# Overview of The Virtual Design Team (VDT) Research Program: 1988-2010

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## About the Authors

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## Introduction

The Virtual Design Team research was launched to enable managers to "Design Project Organizations as Engineers Design Bridges"—i.e., to model and simulate multiple alternative configurations to predict and evaluate their performance in advance of implementing them.

VDT was based on the notion first articulated by Herbert Simon and refined by Jay Galbraith that the first order determinant of an organization's success is its ability to process all of the information associated with:

- **Direct work**, involved in competing assigned tasks by individuals or groups;
- **Coordination work**, arising from the need to resolve task interdependencies and handle exceptions; and
- **Institutional work**, arising from the need to resolve differences in goals, values and cultural norms.

The "big idea" behind the VDT research program was that direct work, coordination work and institutional work could all be viewed as quantities of information to be processed serially by the workers and managers in an organization. Jay Galbraith had proposed this idea as early as the 1970s, but his formulation of the problem was descriptive and qualitative, and could thus not be used to make specific predictions. VDT has progressively quantified, extended and validated Jay Galbraith's information processing view of organizations over the past 20 years to encompass a broad range of project-oriented work processes and organizations.

We began this research in the late 1980s and directed our initial focus on project organizations engaged in semi-custom engineering work under tight time constraints. For such organizations, we could assume a relatively high level of congruency of goals culture and values, so that institutional costs were negligible and could be ignored. However, performing highly interdependent work under tight time constraints creates high coordination costs as interdependent activities increasingly overlap one another in time. Primary emphasis was on modeling the sources of interdependence in project workflow and the way in which exception handling in coordination took place within organizations assigned to do such project work.

Since then, we have extended the representation and reasoning in VDT step-by-step, to address the modeling requirements of less routine work performed by increasingly flexible and dynamic organizations—non-routine product development, service and maintenance work (including healthcare delivery), and highly non-routine work performed in communities of practice—but still assuming negligible institutional cost. Since 2002, we have extended VDT to model multicultural project teams engaged in global projects to develop infrastructure, for which institutional costs are significant. Also, VDT has been extended as "POWER" to model highly non-routine work in extremely decentralized "Power to the Edge" organizations.

This white paper provides an overview of the VDT research program and its evolution over the past 20 years, describes the current status of VDT, and describes our ongoing research in this area.

## VDT in a Nutshell

The Virtual Design Team simulation system is a computational discrete event simulation model of project organizations. VDT analyzes how task interdependencies generate coordination needs and how individual team members' skills and experience, organization design parameters and communication tools change team information processing capacity, and hence project performance. VDT explicitly models actors, activities, communication tools and organizations. VDT simulates actors working on their assigned tasks and the interactions between actors aimed at resolving interdependencies between their interdependent tasks, and interactions aimed at handling technical or interface “exceptions” between subordinates and their supervisors.

The “information processing” view of organizations was first articulated by Herbert Simon and James March in the 1950s, and elaborated by Jay Galbraith during the 1970s. It asserts that the first-order determinant of an organization’s success is its ability to process and communicate all of the information required to carry out and coordinate its work processes. Galbraith’s information processing model of project teams was descriptive and qualitative, not quantitative; it could not make specific predictions about particular organizations. Over the past two decades, Levitt’s ongoing VDT research and its subsequent commercial implementation have extended, quantified and validated Jay Galbraith's (1974) information processing view of organizations to model and simulate team members’ behavior and resulting team performance outcomes quantitatively, with ever-increasing accuracy, for a broad range of project-oriented work processes and organizations.

VDT builds on and quantifies Jay Galbraith’s theories of information processing in project teams, and views both the direct work and resulting coordination work that must be performed by actors on a project as quanta of information to be processed by responsible actors with finite information processing capacity—i.e., “boundedly rational” actors (March & Simon 1956). It simulates the project team executing tasks and coordinating to resolve exceptions and interdependencies. The VDT simulation of a project organization executing its tasks generates a range of outputs that predict the emergent performance of the organization at both the individual actor/task level and the overall project level: duration; production costs, coordination costs (communication, rework and waiting); and several measures of process quality.

VDT takes into consideration the relative match between the complexity of each task versus the skills/experience of the assigned actor to determine the time it would take for the actor to perform the task, and the probability of exceptions in the execution of the task by the assigned actor. Actors are more likely to generate exceptions when confronted with a task for which they do not possess the requisite skills or experience. VDT models exception handling processes to deal with any exceptions that have been generated. Exceptions take time to resolve and result in coordination costs. Actors may be required to partially or completely rework activities that generate exceptions. Further, actors need to attend to communications from other actors and may need to attend scheduled meetings. These communications and meetings generate coordination work and thus increase the amount of total work that must be done to complete a project. Failure to attend to communications or go to meetings increases the probability of errors, thus leading to the possibility of increased downstream coordination and rework costs.

VDT has been calibrated to make accurate predictions of participant backlogs arising from the combination of direct Production Work and emergent Coordination Work, and of the resulting schedule and quality risks for a given project organization. After being validated in multiple real world scenarios, SimVision®, a commercial implementation of VDT, has been used commercially in dozens of real world projects for Fortune 500 companies and governmental organizations to highlight organizational risks and guide interventions aimed at mitigating them.

## Evolution of The Virtual Design Team (VDT) Research Program

The Virtual Design Team (VDT) research was initiated in the late 1980s with the goal of developing new micro-organization theory and embedding it in software tools that could be used to design organizations in the same way that engineers design bridges, semiconductors or space stations—by modeling, analyzing and evaluating multiple virtual prototypes of the system to be designed in a computer.

We recognized from the outset that this was a significant challenge. Micro-theory and analysis tools for designing bridges and airplanes rest on well-understood principles of physics, and involve continuous numerical variables, describing materials whose properties are relatively uniform, and are straightforward to measure and calibrate. Thus analysis of these physical systems yielded easily to solution via sets of differential equations, and subsequently numerical computing. The approach used to develop this engineering science and technology was to embed well-understood micro-theory into the models, and then attempt to reflect the interactions between elemental parts of a model through constraints (such as constraints that maintain consistency between the deflected positions of shared element edges in a finite element model). The result was increasingly accurate predictions of both micro and macro-behavior of many kinds of engineered systems. For many kinds of buildings and bridges, stresses, strains and deflections under a variety of loading conditions can now be predicted to finer tolerances than those to which the facility can be constructed!

In contrast, theories describing the behavior of organizations are characterized by nominal and ordinal variables, with poor measurement reproducibility. Verbal theories incorporating nominal and ordinal variables create a significant degree of linguistic ambiguity, so that experimental results cannot be reliably replicated and contrasting or competing theories are difficult to reconcile or disprove. In the late 1980s, our research group concluded that attempts to model organizations computationally could benefit greatly from the use of non-numerical or "symbolic" representation and reasoning techniques emerging from computer science research on artificial intelligence. Early experiments convinced us —along with many other researchers (e.g,. Masuch & Lapotin, 89)— that this was a fruitful modeling approach. However, VDT took this modeling approach to the next step, which was to combine the symbolic reasoning with numerical, discrete event simulation. VDT used symbolic reasoning about variables like skill levels to set parameters for numerical variables like task processing speeds in a discrete event simulation.

In selecting the kinds of organizations that we would initially model, we picked project teams performing routine design or product development work. For this class of organizations, all work is knowledge work so that we could fruitfully use an information processing abstraction (Galbraith 74) of the work. For routine product development, goals and means are both clear and relatively uncontested, so that we could finesse many of the most difficult "organizational chemistry" modeling problems inherent in the kinds of organizations that sociologists have often studied—e.g., mental health, educational and governmental organizations.

Our quantification and computer implementation of Galbraith's "information demand, capacity and throughput" model can be viewed as an analog to Newton's Laws in physics—a simple, and immensely useful, first order approximation. By operationalizing and extending Galbraith's information processing abstraction in the Virtual Design Team (VDT) computational model, and focusing in an “easy corner” of the space of organizations, we developed several versions of VDT (Cohen, Christiansen, Thomsen,) and validated the representation, reasoning and usefulness of our computational “emulation” models following the rigorous validation trajectory shown in Figure 1 (Thomsen et al,1999; Levitt et al,1994,1999; Kunz et al.,1998).

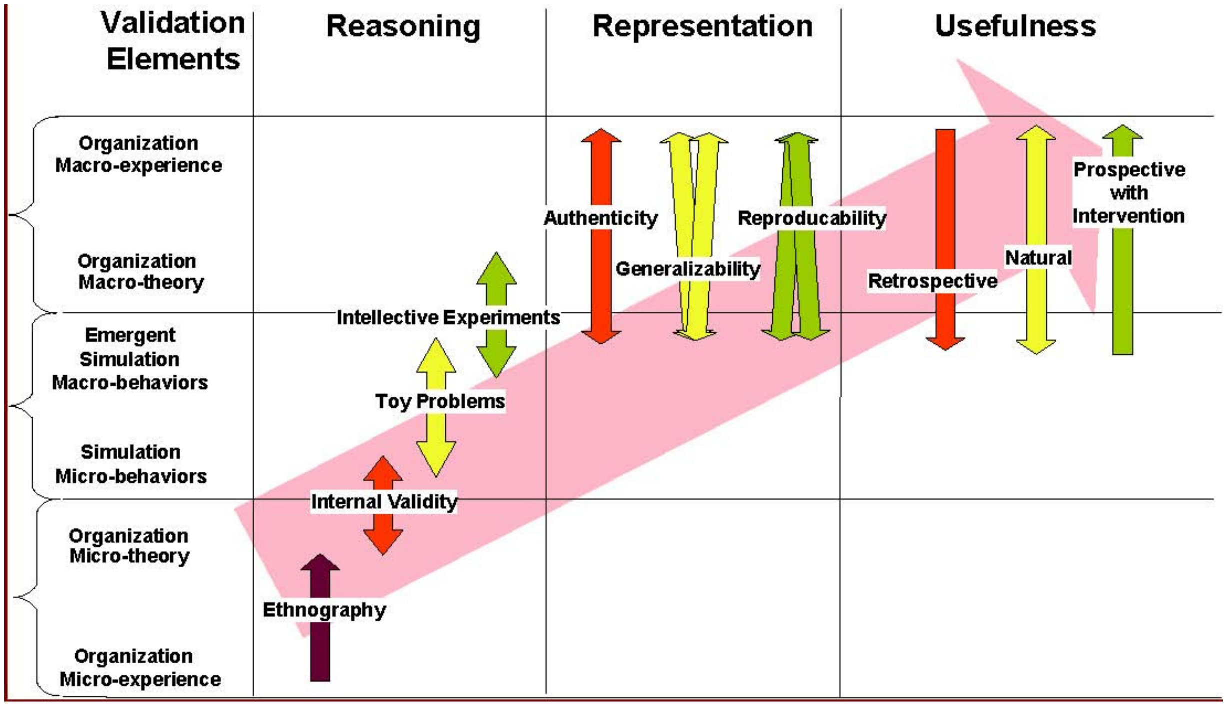


**Figure 1.** Validation Trajectory for Computational Emulation Models, showing how we move successively from validation of reasoning, through validation of representation and, finally, of usefulness. (Source: Thomsen et al, 1999).

Advancing through these validation steps, we were able to develop sufficient confidence in the predictions of our theory and tools that managers in several companies and governmental agencies are now redesigning their project work processes and organizations prospectively, based on the predictions of SimVision™, a commercial implementation of VDT-2 developed by Vité Corporation and subsequently licensed by ePM, LLC < www.epm.cc >. Our VDT theory and analysis tools for project organizations have thus enabled true "organizational engineering" of project teams with congruent goals and relatively routine—albeit complex and fast-paced—design or product development work.

Our intention was always to start with the "organizational information flow physics" and then progressively add elements of "organizational chemistry" to the modeling framework to extend its applicability to less routine tasks and more dynamic organizations. We have executed several steps of this research vision over the past two decades. Completed and ongoing versions of VDT that progressively addressed additional aspects of task and organizational complexity are shown in Figure 2.

The (Cohen, 91) (Christiansen, 99) VDT-1,2 framework has been fully validated through all of the steps shown in Figure 1. VDT-2 is a reasonable model of project work for which: (1) All activities in the project can be predefined; (2) the organization is static, and all activities are pre-assigned to actors in the static organization; (3) exceptions to activities are resolved through the hierarchy and generate extra work volume for the predefined activities to be carried out by the pre-assigned actors; and (4) actors are assumed to have congruent goals, values and cultural norms. These conditions fit many kinds of design and product development work. VDT-2 was commercialized as SimVision™, by Vité Corporation through Stanford's Office of Technology Licensing, and is in use by companies in a variety of industries, and governmental organizations including the US Navy, NASA, and The European Bank for Redevelopment and Construction [ http://.epm.cc ].

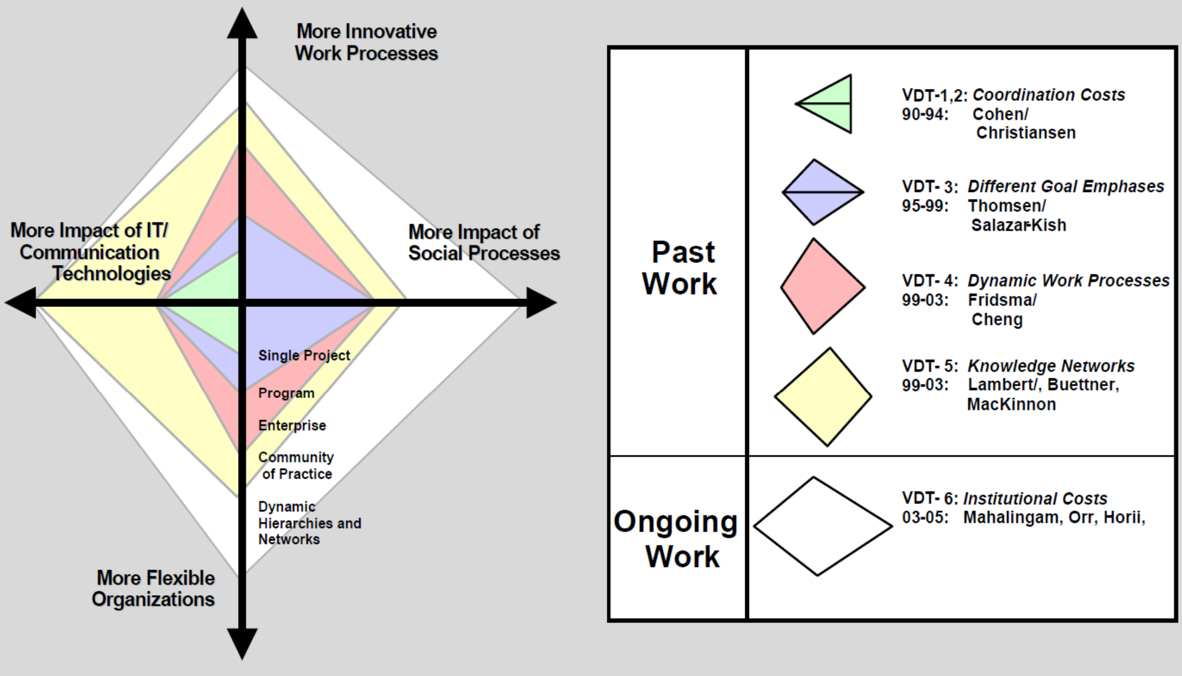


**Figure 2.** VDT Research Trajectory

VDT-3 (Thomsen, 97) extended the range of work processes that could be modeled, to encompass less routine design or product development work, in which tasks are still predefined, but there can be flexibility in how they are executed. Actors can have the same set of goals, but incongruent goal preferences (i.e., a moderate degree of goal incongruency), causing them to disagree about how best to execute activities in the project plan. Following concepts from economic “Agency Theory”, goal incongruency levels between pairs of actors affect both their vertical and horizontal communication patterns. VDT-3 has been validated through "gedanken" experiments—thought experiments, in which the model's predictions are compared to managers' predictions of results. Its prospective predictions have not yet been tested against subsequent real project performance data.

VDT-4 was the goal of a subsequent NSF Grant. VDT-4 extended the applicability of VDT beyond its previous limits on work process routineness and static organizational structure. VDT-4 has been applied to non-routine work involved in health care delivery for bone marrow transplants and similar complex, multi-specialty medical protocols. Diagnosis activities indicate needed repair activities, and any unplanned side effects that arise must be diagnosed and treated contingently. To model this indeterminacy, we had to relax the constraint that all activities and assignments are rigidly prespecified. This required several extensions to the VDT-3 framework. Douglas Fridsma (98) extended the information processing micro-theory in VDT-3 to include a variety of more complex exceptions that can cause activities to be added, resequenced, deleted or reassigned, and actors to be dynamically added to the organization and assigned activities as needed. This extended framework has been implemented and internally validated on *toy problems* (See Fig 1). Carol Cheng Cain (Cheng 01) then extended Fridsma's work to model context-dependent decision making (e.g., medical decision aing in intensive units where organization structure and staffing changes as a function of time of day or day of week) and *retrospectively validated* VDT-4 predictions against empirical data in several clinical settings.

A longer-range goal of our work was to begin modeling even more flexible organizations that could be viewed as dynamically shifting "communities of practice," in which actors can communicate with anyone they choose, either inside or outside their local "organization." Software development teams and some consulting organizations currently approximate this organizational form. Theories based on concepts such as public goods, homophily or reciprocity can be used to describe how these links form and persist or dissolve in cyberspace. We received a NSF KDI research grant to work with colleagues from USC, Carnegie Mellon and the University of Illinois in this exciting new area, and made significant progress in implementing these extensions. VDT-5 was released as POW-ER 3.3 (Ramsey et al 05), and is in use by the US Navy, US Air Force Research Laboratory, NASA and other governmental organizations.

## Ongoing Research on Effects of Institutional Differences

Research by Geert Hofstede and his colleagues (Hofstede 84). Provides one clear point of departure for modeling how differences in values and cultural norms can affect the behavior of participants in project teams. Hofstede identified five dimensions of culture that vary systematically between workers from different countries, and which affect individual and team behaviors in global, knowledge-intensive, dynami, global projects: **Power Distance** (the difference in relative power across levels of the organization); **Collectivism vs. Individualism** (the degree to which individuals pursue self-interest vs. the interests of a larger group); **Masculinity vs. Femininity** (the extent to which work and social roles are gender-stereotyped and different; **Uncertainty Avoidance** (the degree to which members of a culture can cope with risk and ambiguity in work and social relations; and **Time Horizon** (short-term vs. long-term orientation in decisions and relationships). Hofstede has collected large data sets based on IBM employees in > 50 countries indicating that differences along one or more of these cultural dimensions lead to predictable kinds of misunderstandings, conflict and loss of motivation in global work teams.

Drawing on Hofstede's work and on the results of a series of workshops conducted with Professor Douglass North (a Nobel Laureate in Institutional Economics at Stanford's Hoover Institute) and Professor Merlin Donald (an eminent Canadian cognitive psychologist) at the Institute for International Studies at Stanford, we developed a set of initial hypotheses about how to model the emergence of "institutional difference exception" processing costs in global projects within VDT. The PhD research of Mahalingam (2005) and Orr (2005) found that viewing national differences in terms of Scott's (2001) conception of "Institutions", a concept broader than cultures and values, was far more productive in understanding and predicting cross-national exceptions in projects.

A global project contending with significant institutional differences needs to be realistic about the costs that will be incurred in proceeding with the project, and the length of time it will take to begin to reduce these costs. Forewarned with this kind of prediction, planners of global projects can set realistic goals, and can begin to initiate effective institutional interventions, with a clear notion of how long they will take to implement.

Our approach was to model institutional work in the same way that we modeled coordination work— that is, as additional quantities of information to be processed by actors in a project team. However institutional work may also have the side effect of undermining the motivation of actors who find themselves engaged in continual misunderstandings, conflict and even sabotage by project team members whose goals, beliefs and values, cultural norms and legal/regulative systems are significantly different than their own. Figure 3 shows conceptually how we overlaid institutional work on the production work and coordination work that we had modeled to date.

Tamaki Horii (2005) designed and conducted an initial set of computational experiments in which he modeled US and Japanese institutions (practices and values) and simulated the performance of joint venture teams consisting of US and/or Japanese managers and workers in US- vs. Japanese-style project organizations working on projects with different levels of complexity. His path breaking work won the best paper award at CASOS 2005. This line of work has continued since 2005 at the Collaboratory for Research on Global Projects http://crgp.stanford.edu

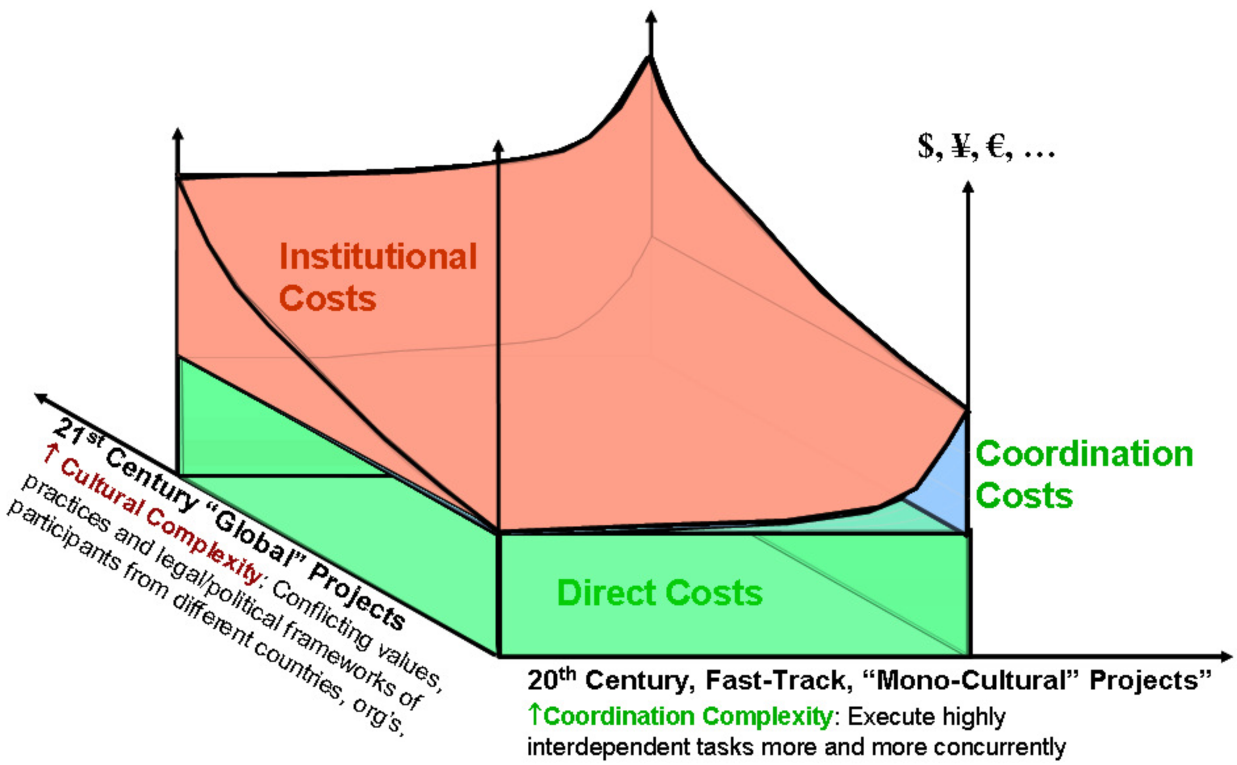


**Figure 3.** Direct Costs for Projects, and Additional Costs from Two kinds of Hidden Work: Coordination Work and Institutional Work

## Research to Develop Postprocessors for VDT

Organizational design is a complex global optimization problem involving continuous and discrete variables. For example, an organizational designer must size functional capabilities, assign staff to tasks, and set communication and control policies. Our extended VDT system is an analysis tool that can predict schedule cost and process quality performance for a baseline configuration of an organization and work process, and help to isolate the most severe risks in these three areas. However, VDT cannot suggest how to change the work process or organization to mitigate any risks that have been identified; the user must experiment with alternatives to find better solutions. Searching the solution space manually to find configurations that address schedule, quality, or cost risks for a baseline case is thus a daunting task. It relies on the expertise of the human user and offers no guarantee of optimality or even near-optimality. Because the VDT solution space is so large, and the interaction between its variables is subtle and sometimes counter-intuitive, even expert users can fail to discover many potentially superior solutions.

Task scheduling and resource assignment is an important sub-problem of organizational design. Search and optimization problems have been studied extensively in the artificial intelligence and operations research communities. Global optimization techniques include operations research methods such as linear, nonlinear, and integer programming; artificial intelligence methods such as constraint propagation; and local search. OR techniques typically achieve high scalability, robust performance, and optimal solutions, but place restrictions on problem formulation. In contrast, constraint propagation offers the ability to model problems more realistically (Baptiste 2001: 8), but good performance requires discovering clever heuristics to guide the search. Local search techniques can rapidly produce good results, but with no guarantee of optimality. OR, AI, and local search techniques have all been successfully applied individually to task scheduling and resource assignment problems (Klein 00, Smith 93, Zweben 94). However, classic task scheduling problem formulations were developed for capital-intensive physical work operations rather than for global knowledge work. The classic formulations ignore the greater flexibility of assignments when performing global work and the options for developing alternative organizations to perform the work.

During the last decade, researchers began combining AI and OR techniques to solve several, similarly complex, kinds of optimization problems (Hooker 2002). Working in collaboration with Prof. John Koza, a pioneer in the development of Genetic Programming, Bijan KHosraviani (KHosraviani et al, 2004a and 2004b) developed a system based on Genetic Programming that was able to evolve VDT models that met a required set of scope, schedule and cost objectives more optimally than multiple teams of human users had been able to do over almost a decade. His work won a silver medal at the GECCO conference in 2004.

## Ongoing Research on Power to the Edge Organizations

The POWER research has continued since 2005. This research was aimed to develop versions of our simulation framework that could be used to model some of the most decentralized and flexible organizations existing anywhere —so-called Power to the Edge organizations Alberts & Hayes, 2000).

POWER has now evolved through multiple versions. As of 2009, Version 3.8 incorporates the ability to model: institutional differences between participants from different nationalities (Horii 2005), learning and forgetting of skills by project team members over the course of an extended project (MacKinnon et al 2007); the development of trust between members of a project team who may or may not be co-located (Zolin 2004); and flexible knowledge sharing through networks of human experts and computational support tools such as databases, expert systems and other computer knowledge archives (Buettner 2002).

A new version of POWER, which we call POW-ID is under development in collaboration with the US Air Force Research Laboratory to model command-and-control work and other kinds of work that is event-driven rather than task-driven as in our earlier versions of POWER or VDT. We expect to begin validating POW-ID in the latter part of 2009.

This overview of a 20 year research project has attempted to explain how a team of researchers was able to begin modeling well specified, routine project tasks completed by homogeneous team members, and then progressively extend the representation and reasoning of the initial theory and tools to address less flexible tasks, more heterogeneous project team membership and finally more dynamic and decentralized organization structures, as shown in figure 2. It has been a delight to participate in this scientific exercise with a remarkable team of colleagues and collaborators in industry and government.

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