Project Summary: Large Scale Collaboration in Critical Environments

Many vital organizations operating in critical environments—hospitals, security agencies, airlines, and others—have evolved into team-based, quasi-decentralized structures. Safety, efficiency, and quality performance in these organizations depend not only on the professionalism of each team, but also on the ability of the organization to support large scale collaboration—coordination across teams, tasks, and resources. This coordination occurs continuously, at all levels of the organization. In an environment of unpredictable events, resource constraints, time pressure, and high workload, teams must be reconfigured, resources reassigned, and tasks negotiated and changed over time and place. Coordination problems in large scale collaboration are common in critical environments, and are a significant cause of errors, miscommunication, and even loss of life. This research begins to tackle problems of coordination in large-scale collaboration. The research begins with field research in one type of vital organization, the hospital. It includes research to understand the issues, and technology development to alleviate the problems. We also will carry out laboratory research on basic questions, and extend the field research to at least one other critical domain.

Research Plan

The planned research grows out of the existing literature on teams, the PIs' extensive research on team collaboration and communication in many kinds of organizations, and our preliminary field work in a shock trauma hospital. From this background, we have developed an initial theoretical framework for understanding the intersecting paths along which work and team members flow in a large scale collaboration. We have adopted the concept of *trajectories* to refer to the sequence of activities and paths through which people, resources, and teams move. In the complex hospital environment, patient, resource, and staff trajectories must interweave or intersect in specific ways for specific purposes. Coordinating multiple trajectories of events and activities requires the orchestration of these trajectories so that they are coupled or decoupled as necessary. Our research attempts to understand how interruption strategies and mechanisms, people's awareness of the flow of trajectories, and social factors, especially leadership and social differences, affect the management of trajectories. We will develop and evaluate technology to improve the management of trajectories. We propose field studies of interruption and trajectory awareness in a shock trauma hospital, laboratory studies of how people manage and lead divergent task and team trajectories in different critical environments, and development of technology for providing people with tools for mobile awareness of the status of relevant trajectories, for remote access to public collaborative artifacts and databases (such as operating room schedules), and for obtaining more relevant visual and other information about activities along various trajectories. The PIs have worked together, and bring relevant experience and disciplines to the project.

Intellectual Impact

This work will lead to an improved understanding of the complex coordination of teams, people, and resources that must be achieved in organizations that operate in critical environments. Our theoretical framework, based on the concept of trajectories, will guide research towards a better understanding of how event-driven interruptions, relevant trajectory awareness, and shared leadership affect large scale collaboration. Our tools will permit us to evaluate new forms of coordination and ways of managing large scale collaboration. The work will involve students at all levels—undergraduate, graduate, and professional, and will result in their further training and education to perform important interdisciplinary research. We propose dissemination and field building activities, and have had experience in doing so in the past.

Broader Impact

The contributions of vital organizations that operate in critical environments depend on the capacity of these organizations to handle problems of large scale collaboration. This project has the potential to improve the way hospitals and other vital organizations manage teams, people, and resources. In hospitals, coordination problems have led to serious patient injuries and financial consequences. Most U. S. citizens are aware that in events surrounding 9-11, some crucial connections across teams were missed. Our aim is to make progress toward preventing mishaps and errors, and increasing the efficiency of these organizations as well. The PIs have already established relationships with hospital personnel, such that learning and impact, in both directions, is woven into the research itself.

Large Scale Collaboration in Critical Environments

(Proposal Excerpts)

Many vital organizations—hospitals, security agencies, and airlines among others—use multiple collaborative teams of specialists to carry out their critical work. The work of vital organizations depends on high levels of specialized training, and the avoidance of risks, errors, and mistakes (e.g., Weick & Roberts, 1993). The work must not only meet exacting standards of performance under time pressure and high workload, but it must be accomplished in a context that is event-driven and, often, crisis-driven as well. Hospital teams must respond to urban emergencies, security teams to unexpected threats of terrorist attack, and airline teams to changes in equipment and weather. Great strides have been made in the way collaborative teams are understood, trained, and organized to operate in these nonroutine, event-driven environments; advances in technology over the past two decades have increased team efficiency and effectiveness. However, less progress has been made in understanding and improving large scale collaboration, especially in the critical environments in which vital organizations must operate. By large scale collaboration, we mean the collaboration of people across teams, tasks, and resources, rather than collaboration within a team (e.g., Nickerson, 1992, p. 311).

Large scale collaboration requires elaborate, fast-paced coordination (Bierly & Spender, 1995; LaPorte & Consolini, 1991; Roberts, Stout, & Halpern, 1994; Rochlin, 1993; Weick, Sutcliffe, & Obstfeld, 1999). In a hospital, for example, highly skilled operating room (OR) teams are constantly reconfigured and exchanged to best utilize staff expertise and resources, and to avoid dangerous fatigue of team members. Team configuration decisions cannot be predicted very well because they depend not only on known parameters, such as the number of OR rooms or patients in the queue, but also on the decisions of other OR medical teams, on the availability of team members who may be attached to multiple teams, and on external and complex unpredictable events such as a spate of accidents. In critical environments like these, the strength of the dynamic, decentralized organization lies in the professionalism of the teams, technology-supported communication and negotiation, and flexible utilization of expertise and resources. However, coordination problems in large scale collaboration are common. In hospitals, coordination problems across teams and specialties are important factors leading to inefficiency and a range of adverse events (Donchin et al., 1995; Leape et al., 1995), including premature discharge of patients with pneumonia (Halm et al., 2002), dangerous interruptions due to phone calls, pagers, and the need to continually negotiate resources (Blum & Lieu, 1992; Coiera & Tombs, 1998), and last minute decisions based on availability and time pressure rather than triage guidelines (Strosberg & Teres, 1997). In non-hospital critical environments, the U. S. public is well aware of large scale coordination problems surrounding the events of 9-11. Notably, some of the most critical problems (as in lack of coordination between police and fire departments) did not occur within teams, but across teams.

This research focuses at the outset on problems of large-scale collaboration in one type of vital organization, the hospital. We will extend the research to at least one other vital organizational domain in later years of the research. Hospitals are a suitable starting domain for this research, first, because, as noted above, serious problems of large scale collaboration have already been identified (also, Gittell et al., 2000). Second, the research is tractable. We have begun preliminary fieldwork and experiments, from which we have developed a conceptual framework for investigating key issues. Third, the domain is important. A recent published report by Institute of Medicine (Kohn, Corrigan, & Donaldon, 2000) projected 98,000 deaths every year due to medical errors, whose causes include communication and coordination problems. Although safety and benefits to patients are our primary concern, health care as a percent of the nation's gross domestic product is projected to be 17% by 2010 (Heffner et al., 2002). Better coordination could lead to significant cost savings (Curley, McEachern, & Speroff, 1998). Improving coordination in hospitals could therefore have benefits not just for patient well being but also for hospital efficiency and, in turn, for the nation's economy. Our immediate research goals, therefore, are to understand how large scale collaboration is organized and managed in hospitals, and to develop technology to improve this organization and management. Our longer term goal is to extend this knowledge and technology to other domains. This work is important theoretically because large scale collaboration in critical environments is not well understood and requires new constructs and ways of thinking about collaboration. Although coordination has been defined as management of interdependencies (Malone & Crowston, 1990; 1994), processes of managing interdependences in critical environments are little understood. This work is socially significant because large scale collaboration in critical environments is essential to the contributions that vital organizations are able to make. Even if an organization has high-performing teams, the organization cannot function effectively if there remain problems of large scale collaboration across teams, tasks, and resources.

Theoretical Framework

Large scale collaboration in the vital organization has some important attributes that can be studied from the perspective of the individual, the team, and the organizational system as a whole. From the perspective of the individual professional worker, such as a surgeon, large scale collaboration implies that the worker belongs to multiple teams. Responsibilities may vary across teams (e. g., lead surgeon in team A; informal consultant to Team B). Periods of membership and coworkers on teams may vary across teams (e.g., assigned to team A for one month; substituting in team B for one surgery). Considerable human factors research has been done to understand how multiple tasks and responsibilities may impinge on the workload of individuals (e.g., Kirwan & Ainsworth, 1992). From the perspective of the team, large scale collaboration means that the team cannot act independently but must coordinate its actions with other teams. For instance, two surgical teams cannot use the same operating equipment, cannot call on the same cardiologist at the same time, and cannot make different decisions about releasing the same patient. Teams must exchange resources and personnel, and work together in many ways. From the perspective of the system as a whole, team interdependencies occur episodically, with different partners working together on different tasks. Team interrelationships may be established by virtue of the tasks or crises that arise, and may be temporary. Team relationships may be ad hoc and opportunistic rather than based on ongoing trusting relationships.

Large scale collaboration only works well if coordination mechanisms are flexible in the face of extraordinary challenges that are typical in critical environments—high workload, time pressure, and limited resources. Although talking things out in meetings is the time-honored way that people have always coordinated flexibly, in the distributed, dynamic environment of a hospital, people and teams may need to rely as well on fast remote methods. All this takes place in a social environment, in which specialists and teams compete with other specialties and teams for resources, influence, and status. Social barriers to open information sharing complicate large scale collaboration and make it more difficult.

"Trajectories" in hospital work

The PIs' previous work on collaboration has focused mainly on within-team multidisciplinary collocated and distributed work (see Prior NSF). To be clear about our current focus, let us refer to this previous focus as "small scale collaboration." In our research on small scale collaboration, we noticed that, increasingly, real world teams and project groups follow a work path that intersects with, and often sometimes joins, the work of others outside the team. For example, members of one team usually belong to multiple teams. Members also join new teams, and teams with overlapping membership may form joint ventures, reformulating their tasks as well. These intersecting paths along which work and members flow result in reconfigurations of the people and the work. To capture these phenomena and the issues they raise, we have adopted the concept of *trajectories* to describe large scale collaboration in hospitals (c.f. "illness trajectories" in Strauss et al., 1984, p.8 and Roe, 2000). We use the term "trajectory" to refer to the sequence of activities and path through which a person, resource, or team moves. In the complex hospital environment, there are at least three key types of trajectories: (a) *patient trajectories* (e.g., a patient moves from admission, through testing, surgery, post-op, and discharge), (b) *resource trajectories* (e.g., an operating room is used for a series of surgeries through the day), and (c) *staff trajectories* (e.g., an MD participates in morning rounds, afternoon patient visits, discharge consultations, and the like). Trajectories differ in their flexibility (e.g., patients must move through a specified set of steps, whereas physicians can adjust their day as they proceed.

In hospital work, many patient, resource, and staff trajectories must interweave or intersect at specific times for specific purposes (Corbin & Strauss, 1993; Kaplan & Fitzpatrick, 1997; Strauss et al., 1984). For example, the paths of a surgeon, a patient, and the OR meet at the time of the patient's surgery, but not before or after this time. Coordinating multiple trajectories of events and activities requires the orchestration of these trajectories so that they are intersecting, separated, coupled, or decoupled as necessary over time. To illustrate the complexities of the coordination problem, we illustrate below using the case of the operating room.

Example: OR scheduling

OR suites in large hospitals consist of several to a few dozen individual ORs. In each OR, more than one case is carried out each day. Successful surgery depends on a team of highly specialized care providers showing up and working effectively together: physicians from different subspecialties (e.g., neurosurgery, orthopedics, anesthesiology), OR nurses, technicians, and housekeepers. Often specialized equipment and supplies are needed as

well. Personal and financial stakes are high for the hospital, the care providers, and the patients. The needed expertise and resources have to be carefully coordinated to ensure safety and operations efficiency.

Intricate dependencies exist among the cases scheduled for a given day, among the care providers, and among other resources. Extensive prior planning and scheduling efforts are designed to maximize efficiency; planning and scheduling are done for the long-term schedule, to fit staffing requirements, as well for the short-term surgical schedules for individual cases (Bardram, 2000). Despite these planning and scheduling efforts, much coordination effort is needed on the day of surgery. Surgical case durations are stochastic (coefficients of variation of 25%; Strum et al., 2000). For approximately 15% of cases, no historical data that can be used in predictions is available, even at the level of procedures (Dexter & Macario, 2000; Zhou et al., 1999). Hence, a dedicated role, usually called the charge nurse, is employed to "run" the ORs.

The charge nurse has to deal with a number of trajectories, including the status of each patient, the availability of OR nurses, the status of OR room, the availability of anesthesia care providers, and the availability of the surgical team. Although there is a target start time for any case, the charge nurse and others monitor these trajectories and their inevitable changes through a range of mechanisms, such as face-to-face encounters, phone calls, and paging messages. Some of the mechanisms, such as phone calls, are themselves disruptive. When a prolonged delay is expected for certain trajectories, the charge nurse may have to set an alternate target start time and then, ideally, disseminate that information back to collaborators associated with each trajectory. The charge nurse may intervene when a surgery is finished unexpectedly much earlier or later than planned, and thus a room's availability has changed, or if an emergency surgery has to be performed ahead of scheduled cases.

In many situations, the coordination of trajectories is vastly more complex due to the number of trajectories to be considered and due to the fact that these trajectories are interwoven in complicated ways, as many workers are multi-tasking and collaborating with different partners over time. Consider, for example, a situation in which a senior surgeon is scheduled to perform an operation in the OR while at the same time she is leading the discussion of discharge plans for intensive care unit (ICU) patients. She is deciding on when to pause the discussion with one group of collaborators and to go to OR to work with another group of collaborators. At the same time, an anesthesiologist in a trauma center is taking care of a patient in the OR with an assistant while providing coverage for the needs of unpredictable incoming trauma patients. He is deciding on how best to triage his time between the two tasks. The interwoven nature of this situation is illustrated in Figure 1. In such a situation, interruption becomes a necessity for workers to transition among multiple task trajectories. The ability to monitor multiple trajectories becomes essential.

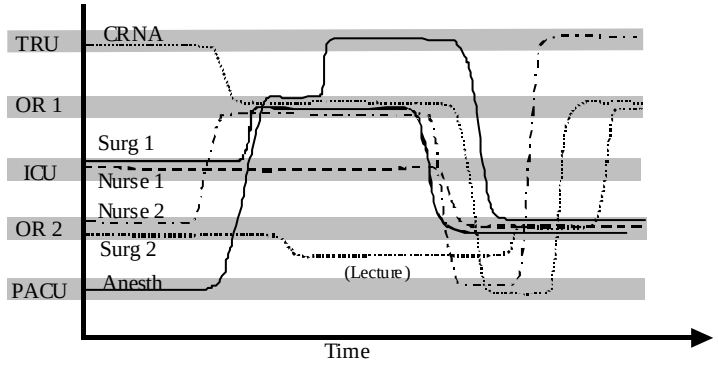

Figure 1. Interwoven trajectories. A surgeon (Surg2) works with a nurse (Nurse2) in OR2, then breaks off to give a lecture, and then joins another case in OR2 with others. An anesthesiologist (Anesth) working in PACU joins a group of people to work in OR1, then moves on to work in TRU, and then joins a second group of people in OR2.

Coordinating complex trajectories

As the example above demonstrates, hospital work requires intensive coordination among trajectories for staff, patients, and resources. Although scheduling algorithms can be used as a starting point for coordination, the dynamic nature of medical work makes preset schedules untenable in most situations. Surgeries can last longer or shorter than anticipated, requiring on-the-fly adjustment of the surgical schedule. Patients can experience setbacks that affect their planned trajectory, and doctors, nurses and other staff can experience interruptions that affect their work trajectories. Even fixed resources, which would seem to be stable, can experience unplanned changes—equipment breaks down, rooms need to be disinfected with special agents, and computers get viruses. At the same

time any one trajectory is experiencing change, others are changing too, necessitating adjustments in still other, related trajectories. There also exist important social realities—cultural and personal differences, hierarchy, and differences in leadership—that determine how well people cooperate.

In the proposed research, we focus on three broad questions regarding the coordination of trajectories:

- *Team level*: How do teams (and individuals within them) organize trajectories across multiple, cross-cutting projects and activities?
- *System level*: How can intersections among multiple trajectories be understood and managed?
- *Technology*: How can we use information technologies to improve trajectory management, at both the team and organization level?

In the next section, we outline our research program to address these issues. To accomplish this work, we propose four lines of research: First, we will observe, trace, and identify problems in multiple parts of a hospital setting. Second, we will conduct controlled laboratory studies to investigate specific issues in wide-scale collaboration under controlled circumstances. Third, we will develop prototype systems to enhance wide-scale trajectory management, which we subsequently deploy and evaluate in a medical setting. Finally, our longer term goal is to take what we have learned from these steps to at least one other domain.

Research Issues

We begin this work having identified four interrelated factors—communication, awareness, leadership, and technology—that affect the management of trajectories in critical environments.

Effects of communication and interruption on trajectory management

Despite increasing availability of information retrieval technologies in hospital settings, interpersonal communication remains the primary means of information exchange. In emergency rooms, staff members spend 80 percent or more of their time in communication (Coiera, 1996; Coiera et al., 2002; Spender & Logan, 2002). Face-to-face communication, particularly informal, opportunistic meetings, accounted for approximately 75% of all communication events (Coiera, 1996). The purpose and content of informal communication have been studied previously in industrial settings (Kraut, Fish, Root, & Chalfonte, 1990; Kraut, Fussell, Brennan, & Siegel, 2002; Whittaker, Frohlich, & Daly-Jones, 1994). We intend to extend this work to critical environments such as hospitals.

In particular, we focus on interruption as a mechanism people use to manage local trajectories of hospital staff, resources, and patients. For example, a doctor tending to a patient will interrupt a nurse assisting another patient to obtain information necessary to make treatment decisions. In emergency rooms and other particularly event-driven settings, interruptions occur at a rate of 10-15 interruptions per hour for both nurses and physicians (Chisholm et al., 2000; Chilshom et al., 2001; Coiera et al., 2002; Spencer & Logan, 2002). Preliminary work by Xiao and colleagues shows a similarly high rate of interruption during discharge rounds. A physician treating a patient might be interrupted face-to-face by a nurse or physician in the area, by a page, phone call, or other technology-mediated message, or by alerts or alarms such as those attached to patient monitors. We will investigate a number of interrelated issues regarding interruptions, including the way interruptions affect activity balancing and the quality and quantity of work.

Urgency of interruptions. It has been suggested that disruption from interruptions might be minimized by the greater use of asynchronous communication technologies (Coiera, 1996); however, asynchrony requires that the situation not be urgent. One of the questions we will address is whether urgency awareness or signaling can be used to influence the content of interruptions or the decisions to interrupt.

Effects of interruptions on trajectory management. Interruptions require on-the-fly restructuring of individual trajectories. As Schneider & Detweiler (1988) noted, people reorganize their work in face of interruptions by either eliminating tasks of low importance or by deferring the original tasks for variable intervals to complete the interrupting task. Tasks may be eliminated because either the original or the interrupting activity is abandoned. For example, physicians ignore pages when engaged in tasks requiring their full attention (Coiera, 1996). In a study of interruptions in the workplace, O'Conaill and Frohlich (1995) found that in 40% of cases, the interrupted party did not return to his/her original task, even though there was no sign the activity was finished before the interruption.

Task abandonment, either through forgetting or flexible reorganization of work priorities, may have serious consequences in medical settings.

Effects of interruptions on performance. Previous research on interruptions has tended to focus on their effects on individual performance (e.g., Altmann & Gray, 2000; Bailey, Konstan, & Carlis, 2000; Cutrell, Czerwinski, & Horvitz, 2000, 2001; Czerwinski, Cutrell, & Horvitz, 2000; Gillie & Broadbent, 1989). In a hospital context, however, in which there are many workers engaged in many activities, the effects of interruptions on individual performance cannot adequately characterize the overall organizational impact of that interruption. At the team and organizational levels, the negative effects of interruption to one trajectory may be outweighed by the benefits to others. McFarlane (1999), for example, found that interruptions led to rapid completion of the interrupting task but led to performance deficits on the interrupted task. Depending on the relative value of the two tasks, the interruption may or may not be of benefit (e.g., a physician might be interrupted to treat a critically ill patient or to answer a nonurgent question). Understanding the effects of interruption thus requires understanding the importance of the interruption to the different staff, patient, and resource trajectories.

Effects of awareness on trajectory management

A second way that trajectories can be managed is through people's own self adjustment by virtue of their passive awareness of ongoing activities in the environment. Nardi and colleagues (1993), for example, found that nurses watched surgeons' progress during operations to anticipate their needs for surgical implements. A growing body of research on situation awareness and development of shared mental models of dynamic environments has shown the value of an awareness of others' activities (e.g., Cannon-Bowers, Salas, & Converse, 1993; Endsley, 1995; Endsley & Pearce, 2001; Kiesler & Cummings, 2002; Kraut, Fussell, Lerch, & Espinosa, under review; Xiao, & The LOTAS Group, 2001). To manage interwoven trajectories in dynamic, uncertain environment, awareness information becomes critical. Awareness information can also be important for joint monitoring of trajectories (de Visser et al., 2002).

Effects of mobility on awareness. In medical settings, staff members are constantly mobile (e.g., Coiera, 1996). Mobility means that staff who work together are often distant from one another. Distance makes it harder for team members to share awareness and mental models of their work environment (Crampton, 2002; Hinds, 1999; Hinds & Weisband, in press; Weisband, 2002). Physical proximity, particularly the ability to see other workers' activities, enhances coordination and performance (e.g., Fussell, Kraut, & Siegel, 2000; Fussell, Setlock, & Kraut, in press; Kraut, Fussell, & Siegel, in press).

Tradeoffs between awareness and privacy. Although there are clear benefits to increased awareness of others' trajectories, there are costs in terms of individual privacy. Indeed, in current hospital environments, it is not unusual for staff to misinform others about their trajectories to obtain certain advantages. For example, a surgeon might say that he is ready to operate when an OR becomes available, even if he is not finished with another surgery, to ensure that the room is held for him. Or, a charge nurse might say that an OR that is ready to go needs disinfecting, to give her staff time for a break without letting others know. With increased awareness of staff, patient, and resource trajectories, these activities would be detected. More generally, inherent tensions in the workplace (e.g., differences in opinion, judgments of priorities, and scarcity of key resources) may create resistance to increased levels of awareness. Privacy issues may also arise when information is transmitted to a different context, such as from a mobile device to a centralized whiteboard (Nardi et al., 1997). Our project will provide delineation of the types of awareness information acceptable and useful for managing trajectories. We will examine whether resource awareness mechanisms (rather person-centered awareness mechanisms) may provide useful information and incentives for managing trajectories efficiently without impinging on the privacy or prerogatives of individual staff members.

Effects of leadership on trajectory management.

A third way that large scale coordination of trajectories may be achieved is through leadership. Despite a plethora of research on leadership in organizations (e.g., Avolio, 1999; Bass, 1998; Katz & Kahn, 1966), there is very little empirical research on leadership in critical environments. After the traumatic events following 9-11, there is a growing in interest in how to lead in times of trauma and stress (e.g., Dutton et al., 2002; Guiliani, 2002), particularly when action requires input from different groups (e.g., police, fire department, FBI), each with their own internal leadership structure.

Multiple leadership. Hospital staff are frequently members of multiple teams, each with its own leadership structure (Coiera, 1996). For example, a surgeon may be part of an operating room team with one set of staff members, and part of a discharge team with another set. The surgeon's power and status position within these various teams may also vary (Rueles & Leatt, 1985). Teams can have multiple leaders as well, and the different leaders may have different priorities, competing demands on resources, and different perspectives. For example, physicians see patients as individuals, whereas hospital administrators see patients as part of a larger organization, with ties to the larger community (Strosberg & Teres, 1997: 13). Having multiple leaders can often lead to conflicts when they give opposing orders, or when they have to answer to different constituencies (Hunt & Rubin, 1973). We will examine these issues in our field and laboratory studies.

Role-based leadership. In dynamic environments such as hospital trauma centers, police organizations, and fire crews (Weick, 1993), teams often come together for the purpose of dealing with critical events (e.g., new trauma admissions). The ad hoc nature of these teams makes it impossible for leaders to establish relationships with their subordinates prior to the task activity. In these types of organizational systems, where people have a fragmented history of working together, there is a strong reliance on role-based structures (e.g., Katz & Kahn, 1966). For example, by following a chain of command, police organizations eliminate uncertainty and secure internal discipline (Bittner, 1990). However, structural frameworks of roles, rules, procedures and authority relations may not be stable, since there must be shared interpretation of what these frameworks mean (e.g., Ranson, Hinings & Greenwood, 1980). When role systems fail, those in charge must create an ad hoc structure for working, or else confusion about what to do increases and coordination fails (Weick, 1993: 636). We will investigate the effects on trajectory management.of role structures that are and are not shared.

Effects of leadership on trajectory management. At the team level, a large number of studies have focused on attributes of good leaders, such as a balance of power (e.g., Corbin & Strauss, 1993), emotional connectedness (e.g., Goleman, 1995; Goleman et al., 2002; Kahn, 1993), coaching (Wageman, 2001), and direction setting (Hackman, 1987). However, in critical, stressful work environments that require intensive coordination among multiple trajectories, leadership may best be understood by examining multiple patterns of influence, based on affiliation, expertise, and authority, and the dynamic interplay between them (Hunt & Rubin, 1973). Such strategies will vary considerably depending on the kinds of trajectories observed in the hospital. For example, hospitals have a wide diversity in race, ethnicities, social classes, and gender, each with different histories and perceptions of how work gets done. Understanding the leadership strategies that various groups of people possess as they move through their trajectories may reveal important lessons. For example, holding back on important information, or pretending to do what others want, could create serious consequences for the patient trajectory. Weick (1990) found that "devices of mitigation" (e.g., phrasing an instruction as a question, or using hedged phrases like "would" or "could") mostly likely caused the Tenerife air disaster, when the co-pilot failed to inform the captain that another 747 airplane was on the takeoff runway directly in front of them as his own captain began takeoff without clearance.

To manage trajectories effectively, it will be important to offer non-defensive responses to questions and challenges. In doing so, members are likely to feel psychologically safe, to feel "a sense of confidence that the team will not embarrass, reject, or punish someone for speaking up" (Edmondson, 1999: 354). Letting people know about interruptions, changes in trajectories, may help to alleviate the stress that most people feel. When leaders withhold information and social support, it is reflected on the behaviors of others in the team. We will study the effects of leader care giving behaviors on subordinates' awareness of each others' and patients' trajectories.

Effects of technology on trajectory management

The discussion above suggestions that technologies for awareness and remote synchronous communication that increase the frequency of important interruptions without increasing the frequency of unwanted interruptions may facilitate large scale collaboration. Our focus is on creating tools for trajectory awareness—ways for people to see how relevant parts of the system are behaving so that they can adjust and negotiate trajectories efficiently and safely.

Public Displays. Public displays are a way to provide awareness of the many staff, patient, and resource trajectories in a hospital environment. A number of previous studies have examined the use of public displays (e.g. Bardram, 2000; Garbis & Waern, 1999; Suchman, 1988; Whittaker & Schwarz, 1999). With the advance of technology, more and more such whiteboards will be based on computer displays (Mynatt, et al., 2000; Berkowicz et al., 1999). In evaluating a computerized patient scheduling system, Bardram (1997) found that users maintained a whiteboard to re-represent the information in the computer system so that it was publicly shared. Bellotti & Rogers (1997) found

that news organizations used wall displays for representing personnel/work status and for discussing designs. The shared display of assignment provided a way for teams to visualize current team activities and resource availability. In a study on operations in emergency resource centers (Garbis & Waern, 1999), public displays played central roles in indicating status information and facilitating discussions.

In a trauma room setting, Xiao and colleagues (Xiao et al., 2001) demonstrated the value of a public whiteboard display (Figure 2) for the coordination of OR staff, patients and resources. However, the current value of public displays in hospitals is reduced by the high level of mobility among staff members (Coiera, 1996). At any given moment, only a limited number of people are situated such that they can make use of the public display. One focus of our development efforts is thus to increase mobile access to public displays, both for reading and posting information.

Figure 2. Public whiteboard at the UM Shock Trauma Center

Shared visualizations. Shared visualizations, either on public displays or individual computing devices, can help workers maintain shared mental models of other staff, resource, and patient trajectories (as illustrated in Brewer [2000] and the ongoing work by the SAGE Visualization Group at CMU [http://www-2.cs.cmu.edu/Groups/sage/sage.html]). We will explore alternative methods for instantiating shared visualizations to determine what methods best facilitate large scale coordination of trajectories.
to other pertinent research at other locations.