Using an organisation model to predict effects on design team productivity

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In engineering, winning a bid for a design project is a first major success, and it leads to a first major problem. Given the contract, an organization must be built to perform the design. This research focuses not on the design of artifacts, but on the design of organizations that will design (or build) an artifact. We report our approach to the organization design problem — building symbolic models of design organizations — and discuss our initial results in simulating organization performance.

1 Introduction

Design is often considered to include a series of phases, including Requirements definition; Synthesis; Analysis; Evaluation; and Acceptance or varying old designs based on the evaluation of performance (Levitt 91). Synthesis is inherently difficult. However, some areas of engineering design, such as design of many physical systems, now have a tradition of analytical models that are useful for analysis. For these areas, design involves repeated creation, analysis and modification of analytical models, and the design process has become quite formalized. Actual artifacts are now built and bench-tested only after extensive modeling and computer analysis. Because of the success of recasting the inherently difficult synthesis problem as an analysis problem, design has become highly formalized in many engineering domains, and tremendous progress has been made both in understanding the behaviors of interest in each domain and in generating interesting new syntheses. Analytical modeling has greatly extending the range of artifacts that can be designed and manufactured safely and economically.

In contrast, the use of models to analyze social systems is very limited. In practice, when a bid is won, a project manager usually designs a new organization based on past experience and discussions with a few interested principals. While the project manager can expect to use models to analyze the artifact prior to building it, the manager does not now have the luxury of using models to evaluate alternative organizational designs. For example, (Tatum 84) reports that managers of large design and construction projects—like most managers designing large scale organizations to carry out complex tasks—still rely on adaptation of past organization structures, rather than on systematic generation and evaluation of alternatives, in designing their organization structures.

Theoretical work in the field of Organizational Behavior is useful, but it has been descriptive, e.g., (Galbraith 77), (Simon 76), (Thompson 67). Most organizational behaviors of interest to scientists or managers can only be represented as discrete, nominal or ordinal variables, leading to a mismatch between these theories and the continuous, quantitative models suited to traditional simulation techniques. Computational models of organizational behavior are only now beginning to emerge (Masuch 89), (Carley 90), (CohenG 92).

Organizations normally create subteams to distribute the specialized work of solving complex problems. They then organize the specialized subteams in some sort of hierarchy to centralize overall project responsibility. In addition to information that flows up and down reporting hierarchies, project teams also allow lateral communication among peers to help groups to obtain missing information with minimum communication. The degree of formalization of communication within a hierarchy is both a practical and a theoretical issue in organizational design.

We have synthesized a description of the theory of organizations and implemented this synthesis in a computational symbolic model. The theoretical framework includes actors, projects, subteams, and communication technologies (e.g., telephone, voice mail). Teams are related by formal organizational reporting hierarchies and informal information-sharing networks. Communication between subteams can follow both vertical hierarchical links and horizontal information-sharing links. This framework forms the basis for our Virtual Design Team (VDT) model; the model explicitly represents organizational entities, and it reasons about the (stochastic) behavior of processing nodes, communications nodes and channels, and exception processing. Given a description of a project, and an organization and the communication tools it uses, the simulation model computes project duration. We describe the generic model and the specific example models that we have built and tested for realistic industrial design projects. While we do not claim to have calibrated it so that the absolute predicted project durations will be accurate, we have found that changes in organizational structure or in communication tools can cause change in simulated project duration. The changes in simulation results are consistent with predictions of theory and of experienced project managers.

This paper reports the initial development and testing of an AI symbolic model of some aspects of the behavior of an engineering design organization. The model explicitly represents concepts from organization theory, the social science discipline that describes the ways that differentiated groups communicate and function in integrated ways in a business organization. We discuss aspects of that theory and how we represented it in the model. The VDT model is a formal symbolic computational discrete event simulation model based on organization theory. It includes a high level of detail about tasks, actors and communications tools, describes static relationships among these entities, and uses simulation to predict their dynamic behavior and to predict project performance.

2 Representation and Reasoning

This section introduces the top-level entities that the VDT model represents. Figure 1 shows an overview of the VDT entities and some of their relationships. As discussed below, the object-oriented VDT model represents most entity attributes qualitatively.

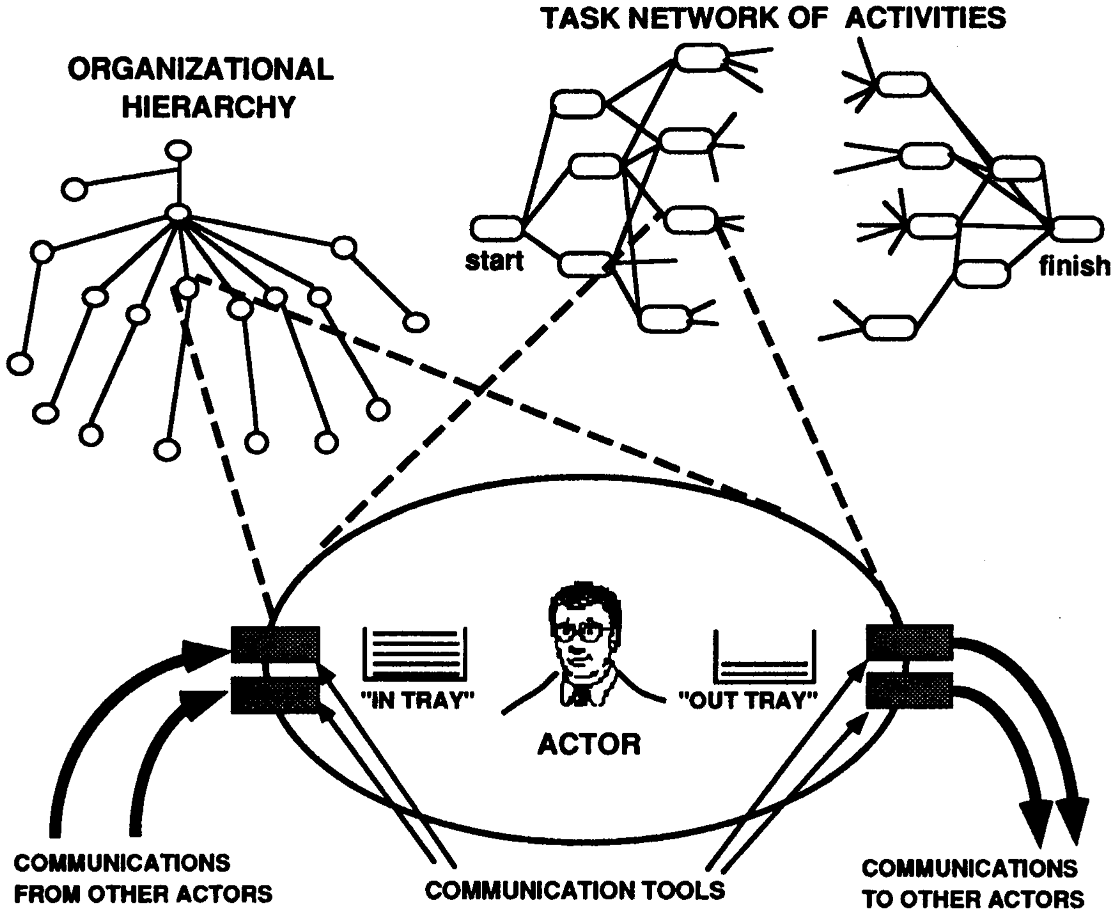

Figure 1. VDT models the design task, actors, organization structure, and communication tools. The organization hierarchy consists of actors that are modeled as information processors. Actors have "attention rules" for selecting communications waiting for the actor's attention in an "in tray," and selection rules for choosing which communication tool to employ for sending communications to other actors via an "out tray." The organization structure is defined in terms of communication paths between actors, and the level of the hierarchy at which reviews and approvals can be made.

Activities are the major processes that create the project deliverables. Activities are processed as multiple chunks of information termed "communications" in a stochastic, discrete event simulation. Activities have a number of attributes including:

- Complexity of technical requirements (one of: high, medium, low): relative engineering difficulty associated with the input to the engineering work of this activity;
- Interdependence (one of: high, medium, low): the degree to which activity performance depends on analyses made by other activities;
- Natural idiom (one or more natural idioms for the activity)
- Precedence relationships that name Predecessor and Successor activities;
- Reciprocal activities: other activities with this activity must work in close concurrence;
- Responsible actor

- Solution complexity (one of: high, medium, low): the relative engineering difficulty associated with the solution created by this activity;
- Tasks: a project is divided into activities that in turn are divided into tasks (with priorities), that in turn are divided into subtasks. Actual work is performed by an actor doing a subtask; tasks, etc. simply provide ways of organizing subtasks.
- Times, (start, end, early start, early end); computed duration;
- Uncertainty (one of: high, medium, low): the degree to which inputs and solutions are well understood, stable and manageable.
- Work volume (arbitrary quantitative units)

Actor attributes include:
- Coordinates-with: other actors with whom this actor will share information with informally. This relationship specifies an informal relationship within the organization hierarchy.
- Location
- Role in the team (one of: project manager, team leader, team member)
- Skill type: the discipline or craft of this actor;
- Skill degree (one of: high, medium, low):
- Speed (a numeric percentage of nominal)
- Supervises and supervised-by - the formal relationship that defines the organization hierarchy;
- Task experience (one of: high, medium, low):

Actors have information processing capability. The VDT does not now model the quality of the engineering judgment of actors, i.e., their product, but it does model their information processing behavior. Actors perform a number of functions including the following, all implemented as object-oriented methods attached to appropriate objects:
- *Select messages from an "in-tray".* Attention, or the information selection process, is a crucial feature of organizations. VDT uses stochastic "attention rules," implemented as methods on actor objects, to select communications from the in-tray.
- *Process information.* Time to process a message depends (stochastically) on the task features, nominal duration, degree of variability, and the degree of the match between the attributes of an actor and a message.
- *Send messages to an "out-tray" for distribution.* Distribution may (stochastically) be by a tool that is suitable for the particular type of communication and the workload of related actors and tools. Actors have methods that assign a priority to outgoing messages, based on the priority of the task.
- *Choose a communication tool for an outgoing message*; considering task priority, tool capabilities (e.g., synchronicity, natural idiom) and difference between actor and tool locations.
- *Generate activities to coordinate actors*, based on the need for exceptions to obtain or share additional information, as suggested by (Galbraith); requirements for periodic or percentage-completion updates; and requirement for milestone review dictated by project policy. VDT generates exceptions based on actor capability and degree of match between actor capability to process a particular message and the message attributes.

Actors use communication tools to exchange information with other actors. The VDT model includes meetings, telephones, voice mail, electronic mail, file sharing, etc. The VDT framework represents each communication tool in terms of a set of qualitative attributes that we theorized would affect both the choice of tool and the results of that choice.

Communication tool attributes include:
- Capacity (volume of messages that can be transmitted concurrently);
- Location, used to check the proximity of the actor and the tool;

- Natural idioms supported by this tool;
- Recordability (whether or not a permanent record of the communication is available routinely);
- Relative speed for communications involving different natural idioms (e.g., text, schematics, 3-D geometry);
- Synchronicity (one of: synchronous, asynchronous, partially synchronous)

3. Results

We have performed observations and built models for several real engineering design tasks. For example, one case (Case-1 in Figure 2) modeled a particular realistic design task and a baseline set of actor and communication tool capabilities. Actors had a set of communications tools including telephone, fax, voice mail, etc. The actors had decentralized control. In the simulation, computed project duration was 862 simulation units with a standard deviation of 8 units. This actual project duration lasted approximately 485 days, so the 862 simulation units corresponds to about 485 days for the assumptions used in this project. Case-2 held the task and actor parameters constant, but actors could not use voice mail as allowed in Case-1. Theory predicts that the overall project duration in Case-2 should be marginally increased than Case-1, i.e., duration "(Increased)" in the table. Bracketed numbers show that simulated project duration was greater than in Case-1, as predicted.

The results are statistically significant, as suggested by the relatively small standard variations. Case-3 used the same task, tool and actor descriptions as in Case-1, except that actors had centralized decision-making control. In each of Cases 2-4, there was three-way consistency about change in duration with respect to Case-1 among predictions made by the project manager of the modeled project, our predictions based on theory, and the simulation results.

	Information Processing Technologies	
Decision-Making	Voice mail	No Voice Mail
Distributed, Decentralized	1. (Baseline) [862, SD 8]	2. (Increased) [888, SD 1]
Hierarchical, Centralized	3. (Increased) [930, SD 10]	4. (Increased) [970, SD 16]

Figure 2. Qualitative change in simulated project performance in different organizational cases. Parenthesized remarks indicate the theoretically predicted change in project duration of Cases-2, 3 and 4 with respect to the baseline of Case-1. Bracketed numbers show number of simulation time units required to perform the project in each case, followed by the standard deviation on those estimates. We conclude that VDT can consistently represent the information processing patterns of engineering organizations doing routine tasks.

4. Conclusion

The simulation model can be "run" relatively quickly. Thus, it can serve as a facility to formulate and test large numbers of precise conjectures regarding how changes in management structure or use of new communications tools will affect the organization's performance. Engineering disciplines have long had mathematical and, more recently, computational models in support of analysis and optimization of physical systems. This work shows that AI symbolic modeling can be used to express and to test social sciences models applied to real organizations. This work demonstrates the applicability of AI symbolic modeling techniques for making models that describe the detailed structure and predict the behavior of social theory and human organizations.

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