The Virtual Design Team (VDT): A Computational Model of Project Teams

by

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Introduction

The Virtual Design Team research was launched to enable managers to "Design Project Organizations like Bridges"—i.e., model and simulate multiple 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 the organization. Jay Galbraith had proposed this idea as early as the 1970s, but his formulation of the problem was qualitative and could not be used to make specific predictions. VDT has progressively quantified and extended Jay Galbraith's information processing view of organizations over the past 15 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 relative congruency of goals culture and values, so that institutional costs were negligible. However, performing highly interdependent work under tight time constraints creates high coordination costs as interdependent activities increasingly overlap one another in time. 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—nonroutine product development, service and maintenance work, and highly nonroutine work performed in communities of practice—but still assuming negligible institutional cost. We are commencing research on modeling multicultural project teams engaged in global projects to develop infrastructure, for which institutional costs are significant.

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 lays out some of our plans for ongoing research in this area.

VDT in a Nutshell

The Virtual Design Team simulation system is a computational model of project organizations that analyzes how activity interdependencies raise coordination needs and how organization design and communication tools change team coordination capacity and project performance. VDT explicitly models actors, activities, communication tools and organizations. VDT simulates actors working on their assigned tasks and the interactions aimed at resolving interdependencies between actors working on interdependent tasks, and interactions aimed at handling exceptions between subordinates and their supervisors. VDT builds on Jay Galbraith's theories of information processing, and views the direct work, and resulting coordination work, that must be performed by actors on a project. It simulates the project and predicts 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 and 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. 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 the project organization, as configured. 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 easy to measure and calibrate. Thus analysis of these physical systems yielded easily to 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 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, 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 and Lapotin 89)—that this was a fruitful modeling approach.

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 potentially use an information processing abstraction (Galbraith 77). 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. 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 usually studied—e.g., mental health, educational and governmental organizations. 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 (Levitt et al, 94; Kunz et al., 98; Thomsen et al, 97).

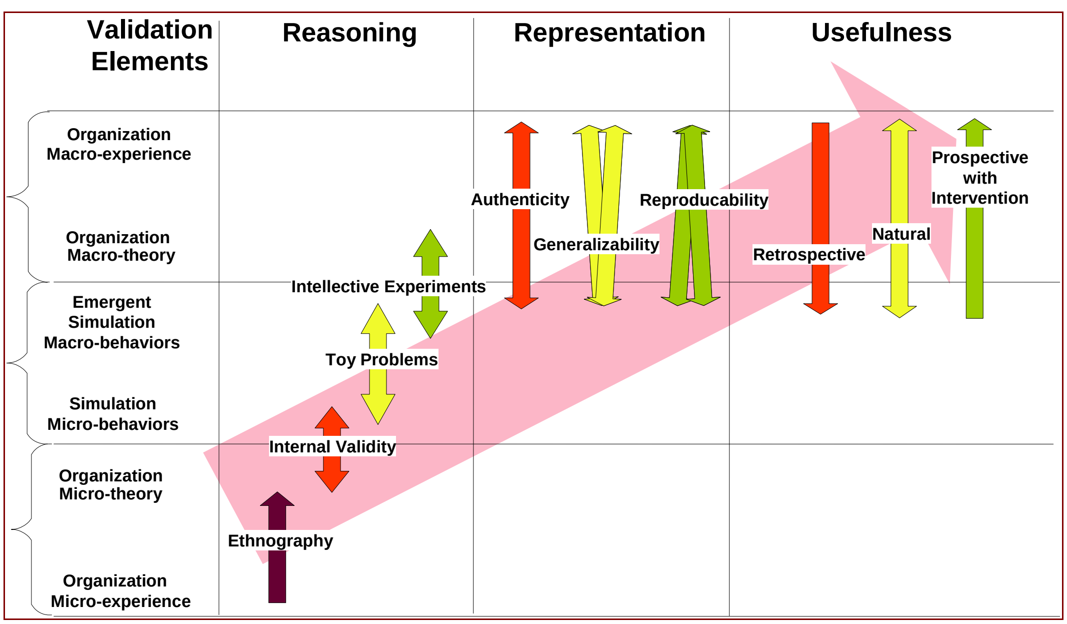

Figure 1. Validation Trajectory for Computational Emulation Models

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.

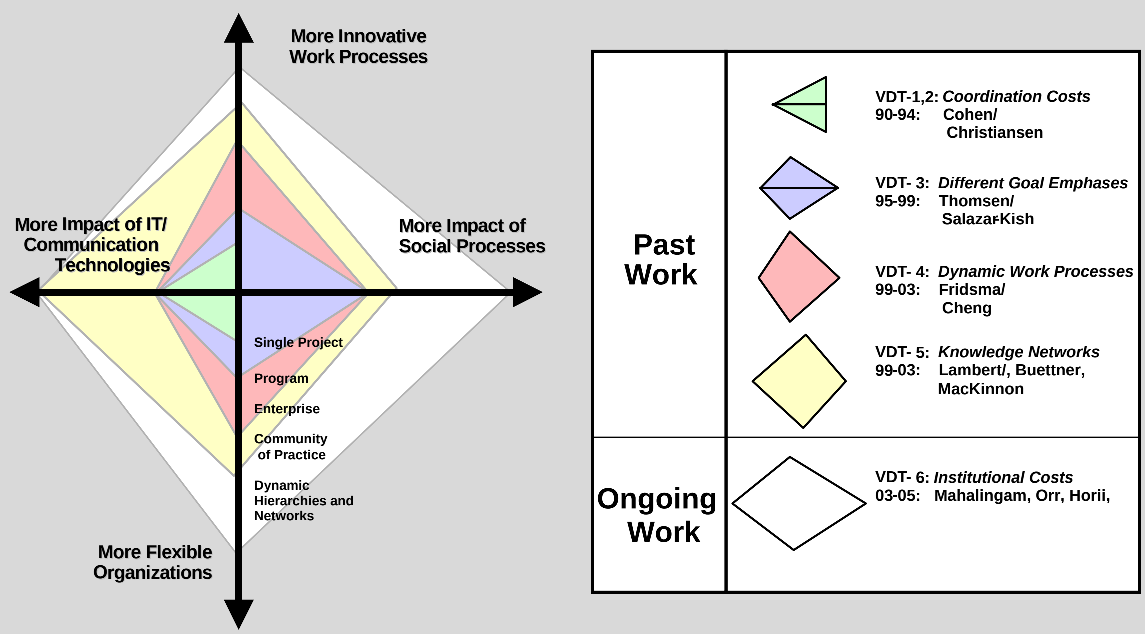

Figure 2. VDT Research Trajectory

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 has been 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 [www.vite.com].

VDT-3 (Thomsen, 97) extends the range of work processes that can 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. We will empirically validate VDT-3 in ongoing research.

VDT-4 (Cheng, 01) 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 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 extended VDT to model context-dependent decision making (e.g., time of day, 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 can 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 recently released as POW-ER 3.3, and is in use by the US Navy and other governmental organizations..

Our ongoing research is attempting to develop VDT-6, a set of extensions to VDT-3, 4 and 5 that will enable us to make predictions for project participants with widely differing goals, values and cultures, embedded in sets of dynamically changing organizations comprising both hierarchies and networks.

Ongoing Research on Effects of Institutional Differences

Research by Geert Hofstede and his colleagues [Hofstede, 1984]. 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 is 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 overlay institutional work on the production work and coordination work that we have 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.

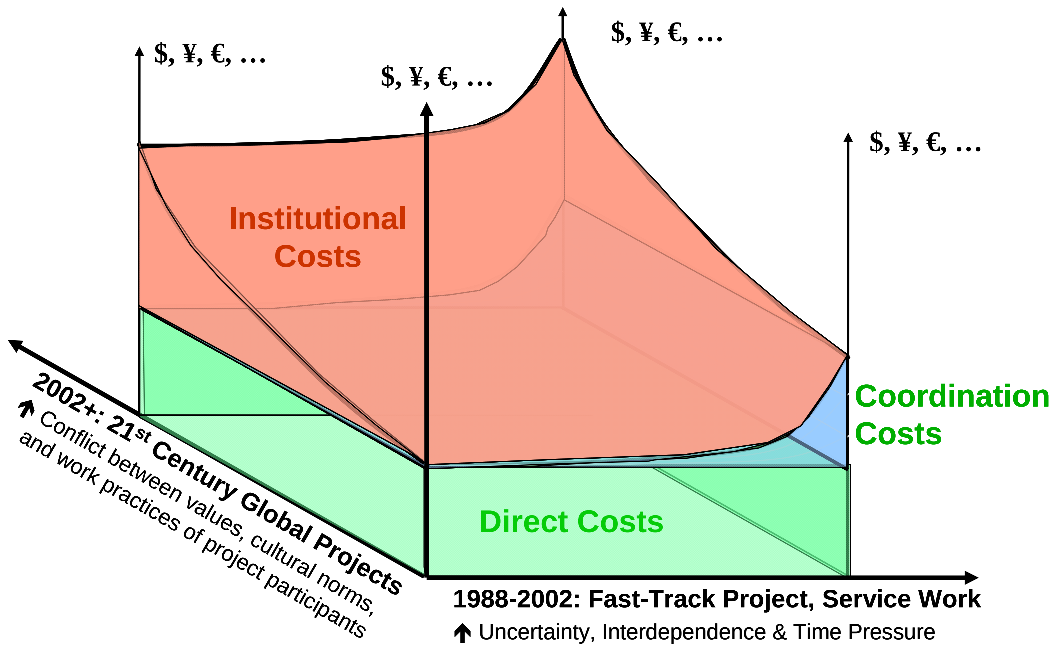

Figure 3. Direct Costs for Projects and Additional Costs from Two kinds of Hidden Work: Coordination Work and Institutional Work

Ongoing 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.

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 01, pg. 8), but good performance requires discovering a clever heuristic to guide the search. Local search techniques can rapidly produce good results, but with no guarantee of optimality. Task scheduling and resource assignment is an important sub-problem of organizational design. 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.

In the last several years, however, researchers have begun combining AI and OR techniques to solve several, similarly complex, kinds of optimization problems (Hooker, 02). The International Workshop on Integration of AI and OR Techniques in Constraint Programming for Combinatorial Optimization Problems has been formed in support of this research (http://www.crt.umontreal.ca/cpaior) Prof. Michael Trick of CMU, (2002 President of INFORMS) has stated that "constraint programming should become a part of every OR person's toolkit" (http://mat.gsia.cmu.edu/INFORMS/cp.ppt). We plan to build on the increasing interest and results in this interdisciplinary area to optimize formulations specifically targeted to dynamic, global project organizations, although our results are likely to be broadly applicable to related problems.

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