CIFE CENTER FOR INTEGRATED FACILITY ENGINEERING

Modeling 21st Century Project Teams: Docking Workflow & Knowledge Network Computational Models

By

Edward T. Palazzolo, Archis Ghate, Roberto Dandi,
Ashwin Mahalingam, Noshir Contractor, and Raymond Levitt

CIFE Technical Report #140
July 2002

STANFORD UNIVERSITY

If you would like to contact the authors, please write to:

c/o CIFE, Civil and Environmental Engineering Dept.,
Stanford University
Terman Engineering Center
Mail Code: 4020
Stanford, CA 94305-4020

Modeling 21st Century Project Teams: Docking Workflow and Knowledge Network Computational Models

Edward T. Palazzolo
University of Illinois at Urbana-Champaign
palazzol@uiuc.edu

Archis Ghate
Stanford University
archis@stanford.edu

Roberto Dandi
University of Illinois at Urbana-Champaign
rdandi@uiuc.edu

Ashwin Mahalingam
Stanford University
ashwin@stanford.edu

Noshir Contractor
University of Illinois at Urbana-Champaign
nosh@uiuc.edu

Raymond Levitt
Stanford University
Ray.Levitt@stanford.edu

Abstract

This paper reports on an attempt to integrate and extend two established computational organizational models—SimVision® and Blanche—to examine the co-evolution of workflow and knowledge networks in 21st century project teams. Traditionally, workflow in project teams has been modeled as sets of sequential and/or parallel activities each assigned to a responsible participant, organized in a fixed structure. In the spirit of Jay Galbraith's (1973) information processing view of organizations, exceptions—situations in which participants lack the required knowledge to complete a task—are referred up the hierarchy for resolution. However, recent developments in digital technologies have created the possibility to design project teams that are more flexible, self-organizing structures, in which exceptions can be resolved much more flexibly through knowledge networks that extend beyond the project or even the company boundaries. In addition to seeking resolution to exceptions up the hierarchy, members of project teams may be motivated to retrieve the necessary expertise from other knowledgeable members in the project team. Further, they may also retrieve information from non-human agents, such as knowledge repositories or databases, available to the project team. Theories, such as Transactive Memory, Public Goods, Social Exchange and Proximity may guide their choice of retrieving information from a specific project team member or database. This paper reports on a "docked"

computational model that can be used to generate and test hypotheses about the co-evolution of workflow and knowledge networks of these 21st century project teams in terms of their knowledge distribution and performance. The two computational models being docked are *SimVision* (Jin & Levitt, 1999) which has sophisticated processes to model organizations executing project-oriented workflows, and *Blanche* (Hyatt, Contractor, & Jones, 1997), a multi-agent computational network environment, which models multitheoretical mechanisms for the retrieval and allocation of information in knowledge networks involving human and non-human agents.

This paper was supported in part by a grant from the U.S. National Science Foundation for the project "*Co-Evolution of Knowledge Networks and 21st Century Organizational Forms* (IIS-9980109).

Modeling 21st Century Project Teams: Docking Workflow and Knowledge Network Computational Models

Edward T. Palazzolo, Archis Ghate, Roberto Dandi, Ashwin Mahalingam,
Noshir Contractor and Raymond Levitt

This paper explores how the evolution from hierarchical to network forms of organizing influences the modeling of project teams. We begin by describing contemporary theoretical models of workflow and knowledge networks in project teams. We overview two computational models -- SimVision® and *Blanche* -- that have been developed to characterize project teams from a workflow and knowledge networks perspective. Next we describe the rationale and process of "docking" these two computational models. We conclude with some thoughts on how docking these models can significantly advance our understanding of the performance of 21st century project teams.

Workflow Models

The intellectual premise of SimVision®, a workflow model grounded in "micro" contingency theory, is that organization behavior emerges from the decisions and actions of individual actors as they process information associated with activities, and as they create and respond to requests for information. SimVision® applies and extends the information processing framework (Galbraith, 1973) and the computational approach of Cyert and March's pioneering "Behavioral Theory of the Firm." Micro-behaviors currently implemented in SimVision® include attention allocation by actors to direct work and communication items in their in-trays; exception generation; communication tool selection; communication routing; and decision making about rework in the face of exceptions.

Actors in SimVision® process work items arising from tasks that are assigned to them, stochastically encounter exceptions, and attempt to resolve the exceptions by sending them up the hierarchy to be resolved by managers to whom they report. SimVision® models actors—where each actor is an individual or an abstracted subteam—as possessing: a *Skill Set*, one or more skills, each rated at low, medium or high (L,M.H); *Application Experience* (L,M,H); and a *Capacity* measured in full time equivalents (FTE). Tasks are modeled in a sequential precedence network and are characterized by: a *Skill Requirement* (a single skill); a *Work Volume* or level of effort (FTE-Days); and zero or more *Reciprocal Dependency* and *Rework Dependency* links to other tasks. The project organization is characterized by a set of decision-making policy attributes, including: *Centralization, Formalization, Matrix Strength* and *Team Experience.*

In additional to modeling the direct work from tasks like Critical Path Method (CPM) models, SimVision® models and simulates the significant information-processing load imposed on the organization by the need to coordinate reciprocal dependencies, and the rework volume for each actor generated by exceptions that require rework to correct them. Actors in a SimVision® simulation—like those in a real project—can easily get backlogged by the combination of direct work, coordination work and rework that they must handle. When they become excessively backlogged (i.e., when their in-baskets contain more than a few FTE-days of work volume), they tend to focus on catching up on their direct work and de-emphasize coordination and error correction. This increases the likelihood of exceptions occurring downstream. In cases involving severe backlogs for critical managers, the workflow can become very turbulent, and the project may not complete (Levitt, et al. 2002). By modeling coordination and rework, and by simulating both the direct and 2nd order effects of backlogs on project teams, SimVision® has been able to generate extremely accurate predictions of failures in real project teams (Kunz et al, 1998). As such, SimVision® is a general framework for examining the impact of specific organizational forms on organizational performance and workflow and can generate detailed predictions for teams faced with routine tasks, stable organizational structures and agents that do not learn. A key limitation of SimVision® is that it adopts the 20th century view of Galbraith and others that "the hierarchy is the knowledge network." This "boss knows better" view of exception handling is clearly outdated for many kinds of 21st century work and needs to be extended. Formal and informal interactions are differentiated, as are interactions via different communication media. SimVision® uses an abstract (skill type) x (skill level) characterization of knowledge. It does not differentiate cognition into different types of internal knowledge.

The authors are collaborating on an NSF KDI Grant (Contractor, et al 1998) to understand how workflow approaches like SimVision® can be integrated with tools that model information and knowledge exchange via flexible and dynamic knowledge networks, as predicted by various social scientific theories. To answer this question, the authors decided to attempt to dock SimVision®'s workflow model with a model of exception handling via flexible knowledge networks implemented in *Blanche*. The docking process is described following a brief overview of knowledge network models.

Knowledge Network Models

The nodes in a knowledge network include individuals as well as aggregates of individuals, such as groups, departments, organizations, and agencies. Increasingly, the nodes also include non-human agents such as knowledge repositories, web sites, content and referral databases, avatars, and "webbots" (Carley, 2002). The *social structures* in these networks refers to "who knows who" in the network, while the *cognitive social structures* refers to "who knows who knows who" (Krackhardt, 1987). The *knowledge network* linkages describe "who knows what," while the *cognitive knowledge network* linkages refer to "who knows who knows what." The *communication* networks linkages include the retrieval and the allocation of information from (or to) other human and non-human agents.

Our goal is to extend the hierarchically based exception handling mechanisms specified in traditional workflow models. As discussed earlier, in traditional workflow models, a person in the chain of command must resolve an exception-handling request. However, in 21st century project teams, rather than seek resolution through the chain of command, members seek information from peers or non-human agents such as project databases. The decision about which peer (or non-human agent) they approach for a specific exception-handling request is at the discretion of the individual. Based on a theoretical and empirical review of the research on organizational networks, Monge and Contractor (in press) propose a multi-theoretical multi-level (MTML) model to explain why an individual may forge an information retrieval tie with another human or non-human agent. Preliminary results from our empirical research indicate that there are multiple social motivations that influence members' tendencies to retrieve from other team members or from collective knowledge repositories such as databases (Contractor, Brandon, Dandi, Huang, Palazzolo, Ruta, Singh, and Su, 2002). The three mechanisms that are particularly influential in explaining the creation of network ties for retrieval of information from other team members include:

(i) *Cognitive mechanisms of transactive memory theory* (Wegner, 1995): Members seek the expertise of others who they think are knowledgeable although they may not be accurate in their assessment of others' knowledge.

(ii) *Social exchange mechanisms* (cf. Cook, 1982): Members retrieve information about a topic from others who, in turn, seek information from them on other areas of expertise.

(iii) *Proximity mechanism* (cf. Rice & Aydin, 1991): In geographically distributed environments, members are more likely to seek the expertise of others who are geographically proximate.

Our research also provides some preliminary insights about the multiple-theoretical mechanisms that explain an individual's motivations to retrieve from knowledge repositories. The two mechanisms that are particularly influential in explaining the creation of network ties for retrieval of information from project databases include:

(i) *Collective interest mechanisms based on public goods theory* (Fulk, Flanagin, Kalman, & Monge, 1996): Individuals are more likely to retrieval information about a particular area of expertise from the project database if they perceive that it has a high provision of knowledge accessible at a low cost.

(ii) *Cognitive mechanisms based on transactive memory theory*: Individuals are more likely to retrieve information from a database if they believe that knowledgeable others are contributing to the database.

Significantly, although the teams we have examined had some hierarchical stratification, there was no significant tendency to retrieve information from the chain of command. This empirical finding underscores our earlier observations that in order to faithfully characterize contemporary project teams, workflow models must capture members' tendencies to seek help for exception handling wherever it might be available in the network – including other team members or knowledge repositories.

Blanche is an object-oriented multi-agent environment for computationally modeling such knowledge networks. It models networks as a set of *actors* characterized by some collection of *attributes* and related by one or more network *relations* (Hyatt, Contractor, & Jones, 1997). In addition, it requires specification of a set of theoretical mechanisms for the dynamic evolution of networks. A discrete set of theoretical mechanisms provides flexibility and expressiveness such that dependencies among actors' attributes and relations are modeled as a function of values at previous time steps. The theoretical mechanisms are implemented as nonlinear difference equations. The suite of mathematical and logical operators implemented within *Blanche* make it a general-purpose computational modeling environment for a variety of network theories (Contractor, 2002). For instance, the dynamic theoretical mechanisms influencing changes in the actors' attributes (e.g., their levels of skills or expertise) and actors' relations (e.g., retrieval of information for exception handling, cognitive knowledge networks) can be specified and executed using *Blanche*. Thus *Blanche* can be characterized as a framework in which multiple theoretical models of network-based behavior can be built. As such, it does not embody a specific theory about the evolution of networks.

"Docking" Workflow and Knowledge Network Models

As discussed earlier, SimVision® provides a sophisticated model of the workflow processes in project teams but a primitive implementation of retrieving information from the knowledge network for exception handling. Blanche, on the other hand, offers a multi-theoretical network model of the knowledge retrieval processes in project teams, but is limited in its implementation of a workflow process. As such the two modeling environments complement one another's strengths and weaknesses. While it is possible for each of these models to develop the features it lacks, a more compelling alternative is to "dock" the two models in order to leverage their core competencies. The term "docking" has multiple interpretations in the computational modeling literature. In some cases docking two models implies running the two models using the same initial data sets and comparing their predictions. In the present context, docking refers to the ability of each model to "call" the other model to carry out some computations, which are then returned to the first model for further processing. The two models being docked may share some – but not necessarily all – of the same initial data.

In the present example, the initial data shared by SimVision® and *Blanche* are the tasks assigned to each project team member, the hierarchical reporting relations among the team members, the expertise (or skill sets) possessed initially by each team member, and the expertise required for each task. Following each discrete event step in the SimVision® workflow model, one or more exception-handling requests are generated. SimVision® "calls" on *Blanche* to help resolve these exception-handling requests. Specifically, it relays to *Blanche* (using APIs) the nature of the exception, the identity of the team member who generated this exception, the expertise (or skills) required to resolve this exception, and the communication backlog of the other team members.

Blanche uses its knowledge network computational model to stochastically identify the person or database that the exception-generating member seeks for help in resolving the exception. In a computational model based on transactive memory theory, members would seek help from others who they think are knowledgeable about that area. In a computational model based on social exchange theory, members seek help from others who have previously sought their help. In a computational model based on public goods theory, the likelihood of members retrieving information from a database is influenced by their perceptions of the provision of that knowledge repository in that area of expertise and the costs incurred in accessing it. Based on our empirical research, we have implemented a multi-theoretical computational model where multiple theoretical mechanisms influence a members' decision to retrieve information from another member or a database. The relative influence of these theoretical mechanisms is specified on the basis of the effect sizes observed in the empirical research.

In addition to identifying the person sought for resolving the exception, *Blanche* also assesses the quality and time required for the resolution. For instance, if a member sought expertise from another person who did not have a high level of expertise and had a high communication backlog the quality of the exception-handling resolution would be low and the time required for the resolution would be high. As a result, members might reconsider seeking help from that individual in the future. An important implication of this process is that the cognitive knowledge network changes based on members' retrieval of information from one another. Likewise, an individual's (or database's) actual level of knowledge in a particular area is not assumed to be static. Rather it can decay gradually over time due to obsolescence or if other members do not call upon it for help with exception handling.

Following each time step, *Blanche* relays to SimVision® the (i) identity of the person sought for exceptional-handling, (ii) the quality of the resolution to the exception, and (iii) the time required for resolution. This updated data is then utilized by SimVision® to model workflow for the next discrete event step at which point, the docking process outlined above is repeated iteratively. The evolving knowledge network can be dynamically visualized in terms of the exception handling retrieval links and the knowledge distribution across the agents.

Using the Docked Model as a Test Bed for Hypotheses Generation and Testing

Docking the two models will facilitate simulation of the co-evolution of workflow processes and knowledge networks and their impact on organizational performance. The docked models can be used in two ways to generate new theory and enhance the effectiveness of real organizations: (i) model idealized organizations to generate predictions about the theoretically specified effects of change in the task, actors, technological infrastructure, communication and knowledge networks on several performance outcomes, and (ii) simulate real organizations to make specific predictions of individual, group and organizational performance and thereby guide interventions. Our goal is to conceptually integrate workflow and knowledge networks and to use them as component models for generating predictions about the effects on team performance of handling exceptions in different ways. These predictions can then be validated against performance data from real project teams to determine the relative importance of the multiple theoretical mechanisms that seek to explain how emergent knowledge networks augment or, in some cases, potentially subvert the hierarchies of project teams.

References

[Carley, 1995] Carley, K. M. (1995). Communication technologies and their effect on cultural homogeneity, consensus, and the diffusion of new ideas. *Sociological Perspectives, 38(4),* 547-571.

[Carley, 2002] Carley, K. (2002). Smart agents and organizations of the future. In L. Lievrouw & S. Livingstone (Eds.), *Handbook of new media* (pp. 206-220). London: Sage.

[Contractor, 2002] Contractor, N. (2002). *A multi-theoretical multi-agent model of the co-evolution of communication and knowledge networks*. Paper presented at the Computational Social Sciences Conference in Lake Arrowhead, CA.

[Contractor, Brandon, Dandi, Huang, Palazzolo, Ruta, Singh, and Su, 2002] Contractor, N., Brandon, D. Dandi, R., Huang, M., Palazzolo, E. T., Ruta, C., Singh, V. and Su, C. (2002). A multi-theoretical multi-level model of information retrieval and allocation in knowledge networks. Unpublished manuscript. University of Illinois at Urbana-Champaign.

[Contractor, Carley, Levitt, Monge, Wasserman, Bar, Fulk, Hollingshead, & Kunz, 1998] Contractor, N. S., Carley, K., Levitt, R., Monge, P., Wasserman, S., Bar, F., Fulk, J., Hollingshead, A., & Kunz, J. (1998). *Co-Evolution of Knowledge Networks and Twenty-First Century Forms: Computational Modeling and Empirical Testing*. Research proposal funded by the National Science Foundation (Grant # IIS-9980109).

[Cook, 1982] Cook, K. S. (1982). Network structures from an exchange perspective. In P. V. Marsden & N. Lin (Eds.), *Social structure and network analysis* (pp. 177-218). Beverly Hills, CA: Sage.

[Fulk, Flanagin, Kalman, Monge, & Ryan,, 1996] Fulk, J., Flanagin, A.J., Kalman, M. E., Monge, P. R., & Ryan, T. (1996). Connective and communal public goods in interactive communication systems. *Communication Theory,* 6, 60-87.

[Galbraith] Galbraith, J.R. (1997). *Organization Design*, Addison-Wesley, Reading, Massachusetts.

[Hyatt & Jones, 1997] Hyatt, A., Contractor, N., & Jones, P. M. (1997). Computational organizational network modeling: Strategies and an example. *Computational and Mathematical Organizational Theory, 4,* 285-300.

[Jin, Levitt, Christiansen, & Kunz, 1995] Jin, Y., Levitt R., Christiansen, T, & Kunz, J. (1995), The Virtual Design Team: Modeling Organizational Behavior of Concurrent Design Teams in *International Journal of Artificial Intelligence for Engineering Design, Analysis and Manufacturing, (AI EDAM), 9,* 145-158.

[Krackhardt, 1987] Krackhardt, D. (1987). Cognitive social structures. *Social Networks, 9,* 109-134.

[Kunz, Christiansen, Cohen, Jin, & Levitt, 1998] Kunz, J. C., Tore R. Christiansen, T. R., Cohen, G. P., Jin, Y., Levitt, R. E. "The Virtual Design Team: A Computational Simulation Model of Project Organizations," *Communications of the Association for Computing Machinery (CACM) 41 (11),* November, 1998, pp. 84-91.

[Levitt, Cohen, Kunz, Nass, Christiansen, & Jin, 1994] Levitt, R. E., Cohen, G. P., Kunz, J. C., Nass, C. I.,. Christiansen, T. R. and Jin, Y. (1994). The Virtual Design Team: Simulating How Organization Structure and Information Processing Tools Affect Team Performance," in K. Carley and M. Prietula, editors, *Computational Organization Theory*, Lawrence Erlbaum Associates, Hillsdale, NJ.

[Levitt, Fyall, Bjornsson, Hewlett, 2002] Levitt, R. E., Fyall, M., Bjornsson, P., Hewlett, W. III (2002). *When information flow in project organizations becomes turbulent: Toward an organizational "Reynolds" number.* Paper presented at the Computational Social Sciences Conference in Lake Arrowhead, CA.

[March & Simon, 1958] March, J. G., & Simon, H. A. (1958). *Organizations*, John Wiley, New York.

[Monge & Contractor, in press] Monge, P. R., & Contractor, N. (in press). *Theories of communication networks.* New York: Oxford University Press.

[Rice & Aydin, 1991] Rice, R. E., & Aydin, C. (1991). Attitudes toward new organizational technology: Network proximity as a mechanism for social information processing. *Administrative Science Quarterly, 9*, 219-244.

[Wegner, 1995] Wegner, D. M. (1995). A computer network model of human transactive memory. *Social Cognition, 13*:3, 319-339.