Coordination, Overload and Team Performance: Effects of Team Communication Strategies

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ABSTRACT
The goal of this paper is to identify the communication tactics that allow management teams to successfully coordinate without becoming overloaded, and to see whether successful coordination and freedom from overload independently influence team performance. We found that how much teams communicated, what they communicated about, and the technologies they used to communicate predicted coordination and overload. Team coordination but not overload predicted team success.

Keywords
Work groups, coordination, cognitive overload, electronic mail, computer-mediated communication, awareness devices

INTRODUCTION
For a work group to accomplish a task effectively, its members must coordinate their efforts in a very detailed way. Two ways groups can coordinate work are through team design and through communication. By design we mean the way teams structure their tasks and the tools they use to aid coordination [11]. By communication we mean the face-to-face meetings, electronic mail (email), file exchanges, and so forth that teams use to perform such tasks as negotiating their goals, making decisions, and providing one another task status information.

Although all teams use some degree of design and communication to coordinate their activities, to some extent these approaches are substitutes for each other. For example, when communication between team members is difficult, they often resort to increased division of labor to reduce their needs for communication [9]. However, sharp division of labor coupled with reduced communication is a poor choice for tasks characterized by high uncertainty, rapidly changing environments, poorly defined outcomes, and a substantial variety of problems to be confronted [8][14]. These conditions, however, characterize many tasks for which teams are used, such as managerial decision making, software engineering, and home contracting. Participants must communicate directly and extensively to coordinate successfully in these interdependent and uncertain tasks.

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Imagine, for example, the top management team in a software company that must respond to an announcement from a competitor that the competitor is giving away a core product in order to build market share. The team must formulate and come to consensus on an initial strategy (e.g., give away the product too, bundle their product with those from other companies, seek anti-trust protection) so that they can all act in a unified way, monitor changes in the business environment, so that they can revise plans as needed, execute these plans, and maintain awareness of what one another is doing so that they do not duplicate or contradict each others actions. The danger is that the effort of communication and monitoring may overwhelm them and deflect them from actually doing work. It is difficult, for example, to craft a press release or lobby justice department officials if one needs to be continually discussing strategy with peers.

The goal of this paper is to identify the communication tactics that allow management teams to coordinate successfully without becoming overloaded and to see whether successful coordination and freedom from overload independently influence team performance. We examine how much teams communicate, what they communicate about, and the technologies they use in order to predict coordination and overload. We also examine the techniques they use to maintain awareness of what other team members are doing at a given point in time.

In addition to measuring team members' use of traditional technologies for maintaining awareness (e.g., group meetings and electronic mail), we provided them with two preliminary tools that were designed to increase awareness without increasing overload. An additional goal of this

study was to evaluate the usefulness of these tools and to draw implications for the design of a new generation of awareness tools.

Awareness

One function of within-team communications is to provide members with information about what their teammates are doing. When decisions and outcomes depend on integrating different team members' efforts, it is important for each member to know the status of the others' tasks—how near to completion the tasks are, preliminary results, and so forth.

The Impact of Technology on Awareness

When groups are co-located, members can maintain awareness by monitoring activities going on around them by, for instance, overhearing conversations between other team members [18]. For distributed work groups, maintaining awareness of others' activities is more difficult and requires some degree of technological intervention. The use of traditional technologies such as email among team members may affect both coordination and overload by allowing those members not directly involved in an exchange to be passively aware of the contents of that exchange. Passive awareness of what other team members are doing, provided by indirect participation in a communicative exchange (e.g., by carbon copying), should enable a team member to better coordinate his/her activities with the rest of the team. For example, several researchers have demonstrated that compared to people who do not use electronic mail, people who are heavy users are more likely to be able to keep up with the more variable aspects of their work environment, even if these are not the focus of their immediate work activities [12][16]. One reason is that electronic mail, through copies and distribution lists, is often sent to people who are only peripherally concerned with its contents.

Trade-offs Between Awareness and Overload

It is plausible, however, that passive awareness comes with the cost of increased information volume. By adding to team members' already large stream of incoming information, passive awareness information may consume too much of the team's attentional resources.

It may be possible to balance the tension between needs for greater information to improve coordination and needs for reduced information to conserve attentional resources. By providing information asynchronously and by aggregating it rather than providing it incrementally, one may reduce attentional demands without reducing the usefulness of the information. Kraut and Attewell [16], for example, show that people receiving asynchronous communication, like fax and email, report that it is much less intrusive than synchronous communication, like meetings or phone conversations. Because the receivers can fit asynchronous messages into their task schedules, an increase in volume of asynchronous messages leads to substantially less overload than an comparable increase in synchronous communication.

Aggregating information may be another technique to reduce the volume of information and amount of overload. For example, rather than presenting each message in order in a user's electronic mailbox, the databases used in several organizational memory systems consolidate all messages on a particular topic and provide an indicator to potential users of the volume of messages [17]. While there has been no explicit assessment of the effects of this technique on overload, it is plausible to assume that this technique consumes less attention than the alternative.

Research questions

We can summarize this discussion through several research questions:

What communication tactics allow teams to be better coordinated? Increased volume of communication in any modality may lead to better coordination. Because the interactivity improves communicators' ability to reach common ground, use of face-to-face communication may improve coordination more than use of electronic mail [1]. Because asynchronous communication reduces scheduling costs in communication, use of electronic mail may improve coordination most for distributed teams.

Topic of communication is also likely to influence coordination. One can broadly distinguish between discussions of substance—what work should be done—and process—how to do the work. Both of these may improve team coordination by clarifying for all team members what the team goals and procedures should be.

What communication tactics allow teams to reduce cognitive overload? Reduced volume of communication in any modality should reduce overload. Because it is asynchronous, use of electronic mail as a substitute for face-to-face communication should reduce overload.

Can well-designed awareness devices enhance team coordination without increasing overload? New awareness tools that follow certain design principles (aggregation of information, passive awareness, asynchrony) may lessen feelings of cognitive overload by reducing the heavy incoming stream of information a team member typically faces. In addition, passive awareness should enhance coordination by allowing team members to monitor or access information on an as-needed basis.

What, if any, are the effects of coordination and cognitive overload on objective and subjective team outcome measures? Although it is widely acknowledged that coordination improves performance and overload hinders it, these relationships, as well as trade-offs between coordination and overload, have rarely been examined in a naturalistic context in which all teams share the same tasks and goals and in which performance can be readily measured and compared using objective measures.

We investigated these four questions within the context of a business simulation, described in the next section.

THE MANAGEMENT GAME SIMULATION

All students in Carnegie Mellon University's (CMU) Graduate School of Information Administration must participate in a realistic business simulation called the *Management Game* ("Game"). In this simulation, five to six member teams are grouped into "nations" of four firms each; within each nation, firms compete with one another over the course of a simulated two-year business period condensed into 14 actual weeks.

During the simulation, teams must make decisions regarding the nature, production, distribution, and financing of their products (detergents). They must also, in a series of reports and presentations, present their companies' strategies to boards of directors consisting of actual business people, and they must trade shares of their own and other teams' companies in a simulated stock market. In addition to these routine business decisions, the game is punctuated by crises such as lawsuits and threats of work stoppages that call for rapid mobilization of effort and quick responses.

Team presidents are elected, but teams typically further divide their labor by assigning members to specific positions such as Chief Financial Officer and Marketing Strategist. Nonetheless, these individual tasks must be integrated in order for teams to make good decisions. Much of this integration process appears to result from the use of both synchronous communications (e.g., face-to-face meetings and telephone calls) and asynchronous, computer-mediated communications (e.g., email, electronic file sharing). Because team members generally have different work and class schedules, teams playing the Management Game tend to work in a distributed manner much of the time.

The Management Game thus combines the best features of both field and laboratory studies: it is a very realistic simulation; yet, it also provides sufficient control to allow meaningful comparisons between groups using different processes, employing different technologies, or varying on other measured dimensions. It is in the context of this simulation that we examined our research questions described above.

METHOD

Overview of Study

Teams of students participating in the Management Game interacted over the course of two seven-week periods. During this time, team process data was collected via three surveys, and team outcome data was obtained from objective sources. As part of the study, two awareness tools were introduced to Game participants and ratings of their usefulness by team members was obtained. In the remainder of this section we first describe the construction of the two awareness tools, then we describe the web-based surveys we administered, and finally we describe the outcome measures used in the study.

Construction Of Awareness Tools

In the context of the Management Game, a team member is likely to be interested in changes to the Game environment (e.g., changes to the firm's stock price), to his/her personal success (e.g., wealth in Game dollars), in the availability of teammates, in the status of others' tasks, and in changes made to shared artifacts such as documents and spreadsheets, among other things. We developed two simple awareness tools designed to address these informational needs without creating information overload: an email archiving system and an activity monitoring tool.

Although these two tools were somewhat primitive, they enabled us to evaluate the importance of several design principles for awareness tools. Both tools were designed to provide passive awareness of others' activities—that is, to make information available in such a way that it does not impose on the user's attentional resources—under the assumption that this will increase coordination and decrease cognitive overload. Both tools were also designed to be asynchronous in order to further reduce cognitive overload. Finally, the activity monitoring tool was designed to test a third design principle, namely, that by aggregating information sources such that multiple inputs are represented as a single flow of information and such that important changes to the environment can be readily identified, awareness tools can enhance coordination while reducing the overload associated with multiple information inputs.

Email Archive

The email archiving tool monitored a user's incoming email and automatically generated and filed copies of Game-related email into his or her email archive—a private collection of Game-related messages similar to an electronic bulletin board (bboard).

In order to evaluate the role of passive awareness on team process variables, we created two types of email archives. A "group archive" stored messages sent from any team member to any other team member and was readable by all members of a particular team. An "individual archive" was specific to each team member and contained all Game-related messages addressed to him or her. The functional difference between these two types of archives was that a team member using a group archive could browse all of the team's Game-related messages, even if he or she had not been directly addressed or copied when that message was originally sent, whereas a team member using an individual archive could only access messages he or she had received.

Activity Monitoring Tool

The activity monitoring tool, our first attempt at developing a tool that would monitor a variety of Game-

specific information sources, provided team members with a personalized display of the state of several relevant team and personal variables. This tool was designed to help team members focus on the right information at the right time by providing background alerting services to indicate when important changes had occurred in the Game environment and by monitoring teammates, shared work objects, and information sources in the environment. The interface permitted users to customize the display by expanding or collapsing subsections to meet their informational needs. An example of an expanded interface is shown in Figure 1.

The activity monitoring tool was designed to monitor a set of heterogeneous inputs (e.g. new email count, firm price of a firm's shares on the simulated stock market, time since a collaborator was last seen, rate of change in personal net worth) and to map measures of these inputs onto a single visualization. That is, we aimed to design a tool that would tell a user if something "interesting" was happening in a variety of Game-related information domains in a single glance, regardless of differences in units of measurement used in these domains.

We chose to apply simple heuristics to map the raw inputs into an 8-point "interest" scale. Each input was then rendered with a graphic gauge that had seven slots arranged horizontally that could "light up"—a "0" on the interest scale would display zero lights, whereas a "7" would display seven lights (see Figure 1). The display updated itself every 15 minutes. Discussion of the heuristics will be presented in a more detailed presentation of the research.

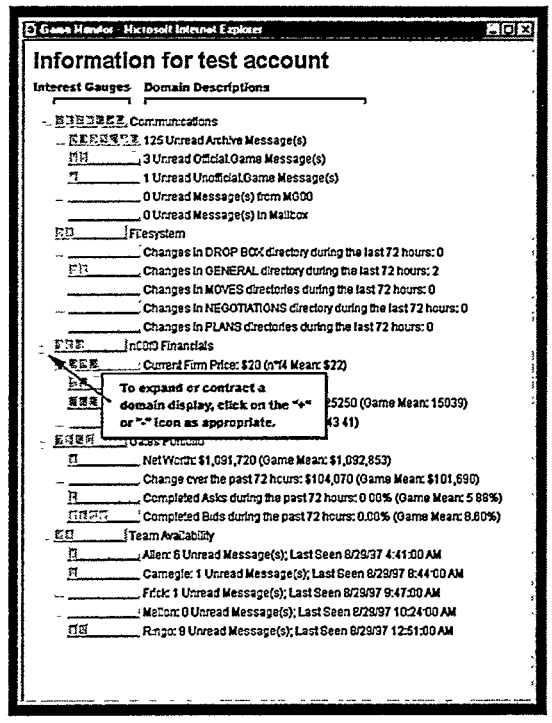

Figure 1. The Activity Monitoring Tool.

Surveys

Game Survey

Participants completed web-based surveys at three points during the game: at the end of the first seven-week period, halfway through the second seven-week period, and at the end of the game. The second and third survey periods coincided with teams' second and third board presentations. The surveys contained a large number of questions addressing a number of aspects of team activity:

Media Importance. In the first survey, respondents were asked to rate the importance to their team of several communications modalities (face-to-face meetings, email, telephone, file exchange, and fax) on a scale of 1 (not at all important) to 5 (extremely important), and to indicate the frequency with which they used each of these modalities on a scale of 1 (never) to 6 (daily). Not surprisingly, frequency and importance ratings were very highly correlated (> .90) and to conserve survey space we retained only the importance ratings in the remaining two surveys.

Rated importance of face-to-face and telephone communications were highly and positively correlated, as were ratings for email and electronic file exchange. To avoid multicollinearity, we selected Game teams' two primary communications modalities—synchronous face-to-face meetings and asynchronous email communication—to use in our analyses.

Topics of Communication. Respondents were asked to rate the frequency with which their team discussed six Game-related topics—financial strategy, product and product development, competitors, board presentations, Game rules, and team process—on a 6-point scale ranging from never to daily. Factor analyses of responses to these questions indicated two independent topic dimensions on which teams differed: strategy-focused discussion (strategy, product, competitors), and process-focused discussion (presentations, rules, team process). Teams' average scores on scales representing these two dimensions were used in our statistical analyses.

Team Process. The surveys contained a number of questions about team coordination (e.g., "Tasks were clearly assigned," "Team members had a clear idea of team goals"), and cognitive overload (e.g., "The pace of Game was overwhelming," "I received more information from my teammates than I could process"). Some of these questions were adapted from prior, standardized scales (e.g., [2][20]) and some were newly constructed for the current study. All responses were made using a 5-point scale ranging from strongly disagree to strongly agree. Scales for coordination and overload were constructed based on factor analyses and our knowledge of the item's author's original intent.

Awareness Tool Use. Surveys also included several questions concerning how often respondents used the email archiving and activity monitoring tools described below, and how important they judged these tools to be.

Outcome Measures. We used two measures of team performance in our analyses. Stock market price for a team reflected the judgment of all 277 Management Game participants of how well a team performed. Because stock prices rose rapidly over the course of the game, we used prices normalized across teams within each of the three survey periods. Board evaluation surveys were distributed to members of the board after each of the three board presentations. Because responses to all evaluation questions were highly inter-correlated, we used overall ratings, averaged across board members, to represent board evaluation scores.

Participants and Procedure

Participants consisted of 277 students, organized into 50 five or six member teams, who participated in the Management Game during the Spring and Fall of 1997. Of these teams, 39 consisted of full-time students and 11 consisted of part-timers.

The study took place over a period of approximately 14 weeks. During this time, teams made decisions about such managerial issues as what products they would sell to what markets ("Game moves"). These decisions changed the state of the Game environment and thus influenced their own and other teams' future moves. In addition, teams wrote three documents and made three oral presentations to their boards of directors. They also had to decide how to handle unexpected crises.

The email archive and activity monitoring device were introduced at separate times. Game teams who agreed to participate were randomly assigned to either the group or the individual archive condition. Archiving was introduced during Phase 1 to all teams who agreed to participate in the study. During Phase 2, we provided participating team members with the activity monitoring tool for a period of seven weeks.

Summary

By way of surveys and other measurement techniques we collected a large set of data that included control, work process, awareness tool, and outcome variables. We then trimmed down the full set of variables to reduce multi-collinearity. The final set of variables selected for use in our analyses is shown in Table 1.

RESULTS

In this section, we first describe the statistical techniques we used to test our hypotheses. We then present the results of structural equation modeling. Finally, we report additional analyses concerning the awareness tools we provided.

CONTROL VARIABLES
Firm starting position (Firms 1-4)
Number of members (5 or 6)
Student status (full-time vs. part-time)
WORK PROCESS
Topics of discussion (self-reported frequency)
Team process (task assignments, scheduling)
Team strategy (production strategy, competitors)
Media importance (self-reported)
Face-to-face meetings
Electronic communications
Team process measures (self-reported)
Self-reported coordination
Self-reported cognitive overload
TOOL USE
Awareness tool importance (self-reported)
Email Archive
Activity Monitoring Tool
Desired features for new awareness tools
TEAM PERFORMANCE
Firm stock price (objective)
Board evaluation (mean subjective evaluation)

Table 1. Measures used in statistical analyses.

Method of Analysis

Because the simulation is played over several weeks, we collected data at multiple points in time, allowing us to examine developmental processes and to test causal paths using panel designs and structural equation modeling.

Two types of regression analyses were used in the analyses reported below. Because the number and identity of members of each team who responded to the surveys differed from survey to survey, the equation used to analyze survey variables included only other variables that had been measured at the same point in time:

$$\text{Success of Team Process}_t = \text{Predictors}_t + \text{Controls}$$

In contrast, the two outcome measures were always analyzed by an equation of the following form:

$$\text{Performance}_t = \text{performance}_{t-1} + \text{Predictors}_t + \text{Controls}$$

This analysis looks at the effects of predictor variables (e.g., team coordination) on an outcome variable measured (e.g., firm stock price) while holding constant the initial value of the outcome variable and other control variables (e.g., team composition). Because the outcome variable is included on both the left and right sides of the equations, the analysis is equivalent to an analysis of change scores on the outcome, controlling for regression towards the mean, unreliability, contemporaneous covariation between the outcome and the predictor variables, and other statistical artifacts [4].

Structural Modeling of Team Processes and Outcomes

The model we report here tests the causal sequence illustrated in Figure 2. In this model, the first step

involved regressing four communications variables (the two topics—strategy and group process—and the two modalities—face-to-face and email) onto users' ratings of the importance of the awareness tools (email archive and activity monitoring tool). Second, these six variables were regressed onto the two measures of team success—self-reported coordination and cognitive overload. Third, because firm price was set prior to each board meeting, we regressed the full set of variables plus standardized lagged firm price (that is, firm price at the time of the previous board meeting) onto current standardized firm price. Finally, we used all these variables plus lagged board evaluation (the evaluation from the previous board meeting) to predict current board evaluations. Because lagged variables were included in the equations, only data from the second and third survey could be included in the analyses.

All the regression equations also included the control variables listed in Table 1. However, because these variables seldom showed any significant effects on the dependent measures and because they were typically of

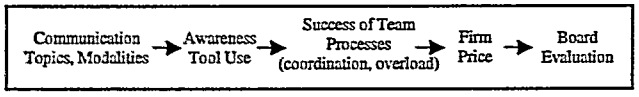

Figure 2. Causal path tested in regression analyses.

little theoretical interest, results for these variables are not reported here unless they are especially strong and theoretically notable.

Step 1: Predicting Rated Importance of Awareness Tools.

Email Archive. The email archive was designed to enhance team coordination while reducing cognitive overload by storing messages in a convenient place. Game participants were not, however, forced to use their archives. Thus, this stage of our structural modeling examined the effects of communication content and modality variables on the rated importance of the email archiving system.

Not surprisingly, the more important teams rated email as a medium for their intra-team communications, the higher they rated the importance of the archive. The email archives were also rated as more important by teams consisting of full-time as opposed to part-time students. We had expected that part-time students would have more difficulty coordinating their schedules and therefore would value the archive more than full-time students. It is likely that this finding, which parallels the part-timers' somewhat lower ratings of the importance of email communications, stems from the difficulties part-time students have in accessing the CMU email system from off-campus.

The overall equation was quite successful at predicting archive use (F [9, 68] = 5.62, $p < .001$; $R^2 = .43$). The strongest predictor was student status ($t = 3.97$, $p = .001$; $\beta = .40$), followed by rated email importance ($t = 2.65$, $p = .01$; $\beta = .28$).

Activity Monitoring Tool. Our analyses found no significant predictors of the use of the activity monitoring tool, nor did we find that use of this tool affected any other variable in the equation. Thus, we have eliminated it from Figure 3 to make it easier to follow. We will discuss other analyses of activity monitoring tool use later in this paper.

Step 2: Predicting the Success of Group Processes

One of our major interests in this study was to examine the effects of team communication strategies (modality and content) and use of awareness tools on team coordination and feelings of cognitive overload.

Coordination. The frequency with which a team reported discussing issues regarding team strategy (marketing, competitors) was a good predictor of how well that team reported it coordinated its activity: The more time spent discussing strategy, the better coordinated the team. In contrast, increased discussion of team processes such as

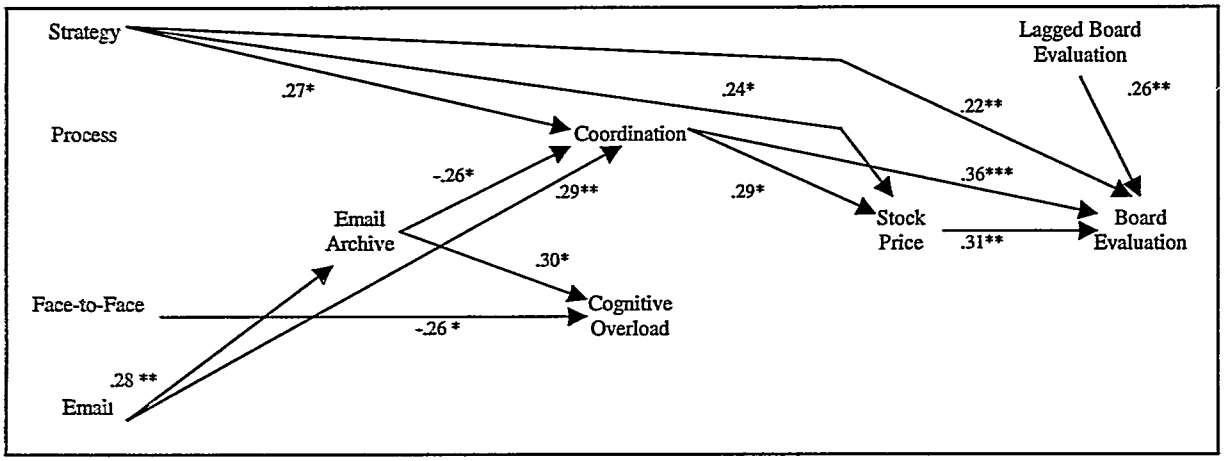

Figure 3. Direct and indirect effects of variables in structural equation analysis.

task assignment did not predict success of team coordination.

Email was also an important mechanism for increasing team coordination. The higher the rated importance of email (strongly correlated with the frequency of email use), the better coordinated the team. Contrary to our expectations, however, rated importance of face-to-face meetings did not predict coordination.

The complete set of variables in the equation was excellent at predicting self-reported team coordination (F [11, 64] = 4.92, $p < .001$; $R^2 = .46$). The best predictors were discussion of team strategy ($t = 2.46$, $p < .05$; $\beta = .27$), and rated email importance ($t = 2.62$, $p = .01$; $\beta = .29$). Use of the email archive was negatively associated with coordination ($t = -2.04$, $p < .05$; $\beta = -.26$), perhaps indicating that team members go back to look at older messages when coordination is poor.

Cognitive Overload. We had anticipated that most teams in this study would reported experiencing a significant amount of cognitive overload. However, most responses were in the intermediate range. Furthermore, contrary to our expectations, the extent of overload was negatively associated with rated importance of face-to-face communication. Because importance ratings were very highly correlated with self-reported frequency of use for each communication mode, these findings suggest that rather than overwhelming members' attentional resources, more frequent within-team communications may help clarify roles, keep others up to date on what one is doing, and otherwise provide information that helps a member complete his or her task.

In the full model, cognitive overload was significantly predicted by our independent measures (F [11, 65] = 2.06, $p < .05$; $R^2 = .26$). The strongest predictor variables were rated importance of face-to-face communications ($t = -1.97$, $p = .05$; $\beta = -.26$), and self-reported email archive use ($t = 1.99$, $p = .05$; $\beta = .30$).

Steps 3 and 4: Predicting Outcome Measures

Firm Stock Price. In predicting firm stock price, we included lagged stock price (the stock price just before the previous board meeting) to the variables already in the equation. The most important predictors of stock price were self-reported coordination and frequency of discussing strategic topics. Greater coordination and more frequent discussion of strategy probably have their effects on stock price by way of their effects on decision-making processes. Stock price was in large part a function of a teams profits, which in turn were based on agreement about product development, marketing, and competitors' strategies. It is conceivable that the goodness of a decision is improved when teams both know how to coordinate and integrate individual members' work activities and when all members understand team strategy.

Stock price was predicted well by the full model (F [14, 61] = 3.52, $p < .001$; $R^2 = .45$). The two primary predictors in this model were team coordination ($t = 2.10$, $p < .05$; $\beta = .29$) and discussion of strategy ($t = 2.00$, $p = .05$; $\beta = .24$). Although lagged price was highly correlated with current stock price, it was not a significant predictor of current stock price when all other variables were entered into the equation.

Board Evaluation. In the last stage of the analysis, we regressed all the previous variables plus lagged board evaluation (the evaluation from the preceding meeting) onto current evaluations. The results indicated that better board evaluation scores could be successfully predicted by higher values of two process variables—the success of team coordination and the extent to which teams discussed strategy—and of two outcome measures—lagged board evaluation and current stock price.

Better coordinated teams may receive better board evaluations because substantial coordination is required to integrate individual members' analyses for the written board reports and to create a unified oral presentation. Similarly, discussion of strategy, in addition to improving coordination, may allow teams to converge on a shared view of what they will present in their oral and written reports.

The full model was highly successful at predicting board evaluations (F [16, 58] = 6.01, $p < .001$; $R^2 = .62$). The most successful outcome-based predictors were lagged board evaluation ($t = 2.42$, $p = .05$; $\beta = .26$) and normalized current stock price ($t = 2.83$, $p = .01$; $\beta = .31$). The most successful process-based predictors were self-reported team coordination ($t = 2.97$, $p < .005$; $\beta = .36$) and frequency of strategy-related discussions ($t = 2.00$, $p = .05$; $\beta = .21$).

Further Analyses of Awareness Devices

In addition to assessing the role of the email archive and the activity monitoring tool within the context of structural equation modeling, we also performed analyses of awareness tool use in which we examined the effects of additional tool-specific variables. In this section we report on these additional analyses.

Email Archive

In the structural equations above, we did not distinguish ratings of email archive importance by teams in the group versus the individual archive condition. As noted above, in the group condition a team member could examine all email exchanges between teammates, regardless of whether he or she was one of the original recipients of those messages. In the individual archive condition, team members could only access email that they had sent or received.

We predicted that group archives would provide teams with more value than the individual archives because they

enabled team members to monitor others' activities, through their email exchanges, on an as-needed basis. In contrast, the individual archive served essentially as an email filtering device—it organized information that the team member already had. We also predicted that archive importance would increase as the total number of messages exchanged between teammates increased.

We tested these predictions in a two (archive condition) by two (survey number) Analysis of Variance (ANOVA). An objective measure of the amount of within-team mail archived per day was used as a covariate, as the need for an archive is likely to increase as a function of email volume.

Consistent with our hypotheses, teams assigned to the group archive condition rated their archives as significantly more important than teams assigned to the individual archive condition (F [1, 73] = 9.74, $p < .005$). In addition, there was a strong effect of the covariate, email volume (F [1, 73] = 15.68, $p < .001$), indicating that regardless of archive condition, teams receiving more email placed greater value on the archive.

The Activity Monitoring Tool

As noted above, several types of information were presented in the activity monitoring tool's display: changes to shared documents and spreadsheets, to team members' whereabouts (e.g., when they last checked their email or logged on), to the team's financial status, and to the Game environment.

Respondents showed a clear preference for notifications about changes to their teams' finances and to the Game environment over information about others' availability or changes to shared documents and files. A two (study condition) by two (task-related vs. process-related information) ANOVA, with repeated measures on the second factor, showed a significant effect for type of information presented (F [1, 290] = 115.68, $p < .001$). There was no effect of which type of the information was presented first nor a presentation condition by type of tool interaction. These results are paralleled by those when frequency of use rather than importance serves as the dependent measure.

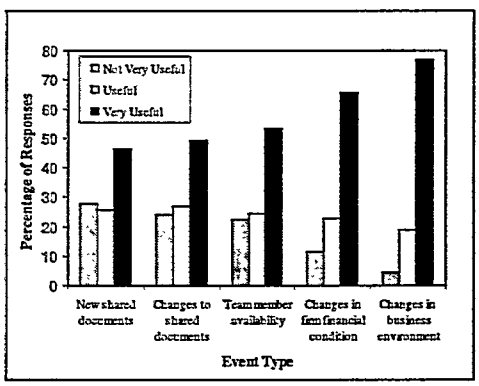

Figure 4: Rated usefulness of automatic notifications by event type

The means of the ratings, however, indicate that neither the team activity nor the Game environment monitoring were rated of high importance. Thus, the relatively low usage and ratings of our first awareness tools could stem from a lack of interest in such tools or from flaws in our first attempts to instantiate awareness tools (e.g., a poor interface, incorrect mappings of raw data to interest indicators).

Some indication that Game teams consider properly constructed awareness tools to be at least potentially helpful comes from responses to five questions we asked all students in the final survey. These questions asked respondents to rate how useful they thought it would have been if their team had been automatically notified about (a) new shared documents, (b) changes to existing documents, (c) the availability of team members, (d) changes to the financial condition of their firm, and (e) changes to the business environment that could impact their firm.

The results are shown in Figure 4. Consistent with ratings of the activity monitoring tool, there was greater interest in our developing future awareness tools for financial and Game environment information than for member availability and shared documents. One way to interpret these findings is that Game participants are in fact more interested in monitoring changes in finances and in the Game environment. However it is also possible that teams already had a notification system in place—email—for document changes and member availability. A casual examination of team members' email content revealed that a large proportion contained notifications about new and changed documents and spreadsheets and about team member availability. Few or none contained information about firm finances or the business environment. Instead, indications of interesting changes in these domains had to be actively sought (e.g., by logging onto the stock market simulation). Awareness tools, then, may benefit users when they provide passive awareness of information that previously had to be actively sought.

DISCUSSION

The results presented above provide us with some preliminary answers to the questions posed in the introductory section of this paper:

What communication tactics allow teams to be better coordinated?

Email was an important means by which teams in this study coordinated their activities. Although survey respondents rated the importance of each modality, not its frequency, the two were found to be so highly correlated in Survey 1 that we can infer that at least in part, the more email a team exchanges the better coordinated their activities will be.

Somewhat surprisingly, we found no evidence that face-to-face communication affected degree of coordination. This may be due to the extent to which teams worked in a distributed manner: because of members' different schedules, face-to-face meetings may simply have occurred too infrequently to allow for rapid coordination of effort. In addition, a substantial proportion of team emails were devoted to coordinating the face-to-face meetings themselves (time, location, agenda).

Choices about what to talk about and how often to talk about them also affected reported coordination. Teams that discussed issues related to their tasks and goals (here, their competitors activities and their products) were better coordinated. Discussion of process-related topics, however, did not appear to affect coordination.

One way to interpret these findings is that discussion of strategy helps team members develop a shared view or mental model of their team's goals and tasks [3][15]. This shared mental model may improve coordination because each team member understands how his or her tasks fit into the team's overall goals.

We are currently coding and analyzing within-team email content and type (question, statement, command, etc.) to help us further interpret our findings on team communications.

What communication tactics allow teams to reduce cognitive overload?

In this study, cognitive overload did not appear to be a function of any specific communication strategies. Self-reported overload levels were lower than we had anticipated and there was little variability across teams. There are several explanations. First, teams may experience different levels of information overload but they may adapt their behavior so that their current level of perceived cognitive overload is tolerable to them. Second, we may not be measuring cognitive overload correctly. Respondents rated their overload levels for the week prior to the survey and it is likely that they couldn't recall precisely how they felt during that time period.

Face-to-face communication had a direct effect on ratings of cognitive overload but interestingly, this effect was in the opposite direction than anticipated: the more communication, the less feelings of overload. We also found a nonsignificant effect in the same direction for email communications. These results may indicate that it is task demands rather than incoming communications that are responsible for feelings of cognitive overload. Alternatively, the results may be due to problems with our measure of overload.

Can well-designed awareness devices enhance team coordination without increasing cognitive overload?

Although we were unable to answer this question in the current study, we were able to identify properties that Game teams desire in future awareness tools. In general, team members find it natural to send one another notifications about their availability and changes to shared artifacts. What they desire is awareness tools that allow them to monitor exogenous changes in the Game environment—lawsuits, competitor actions, financial performance, and so forth.

Another reason teams may prefer notifications about the environment is that unlike the straightforward information provided by notifications of availability and changed artifacts, environmental information requires substantial processing before decisions may be made and/or actions may be taken based on this information.

These results suggest that awareness tools should focus extensively on monitoring and processing environmental information, at least within the domain we studied. The extent to which these results can be generalized to other types of work teams with other collaborative tasks is an issue for future research.

What, if any, are the effects of coordination and cognitive overload on objective and subjective team outcome measures?

Our analyses showed clearly that the better coordinated a team reported being, the better its performance both in the stock market and in board evaluations. Better coordinated teams may have had higher stock prices because smooth coordination allowed them to integrate their individual tasks easily and make good decisions about Game moves. Better coordinated teams also were able to write better documents and give better board presentations. These results, although expected, are important because they demonstrate a relationship between process and outcome that has not often been empirically established.

FUTURE DIRECTIONS

In our current work we are investigating the use of shared mental models as an underlying theoretical construct that explains many of our findings. For example, we found that discussion of team goals and strategies improved coordination and outcomes. It seems likely that this effect occurs because discussion of goals and strategies facilitates the development of shared mental models. These models, in turn, can be used by each team member to coordinate with the others and by teams as a whole to integrate their individual contributions resulting in better decisions (reflected in firm price) and board evaluations.

We also seek to understand the trade-offs and interactions between overload and the development of shared mental models. For example, it is possible that a high volume of communication during a period of frantic deadlines may make it more difficult for team members to achieve a shared mental model because there is too much information to attend to. Once in place, however, shared mental models may reduce feelings of overload by allowing team members to quickly categorize information,

prioritize tasks, and distribute responsibilities. In other words, these models may help teams cope with information and decision environments that would otherwise lead to feelings of overload.

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