance of using peer-to-peer knowledge networks for exception handling?*

Our ongoing research aims to provide new theories, computational models and empirical data to help answer these questions. If we are successful in implementing and validating these knowledge-sharing extensions to the VDT framework, VDT-KS will enable managers to design their organizations, work processes and knowledge aggregation and sharing technologies to optimize the time-to-market and product quality performance of fast-paced, complex, 21st century projects.

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