SHARED MENTAL MODELS AND COORDINATION IN LARGE-SCALE, DISTRIBUTED SOFTWARE DEVELOPMENT

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Abstract

Despite substantial improvements in the last few years in software engineering and collaboration tools, coordination in large-scale software development continues to be problematic. This coordination is important because of the complex interdependencies that exist among software tasks, in that small productivity improvements can lead to substantial cost-savings and competitiveness. Traditional theories suggest that collaborators coordinate by organizing tasks and communicating, but recent research suggests that they also coordinate via implicit mechanisms like shared mental models. However, most of the shared mental model research literature focuses on real-time tasks, and there is very little empirical evidence on how these models affect coordination in more asynchronous and geographically distributed collaboration. Furthermore, none of this evidence is based on large-scale software development organizations. The present research is a field study at a large telecommunications company. It employs qualitative, quantitative, and survey research methods to investigate the effect of shared mental models on coordination in large-scale software development, and to better understand how geographic distance affects coordination.

Keywords: Human factors, groups, distributed work arrangements, software development.

ISRL Categories: AA02, AA09, GA0501, F

INTRODUCTION, RESEARCH AND QUESTIONS

Large-scale software development is a collaborative activity that requires diverse expertise and substantial human resources. However, as a software project increases in size, it is often difficult or impractical to concentrate all the necessary human resources in one location. Furthermore, today's advanced telecommunications and collaboration technologies provide an added incentive to collaborate with geographically distributed colleagues. Some companies may even find it strategically important to distribute tasks to other locations that are closer to clients, skilled personnel, and technical resources (e.g., hardware, tools, test labs, etc.). However, in spite of the abundance of distributed collaboration tools, the fact remains that coordination in distributed, large-scale software development is still problematic for many organizations because working from a distance brings increased coordination overhead, reduced richness in communication media, and more substantial delays (Herbsleb et al. 2000).

Traditional organization theories suggest that teams coordinate explicitly via task organization and team communication (March and Simon 1958; Thompson 1967; Van De Ven et al. 1976). But more recent theories and research also suggest that as collaborators develop familiarity with the task and the team, they develop team knowledge that enables them to coordinate implicitly (Endsley 1995; Wegner 1986; Weick and Roberts 1993; Wellens 1993). Shared mental models are a type of team knowledge that members have in common about the task and each other (Cannon-Bowers et al. 1993, Klimoski and Mohamed 1994, Kraiger and Wenzel 1997). It is suggested that these models help manage sub-task interdependencies effectively, thus positively affecting coordination and performance. However, asynchronous and distributed collaborators have fewer opportunities to interact than real-time and colocated collaborators, thus making it more difficult for them to develop shared mental models. While much has been written about shared mental models, there is very little empirical evidence supporting these theories, particularly in asynchronous and distributed contexts. The objective of this research is to investigate the effect of shared mental models on coordination in large-scale, distributed, and asynchronous software development. More specifically, we investigate the effect of shared mental models on coordination, and how geographic distance affects this coordination.

THEORETICAL FOUNDATIONS OF THE STUDY

Coordination is necessary to manage interdependencies within the task (Malone and Crowston 1994). Coordination of routine activities can be accomplished explicitly using task organization mechanisms (e.g., schedules, specifications, software processes, software tools, etc.), while coordination of less routine activities is generally achieved through communication (March and Simon 1958; Thompson 1967), both formal and informal (e.g., in hallways, lunch rooms, etc.) (Kraut and Streeter 1995). Recent theories also suggest that as collaborators develop experience with the task and with each other, they also develop shared mental models (Espinosa et al. 2001; Levesque et al. 2001). Shared mental models are based on organized shared knowledge, which helps collaborators form accurate explanations and expectations about the task and each other, thus helping them coordinate explicitly (Cannon-Bowers et al. 1993; Klimoski and Mohamed 1994; Rouse and Morris 1986). These models are best exemplified in fast paced real-time contexts like medical emergency rooms and aircraft carriers in which members act in a highly coordinated fashion with little communication, and they are perhaps more evident when lacking because activities become notoriously uncoordinated, which can cause errors that lead to accidents (Helmreich 1997; Weick 1990; 1993; Weick et al. 1993). Weak shared mental models in asynchronous tasks like software development can also lead to uncoordinated activity and productivity losses due to things like re-work and missed deadlines because important task interdependencies may not be adequately managed. This is further aggravated in geographically distributed environments in which team members have fewer opportunities to interact with each other, and often have to do so through less rich media (e.g., e-mail, shared databases, etc.), thus making it more difficult to develop shared mental models.

There are many types of shared mental models, but most of them can be categorized within two general types: those about taskwork and those about teamwork (Cooke et al. 2000; Klimoski and Mohamed 1994; Rentsch and Hall 1994). Taskwork encompasses all activities related to the execution of the task, while teamwork encompasses all activities necessary for teammates to work with each other. Each of these may have different effects on coordination depending on the task. Asynchronous tasks like software development, in which the effective management of sub-task interdependencies is key to performance, may benefit from stronger shared mental models of the task. More synchronous tasks like a basketball game or a flight formation, in which anticipating members' actions is critical to the task, may benefit more from stronger shared mental models of the team. Recent studies show preliminary evidence of the positive effects of shared mental models in synchronous simulation tasks (Mathieu et al. 2000), but more research is needed to fully understand the effect of shared mental models on coordination in more asynchronous and distributed tasks like large-scale software development in which member interaction may not be as frequent, spontaneous, or rich.

In summary, as illustrated in the research framework (Figure 1), we anticipate that: (1) distance affects how teams communicate (e.g., frequency, media, etc.); (2) team interaction and familiarity with the joint task affects shared mental model development; (3) distance provides fewer opportunities to interact and develop experience working together, consequently it is associated with weaker shared mental models; and (4) both explicit coordination mechanisms (i.e., task organization and team communication) and implicit coordination mechanisms (i.e., shared mental models) affect coordination success. Preliminary findings from the qualitative study have identified three general types of coordination problems experienced by software developers, depending on which sub-task interdependencies are involved, which provide the basis for constructing the coordination success variable: technical (i.e., software parts don't work well together), temporal (i.e., software parts not ready per schedule), and process (i.e., lack of adherence to the established software process). Finally, other factors that may affect coordination (e.g., project/team size, complexity, developer experience, etc.) were also included in the framework as control variables.

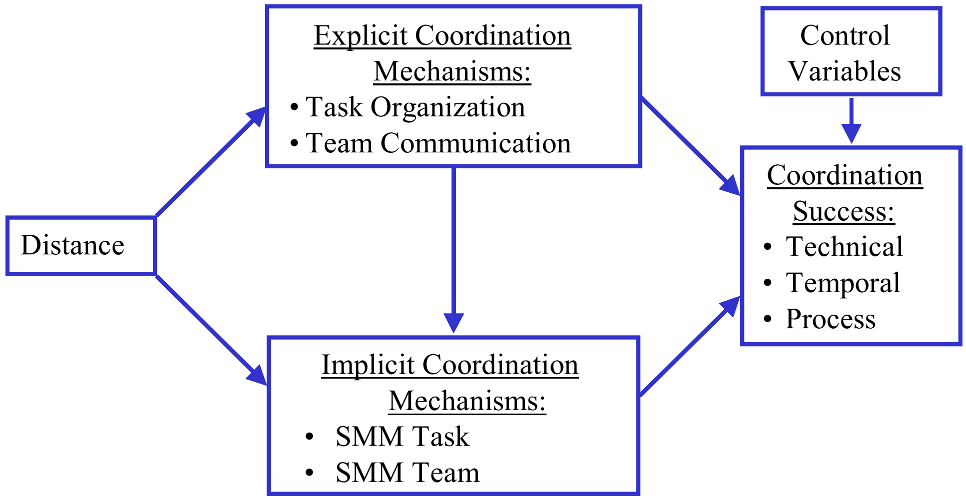

Figure 1. Research Framework

RESEARCH METHODOLOGY

This research takes place in the context of a field study. It involves developers of real-time software at a large telecommunications organization working in an asynchronous, collaborative fashion, both in colocated and distributed modes. The research methodology involves a combination of qualitative and quantitative methods, and a web survey. The qualitative study is based on observations and semi-structured interviews of software developers from two different locations who work for the wireless telecommunications industry in Europe. This part of the study was intended to help us develop familiarity with the context, learn more about the software process and coordination challenges involved, and confirm and refine the theoretical framework.

The quantitative data comes from software production sources. It will be used to measure input variables like project size, complexity, and priority. It is also intended to help develop objective measures of coordination to validate some of the corresponding survey measures. The quantitative data will also be used for complementary analysis using proxy measures of shared mental models, derived from knowledge similarity among collaborators, based on prior experience working on similar subsystems, modules, software files, etc. The survey research is based on developers from two other sites, who produce software for the global telephony industry. The web survey is intended to help us measure process variables, particularly those related to team communication and shared mental models, and to develop measures of technical, temporal, and software process coordination outcomes.

CURRENT STATUS

This research is part of an on-going program in which we are studying the effect of shared mental models on asynchronous and distributed team coordination and performance. Prior completed research includes two separate studies by some of the authors who investigated the effect of shared mental models on asynchronous coordination and performance with decision teams (Espinosa et al. 2001). It also includes two other methodological studies (Espinosa 2001; Espinosa and Carley 2001) undertaken to develop, validate, and visually represent measures of shared mental models of the team and the task, and accuracy of shared mental models.

The qualitative part of the present study has been completed and analyzed. It is based on 36 individual interviews with software developers and technical managers, and observations of nine cross-site coordination meetings. Further coding of interview transcripts and observations by two independent raters is planned to strengthen the validity and reliability of the results. Preliminary results indicate that cross-site software development coordination challenges are more substantial, and that their potential problems are more severe than those of colocated work, mainly because of lack of familiarity with colleagues and context in other sites, and because of problems with less rich communication media. The negative effects of distance are further compounded in some cases by other global factors such as time zones, cultural differences (country and organizational), and language. However, many indicated that prior knowledge with cross-site colleagues and familiarity with the remote site context offset some of the negative effects, and that this resulted in improved quality of communication and working relationships. Similarly, many indicated that having common knowledge of the task helped them achieve more common grounding in their communication, thus resulting in higher coordination. Finally, different interviewees discussed various types of coordination problems, but they were all related to the management of either technical, temporal, or software process interdependencies.

The survey research has already been collected. A total of 97 developers (85% response rate) completed the survey, yielding data for 54 software modification requests developed collaboratively over the prior three years for a main sub-system of a telephony switch product, each unit involving anywhere between two and eight software developers. We selected the modification request as the unit of analysis because it constitutes the basic unit of software work at this organization. Each modification request goes through a formal review process by a change control board and gets assigned a budget. The quantitative data from software production sources has already been collected from this product's configuration management system. This data set is quite large and it contains detailed data for each delta (a delta is a single software file modification done by one developer). An modification request contains anywhere between one and thousands of deltas. We are focusing our attention on all deltas recorded for all software modification units during the last three years for a single subsystem of this telephony switch.

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