

Coordination Processes and Awareness Support in Dynamic Work Environments

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Final Report

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Abstract of the Project Proposal

Computation and communication technology has the potential to improve coordination but to realize that potential requires a deep understanding of the coordination processes used by teams, especially those that rely on awareness of dynamic task and team situations. This project investigates the coordination processes used by distributed expertise teams operating in highly dynamic work domains such as trauma patient resuscitation. The main objective is to develop a framework for modeling coordination processes by team members in dynamic, multi-tasking, highly stressful environments. The project is conducted by an interdisciplinary teams with wide-ranging research background and experience: team performance, information technologies, medicine, nursing, health care informatics, management sciences, biomedical engineering and ethnography. Qualitative and quantitative methods including ethnographic studies, surveys and interviews are used to capture coordination processes in situ in trauma center settings. The project will result in a better understanding of the role of various communication media and how each medium is used in dynamic work settings to achieve work coordination and maintain adequate awareness. A set of design principles will be developed that can guide the deployment of communication-computation systems in domains where tasks are highly dynamic and accomplished by multi-disciplinary teams.

Project Participants

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Arnold Campbell, PhD
Design Interpretive
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¹Worked for more than 160 hours in any one year.

Research and Education Activities

Research organization. A major goal of the proposal was to develop a starting network of multidisciplinary researchers interested in the study of coordination in high velocity environments. Over the course of the project, as evidenced by the list of the project participants, the network has been well-established with researchers from a range of background: human factors, psychology, management science, information systems, nursing informatics, operations research, usability, computer science, medicine, and nursing. The network has been valuable and beneficial to those participated in several aspects. One aspect is the interaction between researchers and clinicians. A regular group meeting has been held to exchange information and brief research activities to clinicians.

Another aspect is the extramurally funded projects based on the researcher network.

- *Nortel Network* support for research on the novel use of wireless technology and automated information processes. Several members of the research network participated in a project funded by Nortel Networks on novel use of wireless communication technology to improve coordination. In fact the research network was instrumental in securing the research funding from Nortel Networks.
- *National Science Foundation (NSF)* support for research on usability issues associated with ubiquitous computing. The collaboration with Dr. Andrew Sears of University of Maryland Baltimore County (UMBC) Department of Information Systems has facilitated the formulation of an Information Technology Research (ITR) group proposal, which was funded by National Science Foundation (NSF).
- *NSF* support for research on expertise coordination in high velocity environments. The PIs of this project formulated a research proposal based on some of the findings of the project and the proposal was funded by NSF's ITR initiative. The PIs have been able to leverage the synergy between the NSF funded projects to understand the existing role of information technology in expertise coordination needed in highly skilled, high tempo environment of trauma patient resuscitation.
- Additionally, two related projects were funded by *Department of Defense* to study team performance and to experiment with novel coordinative artifacts.

In addition to the research network, the project received remarkable support from graduate students. The inherent multi-disciplinary nature of the project plus the exciting opportunity in observing real teams up-close have attracted high-quality graduate students. Two of the best graduate students from the nursing school joined the project (one of which did so without financial support from the project). From the management school, two brilliant graduate students joined the project. The students have been a key to the success so far of the project. In addition, a member of the faculty at the nursing school joined the research team without the support of the project. All counted, the research team now has 11 members. More importantly, the collaboration has broadened the research scope and created more opportunities for further collaborative work.

We expect that the excellent working relationship among all the members of the project and with the clinicians in the study setting will continue to enhance productive research activities. This NSF project has played a pivotal role in establishing a viable research organization through which interesting and productive research is likely.

Data collection. As the first step in understanding coordination in the trauma center, we have utilized several different data collection methods. These methods include interviewing, shadowing and observation with probing. Overall, we observed patient admissions and treatment for a total of 140 hours (average length of session 3.1 hours). We shadowed 9 key personnel in five roles for a total time of 28 hours and recorded all their interactions and behaviors. We conducted 54 in-depth interviews of 56 people (some people were jointly interviewed) and 15 short complementary interviews. The average interview lasted approximately 45 minutes. The range was from 20 minutes to 1.5 hours. The interviews were transcribed and checked for accuracy.

Many different artifacts are used by the clinical and supporting personnel to coordinate activities in the trauma center. Some of the coordination artifacts had unique roles or were used extensively, and thus were specifically the object of our focus. We performed detailed field observation (using in-person observation and picture taking of the artifacts in use. We focused on several different public display boards (“whiteboards”) that played an essential part in enabling daily coordination. The boards used a variety of graphical and textual modes of representation and were characterized by rapidly changing layouts (using of specialized elements such as movable magnet strips). The complexity of the symbols in use and the ever-changing layout are difficult to capture just by using written reports.

Publication. Through out the project period, constant efforts have been devoted to publish and disseminate the results of the research. Below are a list of submission activities, *in addition to* those listed as published, under review, or in preparation in the “Publication” section.

Submitted to ACM 2000 Conference on Computer Supported Cooperative Work (full length papers)

- Moss, J., et al. “Awareness in collaborative work: a study in trauma resuscitation”
- Lasome, C., et al. “Public displays and collaborative work: assisting coordination in highly dynamic work environments”
- Gardner, S., et al. “Organizational coordination in high-velocity high-uncertainty environments”

Submitted to ACM 2002 Conference on Computer Supported Cooperative Work (full length paper)

- Xiao, Y., et al. Orchestrating Trajectories: How Charge Nurses Make Operating Rooms Work

Submitted to Academy of Management 2001 Annual Meeting:

- Yun, S., et al. “Leadership in a High Reliability Team”
- Gardner, S., et al. “Social Cognitive Theory: Application In A High-Reliability Setting; How Surgeons Train In Emergency Trauma Room Medicine”

Submitted to Society for Industrial and Organizational Psychology 2001 Annual Meeting:

- Yun, S., et al. “Leadership in coordinating a Trauma Resuscitation”
- Gardner, S., et al. “Trauma Action Teams: A Study of Distributed Cognition in Action”

Training and Development. The project provides great training experiences to both the principal investigators and graduate students. For the principal investigators, the project has become a vehicle for learning neighboring disciplines and conducting multi-disciplinary research. The project is also an important step in developing programmatic research using the trauma center as a live laboratory for studying coordination in highly skilled expert teams.

For **graduate students**, the project forced and enticed them to learn qualitative research methodologies in a high-velocity environment. One Ph.D dissertation has already been completed under the auspices of the project. Another Ph.D student working on the project is writing a dissertation on the same theoretical angle underlying the project but using different sites. All students are highly motivated and actively participated in data collection and manuscript write-ups. So far we have had five Ph.D. students participating in the projects. Three conference proceeding articles submitted by the students were selected as nominees of best research paper awards.

The project has promoted collaboration between three campuses of the University Maryland: Baltimore, Baltimore County, and College Park. It also bridges a variety of disciplines. We view the collaboration as only the start for future synergistic development in the respective campuses on coordination and information technology.

Of particular exciting area of training and development was associated with the involvement of an international visiting student from Delft University of Technology (Jos de Visser) and a Masters Program student who is also an attending anesthesiologist (Tim Gilbert).

Jos de Visser stayed in the research lab and worked on the distributed planning activities (results presented in an international conference). His work extended the research on large public displays. He used the visiting student opportunity to conduct a Master's thesis work. Part of the research was presented and published in an international conference (see Publication section).

Dr. Tim Gilbert worked on his Master's thesis in the area of information system management. Also extending the work on large public displays of the research program, he conducted a survey study on the use of whiteboards in the management of operating rooms (OR). As an anesthesiologist, Dr. Gilbert already has in-depth knowledge of the issues involved in OR management. The survey was successfully executed. Currently he is finishing up the Master's thesis under the direction of the project Co-Principal Investigator, Samer Faraj. We anticipate the preparation of several articles based on the survey.

Major Findings

More so than we had anticipated, the trauma center as a study setting has offered a range of coordination phenomena which occur in real life and are immediately accessible. Three of the major findings are summarized here.

Coordination supported by shared public displays (Xiao et al, 2001; Lasome & Xiao, 2001; de Visser et al, 2002). One of the areas of investigation of the project was how artifacts are used for supporting coordination. We adopted *distributed cognition* (e.g. Hutchins, 1991) framework and display-based cognition (e.g. Larkin, 1989) to understand the role of coordinating artifacts. Through field studies, we analyzed staff interactions with a large whiteboard (12 by 4 feet) in a Level I trauma center operating room unit. Coordination needs in this setting are exacerbated by the unpredictability of incoming emergency surgery patients admitted to the trauma center as well as other contingencies (such as changes in scheduled surgery cases or staffing). The whiteboard has evolved into a key component for supporting collaborative work. The physical and perceptual properties of the board are exploited by the clinicians to support rapid paced, highly dynamic work. The canvas-like appearances of the display board, combined with magnetic objects attached to the board, allow its users to tailor the board as an effective coordinative tool and to invent new ways of representing information. Based on the concept of display-based cognition, our analysis illustrates the role of public displays in facilitating negotiation of scheduling, joint planning, and augmenting inter-personal communication (Xiao et al, 2001; Lasome & Xiao, 2001; de Visser et al, 2002). Some of the activities supported by the whiteboard include

- Joint planning of who does what
- Joint planning of what case goes when
- Joint assessment of workload
- “Intra-system” display: directing collective attention

Another conclusion drawn from the studies of the whiteboard was that it is almost inescapable that users will invent new applications for such a collaborative tool. Consequently, design should be user-adaptable to new uses and in fact should invite users to exploit new uses. These design principles are being investigated in a prototyping effort to develop a hybrid, tangible user interface.

High reliability team performance (Xiao et al, 2001; 2002). To coordinate in high-stake environments requires teams to perform safely even under adverse circumstances. Previous research in high stake environments has been focused on organizational responses, such as high reliability organization theory (La Porte, 1996) whereas the detailed understanding of team processes may help in training and system designs. Through observation and interviews we collected a set of coordination practices by teams in the domain of trauma resuscitation. The studied teams in the trauma center use different methods for coordination and maintaining awareness. These include verbal but most often non-verbal methods, such as visual scanning. The robust performance of the work teams could partially be explained by the amount of efforts involved in double-checking and in maintaining awareness (e.g. making sure the surgeons know about the patient’s status) when the patient’s status is critical (Xiao et al, 2001). Based on the practices, we propose a tentative formulation of a concept, *transactive responsibility system*, to account for the intricate, complex responsibility system emerged in team interaction (Xiao et al, 2002). With a transactive responsibility system, a team can deal with the challenges of conflicting goals of training and performing and rapidly changing

work environments found in many settings. The concept of transactive responsibility system was proposed to accommodate the knowledge requirement (related to *transactive memory system*) as well as cultural requirement for high reliable performance. We proposed a set of measurements to illustrate the potential practical use of the concept. A direct implication for information technology deployment is the value of cross monitoring of teammates' activities.

Organizational coordination (Faraj & Xiao, under review). As suggested by Hutchins in his book "Cognition in the wild" (1994), we found that the trauma teams have very flexible structures and are highly resistant to performance failures under the condition of varying and uncertain incoming workload. Our initial analysis of data collected leads us to propose dimensions that are essential for effective coordination.

First, a number of unique structuring processes are used in the setting to ensure quick response under almost any circumstance. These include: the usage of detailed medical protocols to ensure medical procedure homogeneity; the reliance on extensive planning and coverage plans to ensure that personnel would be available when and if needed; redundant communication actions to ensure that needed personnel are always connected; and finally, the active management of coordination artifacts (such as boards) for information sharing and the creation of shared awareness.

A second finding relates to the surprisingly important role played by communities of practice (Brown & Duguid, 1991) for organizing and to the specific nature of their interactions. In the trauma center setting, contrary to an expectation of finding much team integration around the patient and little functional separation, we found that the action team that forms immediately around newly admitted patients, is stylized and primarily role based. Most participants view their primary allegiance to the specialty (e.g., nursing, anesthesia, surgery) rather than to the temporary team forming around the patient. Indeed, the specialty teams manage their own affairs (administratively and schedule wise) to such an extent that shifts are not even synchronized and team members may sometimes have to work with new team members midstream during a resuscitation. Nonetheless, having tightly knit communities of practice reduces structure needs and facilitates knowledge sharing among the functional groups and eases the burdens of coordinating patient care.

A third finding is evidence of well-developed expertise coordination processes not just around individual patients but also around the whole Trauma unit. Expertise coordination refers to processes that manage knowledge and skill interdependencies (Faraj & Sproull, 2000). These processes are similar and build upon team research findings about transactive memory, shared cognition, shared awareness, and distributed cognition.

Finally, a fourth finding relates to some unique cultural elements that separate this setting from other organizations as well as the more military-type HRO organizations studied in the literature. Since people chose to be part of the trauma center and can leave at any time, the culture has strong elements of testing newcomers over a long period of time to see if they can be relied on to "pitch in" or be able to handle the stress. In addition, patient safety is recognized as superceding hierarchy. Positions matters little when patient safety is concerned. Indeed, many respondents described situations where a nurse went over the head of the resident surgeon working on the patient to

report a concern related to safety. This behavior is encouraged and its existence a mark of pride for the center.

Our research team plans to follow primarily these four lines of research, with the use of other techniques such as surveys and paper-and-pencil simulations. Building on the detailed studies, we plan to develop an integrated theoretical frame of coordination in such environments.

Outreach activities

1. The PIs organized a high visibility symposium during the Academy of Management annual meeting (2002, Denver, CO). The syposium was jointly sponsored by 3 divisions of the Academy (OCIS-Organizational Communication & Information Systems, TIM-Technology & Innovation Management, and HCM-Health Care Management) and received the rare and valuable “showcase” status.
2. Yan Xiao was invited to give a colloquium at the Human Computer Interaction Institute at Carnegie Mellon University.
3. Leadership of high reliability teams, teaching case, 2001. Prof. Henry P. Sims, University of Maryland College Park. (The data collected in the project was used in graduate and executive education programs).

Publications

Although the project was a pilot for a long-term, high-impact line research on coordination, the project team has published papers in several peer-reviewed conferences. Some of the conferences have exceedingly high acceptance standard. For example, the ECSCW 2001 accepted only 10% of the submissions.

Published.

1. Xiao, Y., Lasome, C, Moss, J, Mackenzie, C.F. & Faraj, S. Cognitive Properties of a Whiteboard: A Case Study in a Trauma Centre. In W. Prinz, M. Jarke, Y. Rogers, K. Schmidt, and V. Wulf (eds.), *Proceedings of the Seventh European Conference on Computer-Supported Cooperative Work*, 16-20 September 2001, Bonn, Germany, pg. 259-278. Kluwer Academic Publishers, 2001
2. Xiao, Y., & Moss, J. Practice of High Reliability Teams: Observations in Trauma Resuscitation. *Proceedings of IEA 20010/HFES 2001 Congress*, p. 395-399, 2001.
3. Lasome, C.E.M.& Xiao, Y. Large public display boards: A case study of an OR board and design implications. *Proceedings of the American Medical Informatics Association*, Washington, DC, 349-352, 2001
4. Moss, J., Xiao, Y., & Zubaidah,S. The operating room charge nurse: Coordinator and communicator. *Proceedings of the American Medical Informatics Association*, Washington, DC, 478-482, 2001. Also in print as Moss, J., Xiao, Y., & Zubaidah,S. The operating room charge nurse: Coordinator and communicator. *Journal of American Medical Informatics Association*, 9(6 suppl):S70-S74, 2002
5. Yan Xiao, Caterina Lansome, Jacqueline Moss, Colin Mackenzie, Dale Downey, Richard Dutton, Cognitive Properties of a Trauma Center Operating Room (OR) Whiteboard, American Society of Anesthesiologists (ASA) 2001 Annual Conference
6. Jos de Visser, Peter A. Wieringa, Jacqueline Moss, Yan Xiao (2002). Supporting Distributed Planning in a Dynamic Environment: An Observational Study in Operating Room Management. In C.W. Johnson (ed.) *Proceedings of 21st European Conference on Human Decision Making and Control*, GIST Technical Report G2002-1, Department of Computing Science, University of Glasgow, Scotland. 225-227.
7. Xiao, Y., Moss, J., Mackenzie, CF, Seagull, FJ, & Faraj, S. Transactive Responsibility Systems and High Reliability Teams: A Tentative Formulation. *Proceedings of Human Factors & Ergonomics Society Annual Meeting*, 1428-1432, 2002
8. Teich KM, Wagner MM, Mackenzie CF, Schafer KO. The informatics response in disaster, terrorism, and War, *Journal of American Medical Informatics Association*. 9: 97-104, 2002
9. Moss J , Mackenzie C F , Xiao, Y , Seagull , J: Coordinating Operating Room Suites : A Communication Analysis for Technology Design. *Anesthesiology* 2002; 97: A - 524

Dissertation

Seokhwa Yun. Leadership in an Intense Situation. Finished December 2001

In Press.

1. Seokhwa Yun, Samer Faraj, Yan Xiao, & Henry P. Sims Jr. A Trauma Resuscitation Team and Leadership, *Advances in the Interdisciplinary Study of Work Teams*, JAI press (to appear in 2003)
2. Moss, J., & Xiao, Y. (2002). The operating room charge nurse: Coordinator and communicator. *Proceedings of the American Medical Informatics Association*, in press

Under Review.

1. Samer Faraj & Yan Xiao. Coordination In Fast Response Organizations. *Management Science*
2. Moss, J., & Xiao, Y. Communication Patterns of Articulation Work: A Study of Charge Nurse Communication in Four Operating Room Suites. *Journal of American Medical Informatics Association*.
3. Yun, S., Faraj, S., & Sims, H. Contingent Leadership In High Risk and High Reliability Settings. *Academy of Management Journal*.
4. Yun, S. (2002). Contingent Leadership in a High Reliability Team. *Society for Industrial and Organizational Psychology*.

In Preparation.

1. Seokhwa Yun, Samer Faraj, Yan Xiao, & Henry P. Sims Jr. Leadership in an Intense Situation.
2. Sharyn Gardner, Samer Faraj, & Yan Xiao. Trauma Action Teams: A Study of Distributed Cognition in Action.
3. Yan Xiao, Jacqueline Moss, & Samer Faraj. Transactive Responsibility System in High Risk Environment. To be submitted to *International Journal of Cognitive Ergonomics*.
4. Yan Xiao. Joint Display-Based Cognition: Coordination Through Shared Displays. To be submitted to *Journal of Computer Supported Cooperative Work*.

Presentation without proceeding articles.

1. Seokhwa Yun, Samer Faraj, Yan Xiao, & Henry P. Sims, Jr. "Leadership and coordination in a Trauma Resuscitation Team", presented at Collaborative Work Systems Symposium, May 23-25, 2001, University of North Texas. <http://www.workteams.unt.edu/speakers/schedule.htm>
2. Yun, S. (2002). Leadership during emergency health care. Paper presented at Academy of Leadership, Seoul, Korea.
3. Sharyn Gardner, Samer Faraj, & Yan Xiao. Team Coordination in High-Velocity High-Uncertainty Environments, Presented at the Society for Industrial and Organizational Psychology 16th Annual Conference, April 26-29, 2001, San Diego.

4. Moss, J., Xiao, Y., & Mackenzie, C. Awareness in collaborative work: A study in trauma resuscitation. Poster session presented at the Southern Nursing Research Conference, Baltimore, MD, 2000
5. Samer Faraj (Session Chair). Coordination of Expertise in High-Reliability Work Environments: What Constitutes Effective Practice? Academy of Management Annual Meeting, Denver, CO, 2002
6. Samer Faraj & Sharyn Gardner. Expertise Coordination In High-Velocity High-Uncertainty Environments? Academy of Management Annual Meeting, Denver, CO, 2002
7. Yan Xiao and Colin F. Mackenzie. Study of team excellence: Practices of teams in high-velocity, high-stake environment. Academy of Management Annual Meeting, Denver, CO, 2002

Internet

A project website was developed for dissemination of research findings:
<http://hfrp.umm.edu/coordination>

Other specific products

We have developed a communication data collection tool (Moss et al, 2001; Moss & Xiao, 2002) for capturing communication activities. We plan to make it available on the project website for others to use.

Contributions

The principal discipline. As the project is highly inter-disciplinary, it is difficult to assign a principal discipline. Nevertheless, two disciplines are directly related to the project: CSCW and organization studies. For CSCW, our contributions are in the understanding of coordination by high-velocity teams and their use of various coordinating artifacts. We contribute to the field of distributed cognition in terms of how coordinating artifacts are used for highly dynamic environments. For organization studies, we contribute to how work teams organize and perform. In recent years, more and more organizations are shifting to team organizing structures. For teams in high-velocity environments, much can be learned from studying how trauma teams perform. By understanding a trauma team, we can provide principles of how to organize and manage knowledge teams and professional task-forces. Those management principles can be applied to other teams in complex settings such as aircraft cockpit teams, consulting teams, product development teams, etc.

1. Xiao, Y. et al's paper in ECSCW 2001 proposes a theoretical analysis of the strengths of a traditional whiteboard in facilitating the management of operating rooms, a task that is highly dynamic, distributed among many stakeholders with differing goals and priorities.
2. Moss et al's papers in AMIA 2001 and in AMIA 2002 propose a method of quantifying communication patterns in a coordination intensive task of operating room management. The method used real-time coding method to document several important parameters of communication.
3. Visser et al's 2002 paper in European Annual Manual described an analytic approach to coordination study from the point of view of distributed planning.
4. Yun's 2001 dissertation described a study of team coordination from the angle of leadership. The dissertation proposes a model of leadership that encompasses the contingency of leadership styles under different task conditions and emphasizes the phenomenon that a set of leadership styles can potentially be used by leaders in response to the task and team situations.

Other disciplines. There are several disciplines to which this project contributes. We contribute to social psychology through our examination of team performance and leadership behaviors. We contribute to human factors and ergonomics by studying the relationship between people and technology. We contribute to information systems by studying the potential role of communication technologies. Last but not least, our studies provide guidance to design of communication tools to increase the level of shared awareness.

Development of human resources. One long term goal of the project director (YX) is to establish a research center studying teams and the role of information technology in highly dynamic environments. The project, by the nature of the funding source, has increased the profile of research in coordination and information technology in the medical school. The project helps another senior member of the research team (SF) in extending his research on coordination in the school of management. Potentially the project could make it possible for extensive research activities in the school of management in understanding teams in high-velocity environment.

Synergistic Activities. The research team has been conducting research activities complimentary to the project. A few will be highlighted here. (1) National Science

Foundation's Information Technology Research (ITR) initiative. A proposal was submitted to study the role of information technology in expertise coordination and the proposal was funded. That project is under way. (2) Nortel Networks provided substantive funding to a project exploring communication and computing technology to automate information flow for coordination. A GPS based event notification system was prototyped, in collaboration with researchers from Nortel Networks, and tested in the operational settings. (3) Under the directives of a Congressional mandate, several members of the project team participated in a project aimed at improving the coordination reliability and efficiency in the management of operating room activities.